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(54) Título: SISTEMA E MÉTODO DE DOSAGEM E DISPENSADOR AUTOMÁTICO, AUTÔNOMO E PORTÁTIL DE PÉLLET E ÁGUA PARA UM ANIMAL OU MASCOTE

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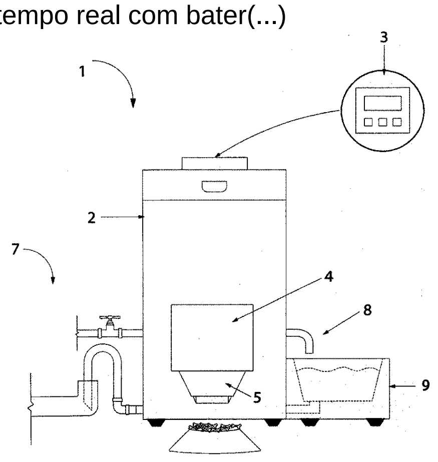
(57) Resumo: SISTEMA E MÉTODO DE DOSAGEM E DISPENSADOR AUTOMÁTICO, AUTÔNOMO E PORTÁTIL DE PÉLLET E ÁGUA PARA UM ANIMAL OU MASCOTE. Sistema (1) e método de dosagem e dispensador de péllet e água para mascotes, automático, autônomo e portátil, que compreende: um recipiente de péllet (2) com uma base interna inclinada em cerca de 45198> em sentido descendente em direção á parede frontal e que termina em uma comparta vertical de saída acionada pela energização de um solenóide; ambos se encontram protegidos por um alojamento (4) na parte frontal eexterna do recipiente de péllet (2), para deixar passar o péllet movido por gravidade em direção a um prato recipiente (5); um sensor de peso (célula de carga), que mede o peso do péllet que está dentro do recipiente de péllet; um sistema de dispensa de água (7) que compreende uma válvula de preenchimento, uma bomba de esvaziamento, um sensor de nível de água e uma saída de água (8), no qual todos esses elementos permitem encher e encher novamente um recipiente de água (9) ao alcance do animal ou mascote; e um controlador eletrônico (3) que compreende um micro controlador, um relógio de tempo real com bater(...)



SISTEMA E MÉTODO DE DOSAGEM E DISPENSADOR AUTOMÁTICO, AUTÔNOMO E PORTÁTIL DE PÉLLET E ÁGUA PARA UM ANIMAL OU MASCOTE

CAMPO DE APLICAÇÃO

A presente invenção refere-se a um sistema de dosagem de péllet para alimentação de mascotes, mais especificamente a um sistema e método de dosagem e dispensador de péllet e água de acordo com a quantidade e a frequência recomendadas de rações segundo o peso do animal, que é automático, autônomo e portátil.

DESCRIÇÃO DO ESTADO DA TÉCNICA

A alimentação animal baseada em péllet apresenta a necessidade de dosar a quantidade e a frequência recomendadas de rações segundo o peso do animal. Além disso, é necessário que se mantenha a água que bebem fresca e limpa para incentivar o animal a beber o elemento vital, para que se mantenha uma dieta sadia que permita que as fezes se solidifiquem rapidamente, não tenham mau cheiro e os animais se mantenham sãos, graças a que a presente invenção ajuda aos responsáveis pela manutenção do animal.

No pedido de patente Nº US 5.299.529 de 5 de abril de 1994, intitulada "Utomatic Feeder Dogs and Other Animals" é descrito um dosador de péllet e água que utiliza um motor com rosca sem fim para produzir a dosagem de péllet que cai em um recipiente. Esse tipo de sistema apresenta o inconveniente de que o péllet que se parte ou o pó de péllet vai travando o sistema até produzir falha por obstrução, obrigando o usuário a retirar todo o péllet e realizar manutenção do sistema. Isto os faz pouco confiáveis. O péllet, estando na mesma zona em que se produz o movimento da rosca sem fim que desloca o péllet em direção ao recipiente externo no qual cai o péllet ou "prato de comida", vai produzindo a obstrução do dispensador que inclusive pode chegar a apertar todo o sistema travando o motor ao ficar péllet entre a rosca sem fim e a parede. Esse tipo de dosador não é confiável para usuários que precisam deixar os animais sós por vários dias, já que ao ocorrer a falha não é possível dosar até que uma pessoa solucione o problema. No que se refere à forma de dosagem da água, a figura e a descrição do sistema não são claros, mas pode-se ver que se trata de um recipiente de água que deve ser cheio manualmente pelo usuário.

No pedido de patente Nº US 6.622.655 B2 de 23 de setembro de 2003, intitulado "Automatic Feeder Dogs and Other Animals" também é utilizado um motor com um sistema giratório que permite a dosagem. Esse tipo de dosagem tem o inconveniente de que o péllet ou fragmentos podem se colocar entre a peça que gira e a borda de saída do recipiente, travando o sistema, assim provocando uma falha que deve ser resolvida pelo usuário. Em ambos os casos, estando o sistema de fornecimento em contato direto com o péllet, produz problemas por fragmentos ou pó de péllet que se introduz no sistema de fornecimento, além disso, são dependentes de motores, não permitindo um sistema livre de manutenção e, finalmente, se ambos os sistemas falharem por problemas de manutenção, estes não podem ser solucionados a não ser pelo usuário. Não têm como sair do problema se não quando o usuário vá superar a falha.

O sistema de fornecimento de péllet e água da presente invenção oferece uma melhora e simplificação do sistema de fornecimento de péllet existente, já que não depende de motores e sistemas rotativos complementares para dispensar o alimento e água de forma simultânea.

Os animais que se alimentam à base de péllet precisam comer rações controladas em quantidade e frequência para que seu organismo processe de maneira otimizada o alimento, e por sua vez precisam tomar água limpa e fresca para completar o processo digestivo. Se a água não está fresca ou limpa, o animal perde o incentivo para bebê-la e assim seu organismo deixa de receber a quantidade do líquido vital, causando problemas a sua saúde, fezes não sólidas, com mau cheiro, possíveis cálculos renais, etc.

O sistema dispensador e dosador de péllet e água da presente invenção vem em auxílio dos usuários que não têm tempo e cuidado de manter as rações em quantidade e frequência e nem sempre podem depender de manter a água limpa e fresca. Além disso, trata-se de um sistema que soluciona o problema de alimentação animal na ausência das pessoas encarregadas dos animais para:

- Número muito grande de animais para cuidar e manter, como no caso de zoológicos, canis, criação de porcos, outros;
- Saídas para o trabalho durante todo o dia, sem pessoas em casa;
- Saídas em fim de semana;
- Saídas em férias;
- Cães de guarda de empresas em fins de semana.

RESUMO DA INVENÇÃO

O sistema de fornecimento e dosagem de péllet e água da presente invenção compreende um recipiente de péllet com uma inclinação interna de cerca de 45° que permite que o péllet esteja sempre em sentido de queda e um sistema de comporta vertical que se abre graças à ação de um solenóide que é controlado para dispensar a quantidade de péllet programada pelo usuário.

Além disso, o sistema proposto apresenta o sistema de fornecimento de péllet pelo lado contrário ao depósito de péllet, evitando que pó de péllet assim como fragmentos de péllet obstruam o sistema.

O sistema compreende ainda um controlador eletrônico e uma interface do usuário com base em um micro controlador que permite realizar de forma automática as gestões de fornecimento de péllet assim como as gestões de manutenção da limpeza e frescor da água ao obter a água de forma automática da rede de água potável, sem a necessidade de intervenção do usuário; isto confere ao sistema total autonomia, tanto para encher o depósito de água quanto para executar a gestão de limpeza do recipiente, isto mediante uma lógica programada que permite retirar a água, encher ao nível mínimo com água limpa (enxágue), voltar a retirar a água para limpeza e logo voltar a encher até o nível máximo permitido para que o recipiente se mantenha limpo, com água fresca e limpa renovada de acordo com a quantidade de vezes ao dia programada.

BREVE DESCRIÇÃO DAS FIGURAS

A figura 1 mostra uma vista de perfil do sistema de dosagem e dispensador de péllet e água para mascotes da presente invenção.

A figura 2 mostra uma vista frontal do sistema de dosagem e dispensador de péllet e água para mascotes da presente invenção.

A figura 3 mostra um detalhe do sistema hidráulico do sistema de dosagem e dispensador de péllet e água para mascotes da presente invenção.

A figura 4 mostra o dispositivo dispensador de péllet para mascotes da presente invenção.

As figuras 5, 6 e 7 mostram uma sequência do funcionamento da comporta vertical de saída pela qual se dosa a quantidade de péllet que cai no recipiente ou prato de alimentação da mascote.

DESCRIÇÃO DETALHADA DA INVENÇÃO

Como mostra a figura 1, o sistema de dosagem (1) de péllet e água para mascotes compõem-se de um recipiente de péllet (2) com uma base interna inclinada (10) em cerca de 45° (ver figura 3) em sentido descendente na direção da parede frontal que termina em uma abertura (14) (ver figura 5) por onde sai o péllet movido por gravidade. Obtém-se a saída ou retenção do péllet acionando uma comporta vertical de saída (12) mediante um solenoide (11), como mostram as figuras 5 a 7, onde esse solenoide (11) aciona a comporta vertical de saída (12) levantando-a para permitir que o péllet flua em direção a um prato recipiente (5). A comporta vertical de saída (12) se fecha por queda livre (gravidade) quando se corta o fluxo de corrente no solenoide (11). Tanto o solenoide (11) quanto a comporta vertical de saída (12) estão protegidos por um alojamento (4) na parte frontal externa do recipiente de péllet (2), de modo que o inteiro mecanismo que permite a saída do péllet está localizado no exterior do recipiente de péllet (2), evitando o contato direto do péllet com os elementos que permitem a saída deste, evitando falhas por sujeira e obstrução por péllet fragmentado, por exemplo.

O tempo de energização do solenoide é controlado por um microcomputador eletrônico (3) configurado pelo usuário de acordo com as rações a dispensar e as horas selecionadas. A quantidade de péllet a dispensar é definida pelas dimensões da abertura (14), a inclinação da base interna inclinada (10) e o tempo de abertura da comporta vertical de saída (12).

O controlador eletrônico (3) compreende um micro controlador, um relógio de tempo real com bateria externa de reserva, uma tela de visualização (display) e um módulo de entrada de dados que permitem o acesso a um menu para configuração do sistema por parte do usuário.

Carrega-se nesse micro controlador um programa de controle com projeto próprio e se codifica em linguagem de programação C para ser compilado e transformado em linguagem *assembler* do micro controlador. Esse programa passa a ser o programa embutido dentro do micro controlador que apresenta todas as funções e algoritmos que foram projetados para o funcionamento do dispensador.

O programa computacional se encarrega de administrar uma memória não volátil que incorpora o micro controlador para guardar configurações, isto é: rações, horas, níveis e todas as variáveis que se necessita recuperar em caso de corte de energia ou perda desta no caso de o sistema de reserva ou UPS esgotar sua bateria.

As configurações permitem ao usuário ajustar a quantidade de péllet de uma porção, para a qual existem três alternativas de porção: porção pequena (50 a 125 gramas) porção média (125 a 250 gramas) e porção grande (250 a 500 gramas). Permitem também configurar o número de rações por dia, por exemplo, de 1 a 4 rações e estas combinadas com o tipo de porção. Também permitem ao usuário a troca de água uma vez por dia à hora programada ou trocar a água a cada "N" níveis mínimos, predeterminar um nível mínimo de água como, por exemplo, entre 10% a 50% da altura total do recipiente de água (9), de onde esse recipiente está ao alcance do animal ou mascote, predeterminar um nível máximo de água, como por exemplo entre 50% a 100% da altura total do referido recipiente de água (9).

O início da queda do péllet é obtido com um golpe natural que o solenoide provoca (11) quando apresenta uma força eletromecânica para levantar um determinado peso da comporta vertical de saída (12) e que, sendo essa força eletromagnética maior que o peso da comporta vertical de saída (12), a força extra ou restante se transforma em energia de agitação ou de vibração (força em movimento de choque) do recipiente de péllet (2), provocando o início do movimento de queda dos péllets. Se os péllets se travam, um conjunto de sensores óticos (13) (emissor, receptor) à saída da abertura (14) detecta que os péllets não estão fluindo e envia um sinal ao controlador eletrônico (3), o qual inicia uma sequência de agitação do recipiente de péllet (2) para que os péllets fluam; isto se consegue provocando duas subidas e descidas rápidas da comporta vertical de saída (12) (duas subidas e descidas em 200 ms), provocando a agitação do recipiente de péllet (2) que libera o travamento dos péllets, que fluem para permitir a entrega da dosagem programada.

Por outro lado, o sistema de dosagem e dispensador (1) de péllet e água para mascotes compreende um sensor de peso ou célula de carga (15), que mede o peso do péllet que está destro do recipiente de péllet (2); a célula de carga (15) está montada em um pilar rígido (17). O péllet exerce pressão sobre o sensor de peso, já que a base interna inclinada (10) se encontra a 45°, não se encontra fixa em sua parte superior, só a mantém em sua posição um suporte (16) que se encontra entre o sensor de peso e a base inclinada (10). O sinal de saída da célula de carga (15) é proporcional ao peso da quantidade de péllet, a qual é transmitida ao controlador eletrônico (3).

A medição de peso serve tanto para dispensar uma porção predeterminada de péllet quanto para detectar uma medida mínima de péllet no interior do recipiente de péllet (2), o que conduz a aparecer uma mensagem ou alarme na tela de visualização para indicar ao usuário que deve encher o recipiente de péllet (2). Além disso, o controlador eletrônico (3) permite comparar os sinais consecutivos do sensor de peso antes e imediatamente após dispensar uma porção de péllet. Se não há diferença numérica entre essas duas medições, há indícios de que o péllet se encontra travado, e portanto o sistema inicia a sequência de agitação do recipiente de péllet (2) para destravá-lo. Esta ação se repete duas vezes; se na terceira tentativa de agitação a diferença de medição continua sendo zero, o sistema o indica com um alarma permanente.

Então a medição de peso através da célula de carga (15) permite dispensar a medida de péllet selecionada com maior precisão; permite registrar a conta das rações e as que permanecem por dispensar; permite configurar o alarme quando permaneçam menos de "n" rações a dispensar; e permite saber se o fluxo de péllet se encontra com problemas de obstrução em sua saída do recipiente de péllet (2).

Como os péllets não estão em contato direto com a zona de trilhos de deslocamento da comporta (12), evita-se que a comporta (12) fique obstruída, um problema que outros sistemas existentes no mercado, baseados em motores e roscas sem fim, têm,

Como mostra a figura 3, o sistema de dispensa de água (7) também é programado pelo sistema de controle eletrônico que controla uma válvula de preenchimento (71), uma bomba de esvaziamento (72), e um sensor de nível de água (73) e uma saída de água (8), com o que todos esses elementos permitem encher e encher novamente um recipiente de água (9), quando está em nível inferior a um nível predeterminado e trocar completamente a água do recipiente de água (9).

A medição do nível de água no recipiente de água (9) é realizada através de um sensor de pressão que transmite um sinal ao controlador eletrônico (3). Quando se inicia no sistema o processo (colocação em serviço), o sensor de nível de água transmite uma medição da altura de água, na qual, se esse nível é zero, o controlador eletrônico (3) envia um sinal para abrir a válvula de preenchimento (71) e se inicia o preenchimento do recipiente de água (9). O sensor continua medindo até que o sinal coincide com um valor predeterminado, configurado pelo usuário, que determina um nível máximo de água e é enviado um sinal para fechar a válvula de preenchimento (71).

Para realizar o preenchimento de água no recipiente de água (9), pode-se optar por encher uma vez por dia à uma hora selecionada. Para realizar a troca total da água, pode-se eleger uma quantidade de ciclos de preenchimento no qual, cumprindo-se essa quantidade de ciclos de preenchimento, procede-se ao esvaziamento completo do recipiente de água (9) e a seu preenchimento total para fazer uma troca de água e enxágue do recipiente de água (9), para o que o sistema de dosagem e dispensador (1) verifica a presença de água na rede de água potável, e para isso abre a válvula de preenchimento (71) e mede se há aumento do nível de água no recipiente de água (9). Se existe aumento do nível de água, procede-se a ativar a bomba de esvaziamento (72) para esvaziar toda a água até que o sensor de nível detecte nível zero para desativar a bomba de esvaziamento (72) até um nível predeterminado denominado “nível de enxágue”, que corresponde a cerca de 20% do nível máximo predeterminado para o recipiente de água (9). Passado um tempo, de cerca de 10 segundos, procede-se a esvaziar novamente o recipiente de água (9), com os resíduos que decantaram no fundo. Finalmente, depois de haver retirado a água de enxágue, o sistema abre a válvula de preenchimento (71) até detectar o nível máximo predeterminado e deixar o recipiente de água (9) cheio de água limpa e fresca, ficando pronto para iniciar outro ciclo.

Se o sistema de dosagem e dispensador (1) detecta a ausência de água na rede de água potável, um alarme é ativado na tela de visualização para que o usuário possa resolver o problema e, obviamente, não se realiza a troca de água e enxágue do recipiente de água (9).

Existe uma série de alarmes para determinados eventos, como por exemplo, número de rações restantes antes que se termine todo o péllet no recipiente de péllet (2), ausência de água na rede de água potável, péllet obstruindo a saída do recipiente, entre outros.

Finalmente, é previsto um sistema de reserva de energia tipo UPS para assegurar o funcionamento do sistema em eventuais cortes de energia da rede de energia elétrica.

EXEMPLO DE APLICAÇÃO

O controlador eletrônico (3) compreende um micro controlador, por exemplo, PIC 17F4520 de 40 pinos, um relógio de tempo real, por exemplo, DS 1307, com bateria externa de reserva, uma tela de visualização de 2 linhas, 16 colunas e um módulo de entrada que compreende, por exemplo, três pulsadores do tipo de botão que permitem acessar o menu para configurar o sistema.

Mediante a célula de carga mede-se o peso do péllet que está dentro do recipiente de péllet (2). O péllet exerce pressão (proporcional ao peso) sobre a célula de carga através do suporte, e seu sinal de saída (2 mV/kg) é proporcional ao peso da quantidade de péllet. Esse sinal entra em um circuito amplificador diferencial de instrumentação, que se ajusta para transmitir uma saída proporcional ao peso equivalente a 0-5V, por exemplo 0 [V] para 0[kg] e 5[V] para 20 [kg]. A saída do amplificador de instrumentação entra em um canal de conversão AD do micro controlador de 10 bits, que processa o sinal para convertê-lo em seu equivalente em peso (kg).

Quando o sistema é colocado em serviço (pela primeira vez), a tela de visualização indica imediatamente que se deve depositar o péllet, indicando uma medida de peso igual a 0 kg.

Ao esvaziar o péllet o sistema deve ir indicando o peso de entrada equivalente;

se é um saco de 15 [kg], pode indicar, por exemplo, 15,4 [kg] ao esvaziar o alimento completamente. Com esse valor o sistema calcula a quantidade de rações estimada que se possa dispensar, isto considerando a quantidade de rações por dia e o tipo de ração, isto é, pequena, média ou grande. Cada ração é ajustada pelo usuário.

Se a ração média é ajustada a 200 [g], e a ração grande é ajustada a 300 [g], se o sistema é ajustado para dispensar 2 vezes ao dia, uma com ração mediana e a segunda com ração grande, então o equipamento indicará em sua tela de visualização o número de dispensas que é equivalente a 15,4 [kg] / (0,2+0.3) [dia/kg] =30,8.

A medição do nível de água no recipiente se realiza através de um sensor de pressão que transmite um sinal de [mVpsi], no qual a pressão é proporcional à altura do nível de água; para isso, a saída do sensor entra em um amplificador de instrumentação que transforma os [mV] de saída do sensor em um sinal proporcional de 0 a 5 [V] DC, sendo 0 [V] em ausência de água e 5 [V] quando há uma altura máxima, por exemplo de 15 [cm] de água. O sinal é introduzido em uma entrada analógica-digital do micro controlador para ser convertida em nível de água com resolução de 10 bits.

Quando o sistema inicia o processo (colocação em serviço), o sensor transmite uma medição da altura de água que existe no recipiente. Apresentar o nível 0 de água equivale a um sinal de 0 [V]; portanto, o sistema inicia o preenchimento do recipiente de água (9), este se realiza ativando a válvula de preenchimento (71). O sistema continua de forma contínua a sinalizando o nível de água até conseguir uma medição igual a um valor máximo predeterminado e nesse momento a válvula de preenchimento (71) é desativada.

Os critérios para trocar a água são selecionados pelo usuário e podem ser uma vez por dia a uma hora predeterminada ou quando se cumprem “N” ciclos de preenchimento, isto é, o sistema chegou a seu número máximo de preenchimento de água até alcançar “N” ciclos de preenchimento. Por exemplo, se N=2, o nível se encontra em seu máximo, os animais bebem água até o nível baixar ao mínimo configurado, essa condição é detectada e o sistema inicia o preenchimento de água, até que se chegue ao máximo, os animais, ao beberem novamente, fazem que se chegue ao mínimo (segunda vez); uma vez que se cumpre a segunda vez que se chega ao mínimo, é iniciada a sequência “Troca de água e enxágue”.

REIVINDICAÇÕES

1. Sistema de dosagem e dispersador de péllet e água para mascotes, automático, autônomo e portátil, **caracterizado** pelo fato de que compreende:

a. um recipiente de péllet com uma base interna inclinada em cerca de 45°, em sentido descendente na direção da parede frontal que termina em uma comporta vertical de saída, que ao ser acionada deixa passar o péllet movido por gravidade;

b. um sensor de peso (célula de carga), que mede o peso do péllet que está dentro do recipiente de péllet;

c. um sistema de dispensa de água que compreende uma válvula de preenchimento, uma bomba de esvaziamento, um sensor de nível de água e uma saída de água, no qual todos esses elementos permitem encher e encher novamente um recipiente de água ao alcance do animal ou mascote; e

d. um controlador eletrônico que compreende um micro controlador, um relógio de tempo real com bateria externa de reserva, uma tela de visualização (display) e um módulo de entrada de dados que permite o acesso a um menu de configuração do sistema por parte do usuário, para seu funcionamento de forma automática.

2. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 1, **caracterizado** pelo fato da comporta vertical de saída é acionada pela energização de um solenoide.

3. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 2, **caracterizado** pelo fato da comporta vertical de saída e o solenoide encontram-se protegidos por um alojamento na parte frontal externa do recipiente de péllet.

4. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 1, **caracterizado** pelo fato da medição de peso permite: dimensionar a porção de péllet a dispensar; detectar um nível mínimo de péllet no interior do recipiente de péllet e detectar obstrução no deslocamento do péllet pela comporta vertical de saída.

5. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 2, **caracterizado** pelo fato do tempo de energização do solenoide permite determinar a quantidade de péllet a dispensar estabelecendo tipos de porções a fornecer.

6. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 1, **caracterizado** pelo fato do controlador eletrônico compreende sinais de saída para ativar alarmes visuais ou audíveis quando os sinais dos sensores de peso e nível de água estão fora de valores predeterminados.

7. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 1, **caracterizado** pelo fato do controlador eletrônico inicia uma sequência de agitação do recipiente de péllet em caso de detecção de obstrução do fluxo de péllets.

8. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 7, **caracterizado** pelo fato da sequência de agitação do recipiente de péllet consiste em provocar duas subidas e descidas rápidas da comporta vertical de saída de 200 [ms].

9. Sistema de dosagem e dispensador de péllet e água para mascotes da reivindicação 1, **caracterizado** pelo fato do sistema controlador eletrônico permite acionar a válvula de preenchimento e a bomba de esvaziamento, de acordo com as medições transmitidas pelo sensor de nível de água do recipiente de água.

10. Método de dosagem e dispensador de péllet e água para mascotes, automático, autônomo e portátil, **caracterizado** pelo fato de compreender as etapas de:

a) prover um sistema de dosagem e dispensador de péllet e água para mascotes que compreende um recipiente de péllet com uma base interna inclinada em cerca de 45°, em sentido descendente em direção à parede frontal e que termina em uma comporta vertical de saída, que ao ser acionada deixa passar o péllet movido por gravidade; um sensor de peso (célula de carga), que mede o peso de péllet que está dentro do recipiente de péllet; um sistema de dispensa de água que compreende uma válvula de preenchimento, uma bomba de esvaziamento, um sensor de nível de água e uma saída de água, no qual todos esses elementos permitem encher e encher novamente um recipiente de água ao alcance do animal ou mascote; e um controlador eletrônico que compreende um micro controlador, um relógio de tempo real com bateria externa de reserva, uma tela de visualização (display) e um módulo de entrada de dados que permitem acessar um menu de configuração do sistema por parte do usuário, para seu funcionamento de forma automática;

b) conectar a rede de água potável ao sistema de dosagem e dispensador de péllet e água para mascotes;

c) conectar a rede de energia ao sistema de dosagem e dispensador de péllet e água para mascotes;

d) introduzir dados iniciais de valores máximos e mínimos de altura para o nível de água e valores máximos e mínimos de peso para a quantidade de péllet no interior do recipiente de péllet;

e) selecionar o tipo de porção de péllet e a quantidade de dosagens diárias e

f) iniciar o processo de funcionamento do sistema de dosagem e dispensador de péllet e água para mascotes.

11. Método de dosagem e dispensador de péllet e água para mascotes da reivindicação 10, **caracterizado** pelo fato do início do processo de funcionamento compreende ativar os sensores de peso e pressão para medir a carga de péllet no interior do recipiente de péllet e o nível de água do recipiente de água, respectivamente.

12. Método de dosagem e dispensador de péllet e água para mascotes da reivindicação 11, **caracterizado** pelo fato das medições dos sensores de peso e pressão são iguais a zero ao se iniciar o processo de funcionamento pela primeira vez.

13. Método de dosagem e dispensador de péllet e água para mascotes da reivindicação 12, **caracterizado** pelo fato de que se ativa a válvula de preenchimento de água para alcançar o valor máximo inicial predeterminado pelo usuário.

14. Método de dosagem e dispensador de péllet e água para mascotes da reivindicação 12, **caracterizado** pelo fato de que se ativa a tela de visualização indicando a necessidade de encher o recipiente de péllet e indicando uma medida de peso igual a 0 [kg], para que o usuário encha manualmente o recipiente de péllet.

15. Método de dosagem e dispensador de péllet e água para mascotes das reivindicações 13 e 14, **caracterizado** pelo fato dos sensores de peso e pressão continuam seguem operando de forma contínua.

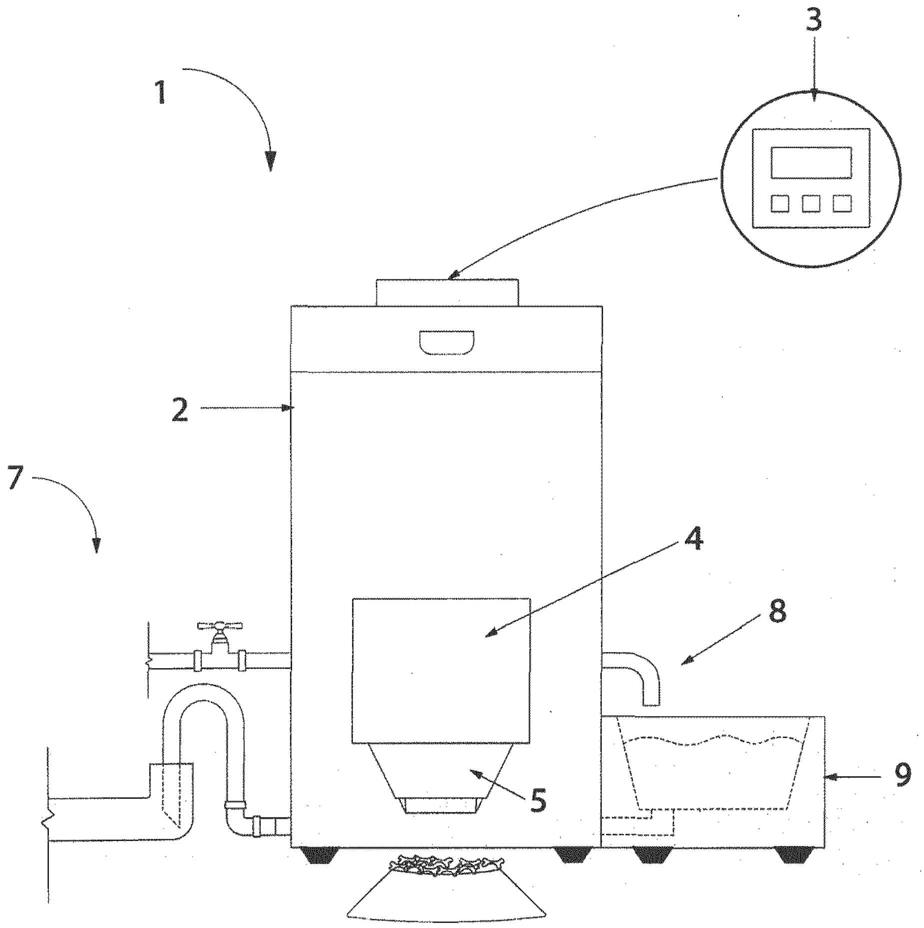


FIG. 1

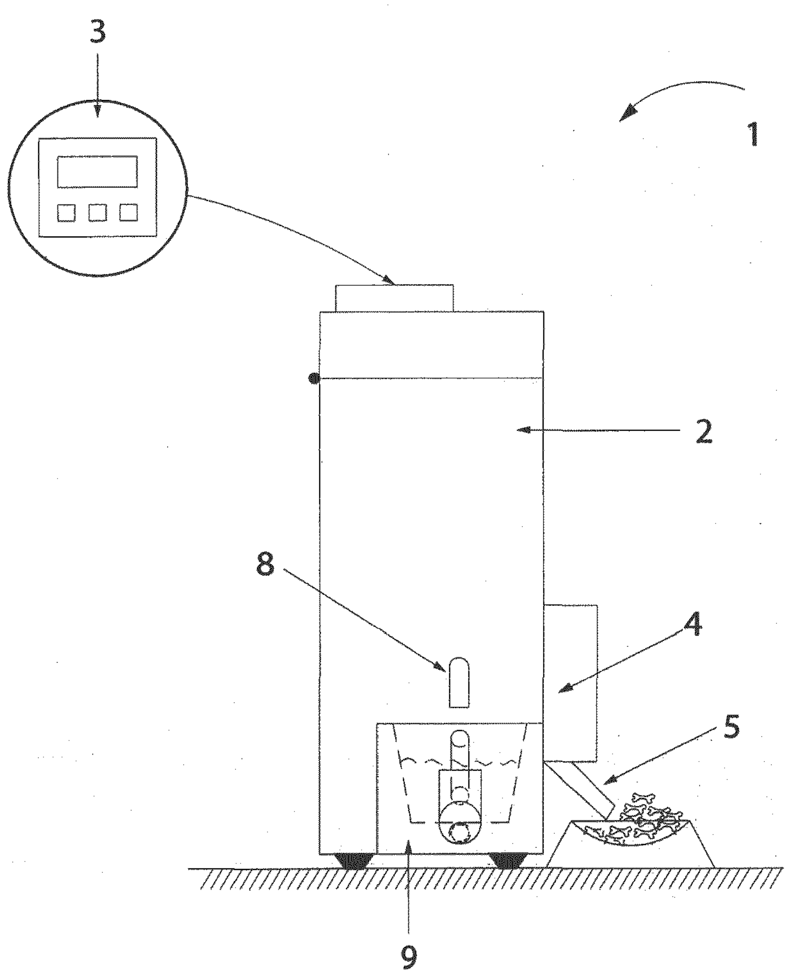


FIG. 2

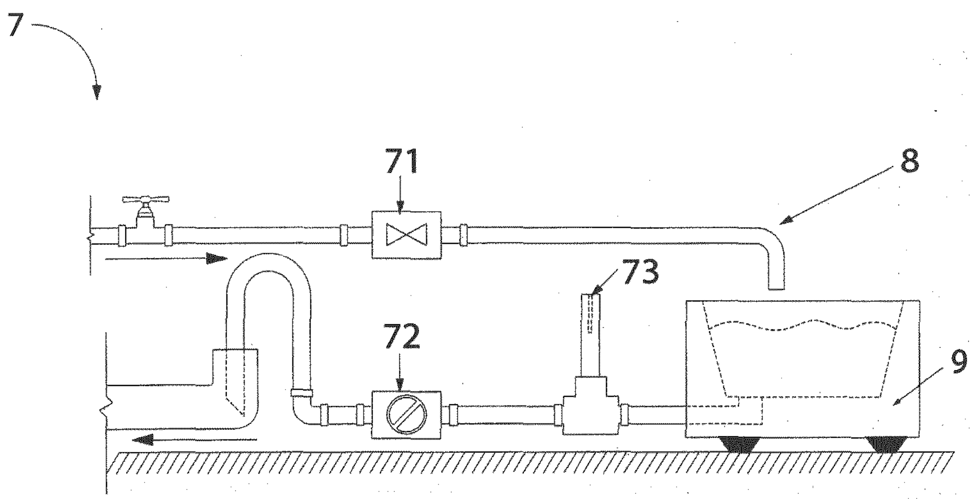


FIG. 3

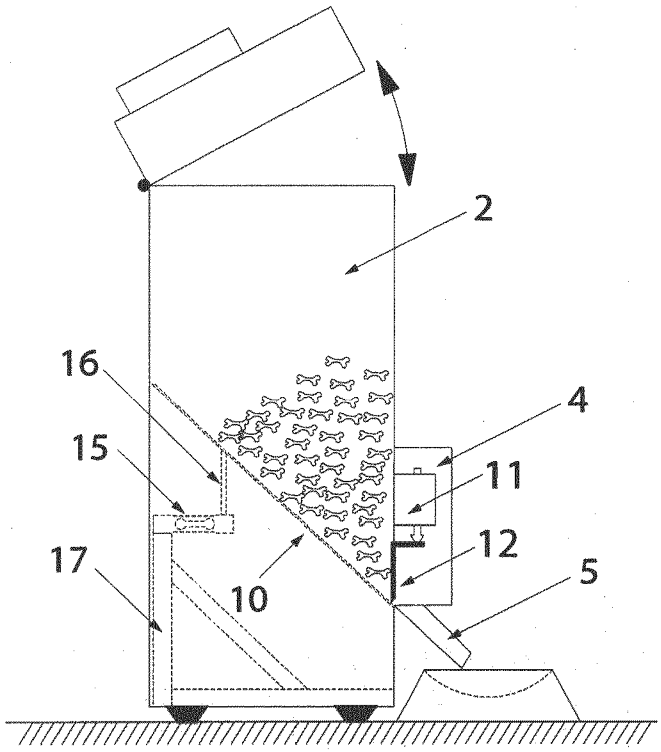


FIG. 4

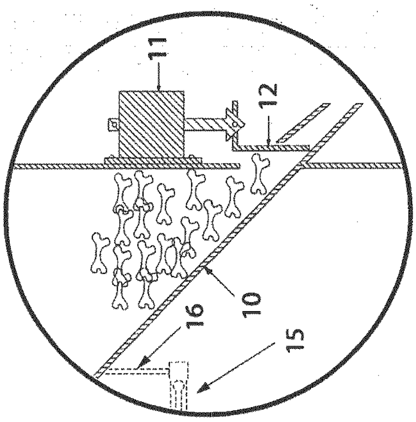


FIG. 5

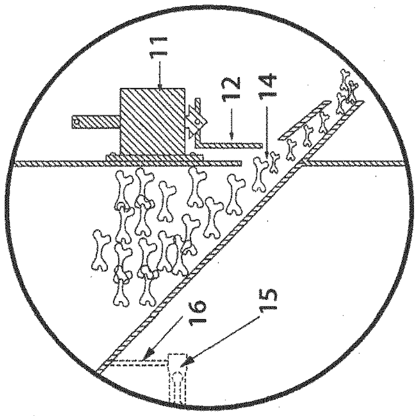


FIG. 6

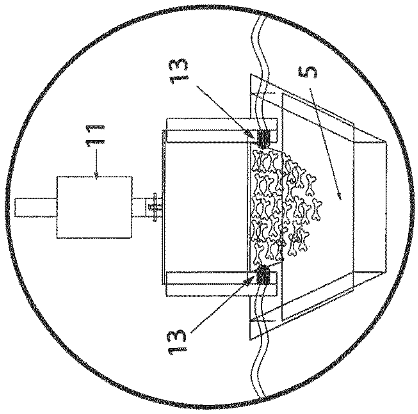


FIG. 7

RESUMO

SISTEMA E MÉTODO DE DOSAGEM E DISPENSADOR AUTOMÁTICO, AUTÔNOMO E PORTÁTIL DE PÉLLET E ÁGUA PARA UM ANIMAL OU MASCOTE. Sistema (1) e método de dosagem e dispensador de péllet e água para mascotes, automático, autônomo e portátil, que compreende: um recipiente de péllet (2) com uma base interna inclinada em cerca de 45° em sentido descendente em direção à parede frontal e que termina em uma comporta vertical de saída acionada pela energização de um solenóide; ambos se encontram protegidos por um alojamento (4) na parte frontal externa do recipiente de péllet (2), para deixar passar o péllet movido por gravidade em direção a um prato recipiente (5); um sensor de peso (célula de carga), que mede o peso do péllet que está dentro do recipiente de péllet; um sistema de dispensa de água (7) que compreende uma válvula de preenchimento, uma bomba de esvaziamento, um sensor de nível de água e uma saída de água (8), no qual todos esses elementos permitem encher e encher novamente um recipiente de água (9) ao alcance do animal ou mascote; e um controlador eletrônico (3) que compreende um micro controlador, um relógio de tempo real com bateria externa de reserva, uma tela de visualização (display) e um módulo de entrada que permitem acessar um menu de configuração do sistema por parte do usuário, para seu funcionamento de forma automática.

US005752498A

United States Patent [19]

Lake et al.

[11] Patent Number: 5,752,498

[45] Date of Patent: May 19, 1998

[54] **ELLIPTICAL BEAM LOAD CELL**

[76] Inventors: **Jared L. Lake**, 1365 Old Garth Hts., Charlottesville, Va. 22901; **Brad C. Koelblinger**, 1302 Little Fawn, Fairfield, Iowa 52556

[21] Appl. No.: **592,865**

[22] Filed: **Jan. 24, 1996**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 319,935, Oct. 7, 1994, Pat. No. 5,546,926.

[51] **Int. Cl.**^{6} **F24F 3/14**; G01G 3/14

[52] **U.S. Cl.** **126/113**; 137/403; 177/211; 392/402

[58] **Field of Search** .... 126/113; 392/391, 392/402, 142; 261/DIG. 46, DIG. 45, DIG. 65; 137/403; 177/211, 118

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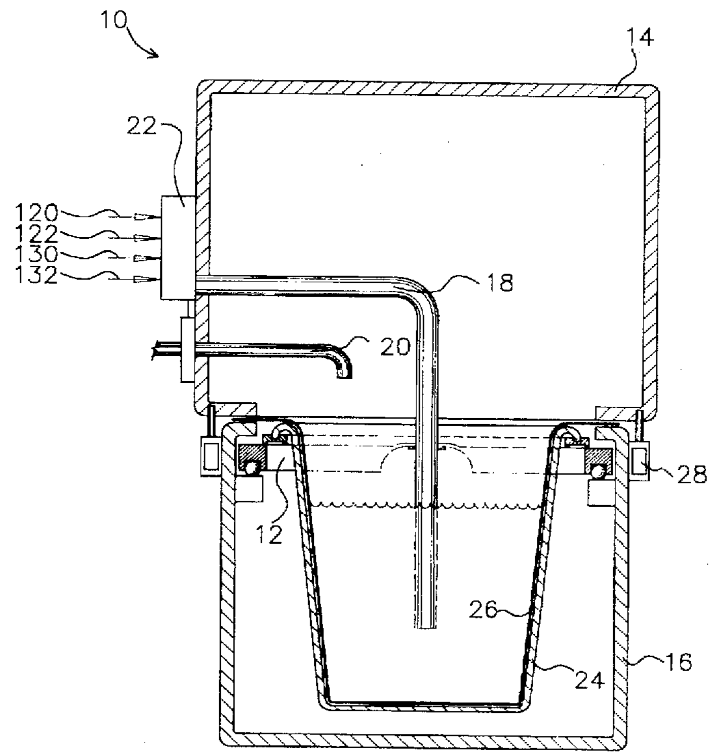
Primary Examiner—William E. Wayner
Attorney, Agent, or Firm—Sheldon H. Parker

[57] **ABSTRACT**

A humidifier for use with a hot air furnace has an upper and lower housing removably connected to one another. The upper housing has a heating element and sensor, water refill inlet, and a control circuit connected to the heat sensor and inlet. The lower housing contains a water vessel and a water level sensor secured the lower housing to receive the water vessel. The water sensor registers the minimum and maximum water weight and is connected to the control circuit. A bacteria resistant, semi-flexible removable liner fits within the vessel for the removal of built up mineral residue. Preferably the water sensor is an elliptical beam load cell with an open center surrounded by a rim and a pair of tab ends opposite one another. At least one bridge is machined within the rim to increase sensitivity. A strain gage registers strain changes and an electronic connector transfers the changes to the control circuit where they are converted to the current weight. Multiple steps along the rim receive the water vessel in insulating gaskets to prevent horizontal movement and temperature transfer. Ball bearings within the tabs balance the cell on a support ledge to allow for surface variations. Spring/screw combinations maintain the ball bearings in contact with the support ledge during mounting.

11 Claims, 12 Drawing Sheets



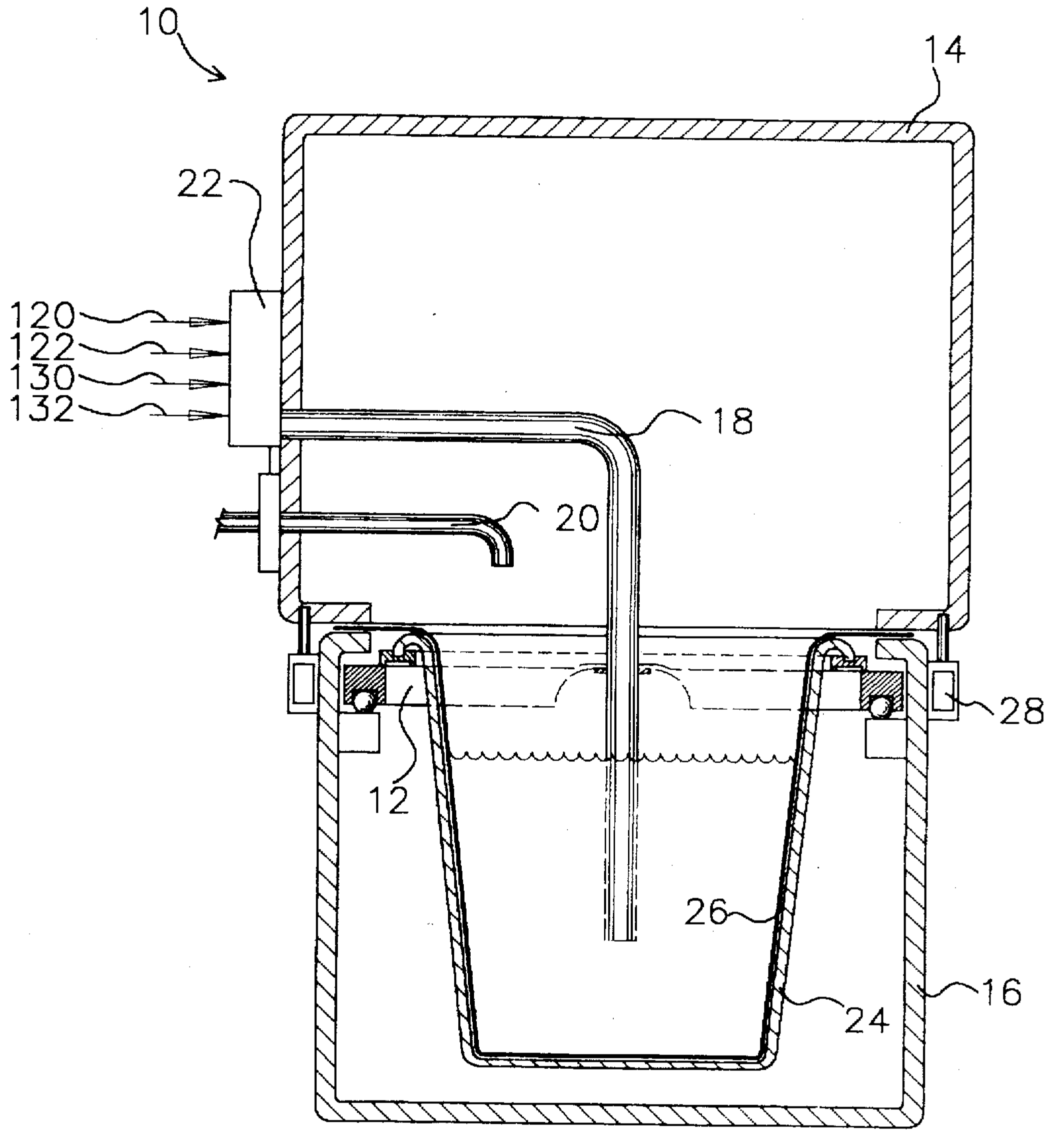


FIGURE 1

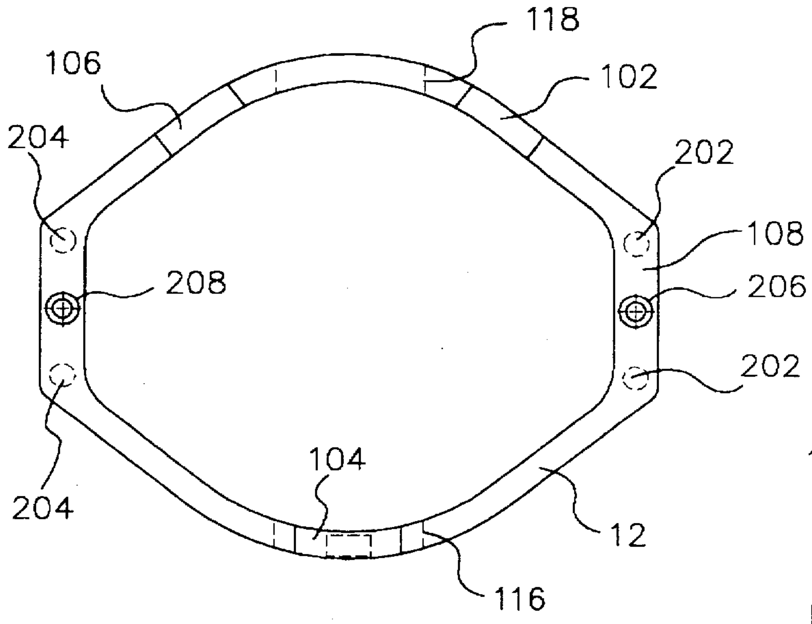


FIGURE 2

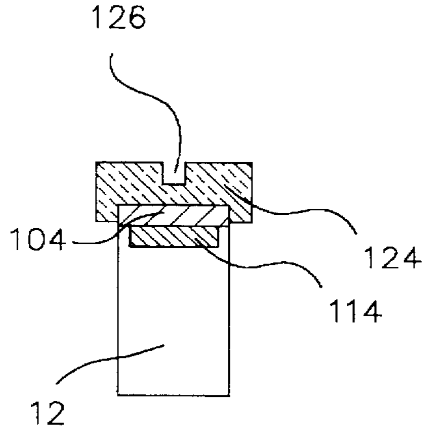


FIGURE 4

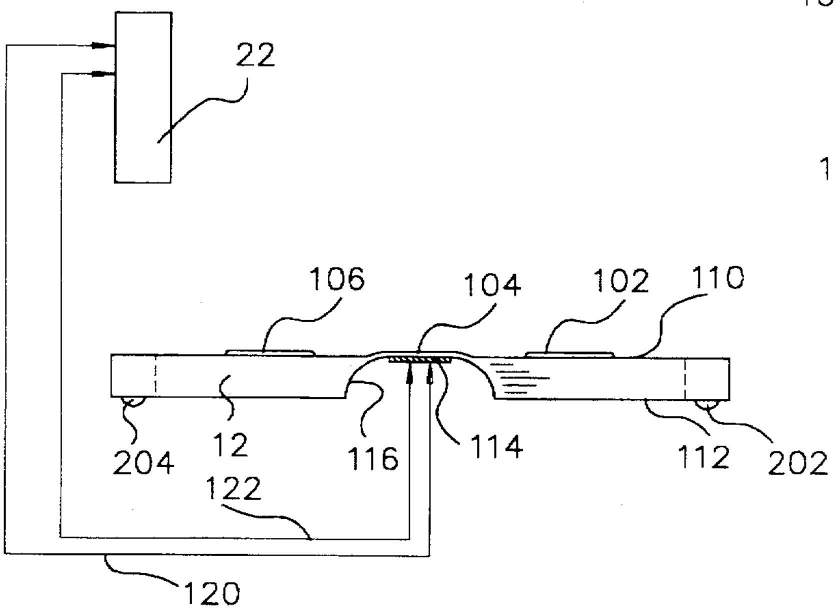


FIGURE 3

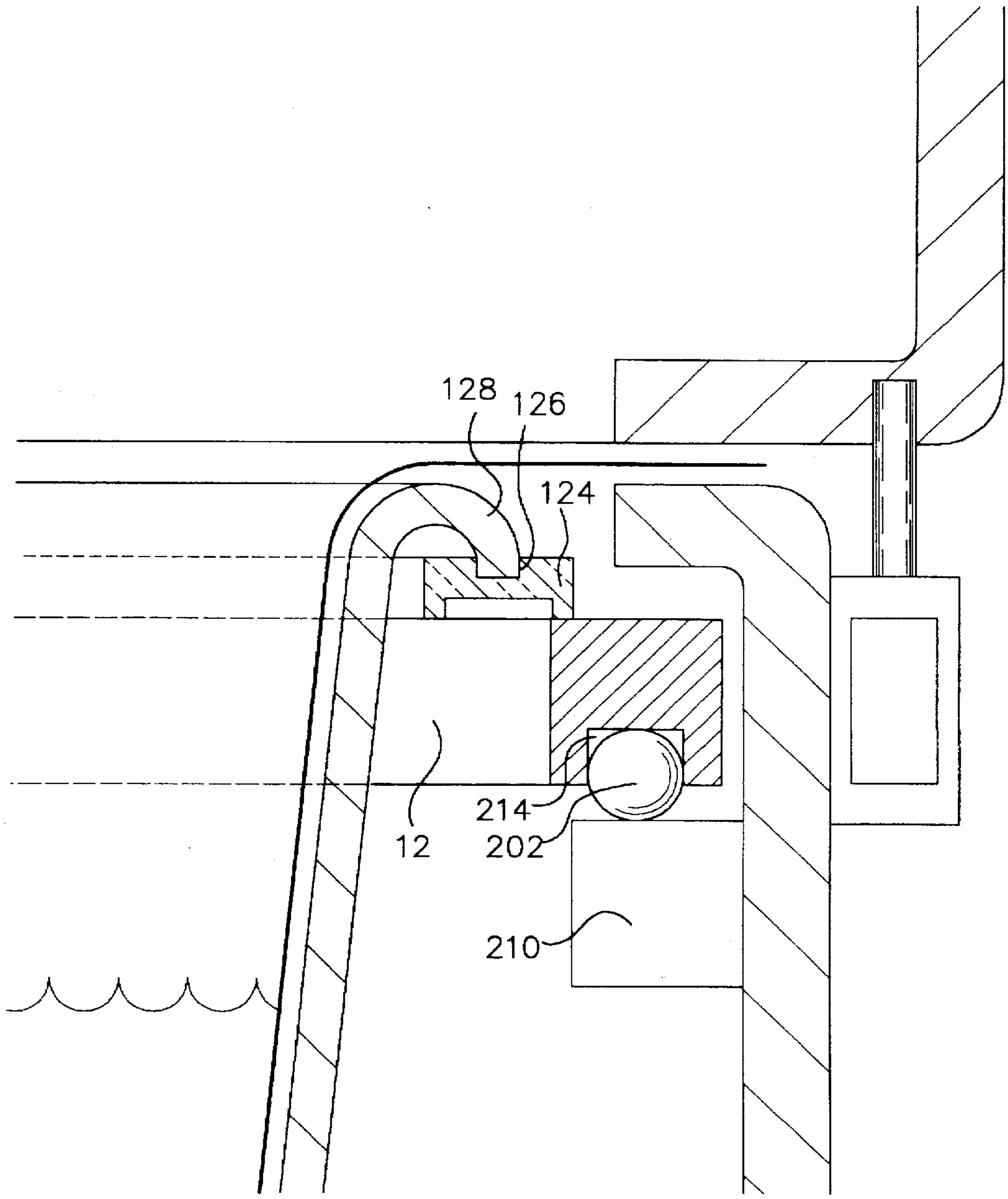
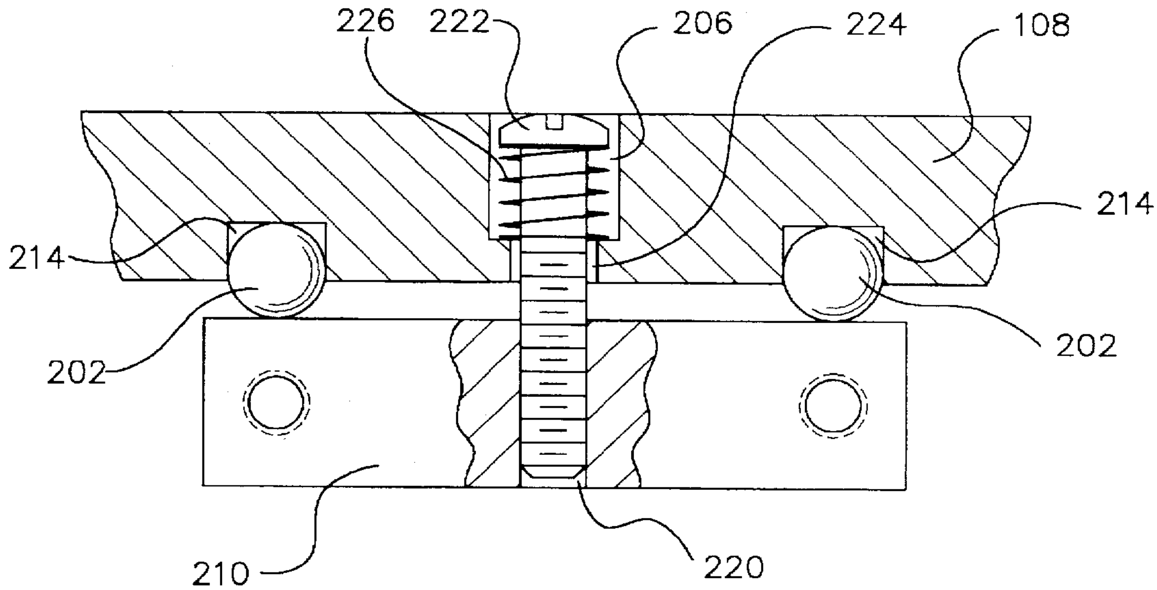


FIGURE 5



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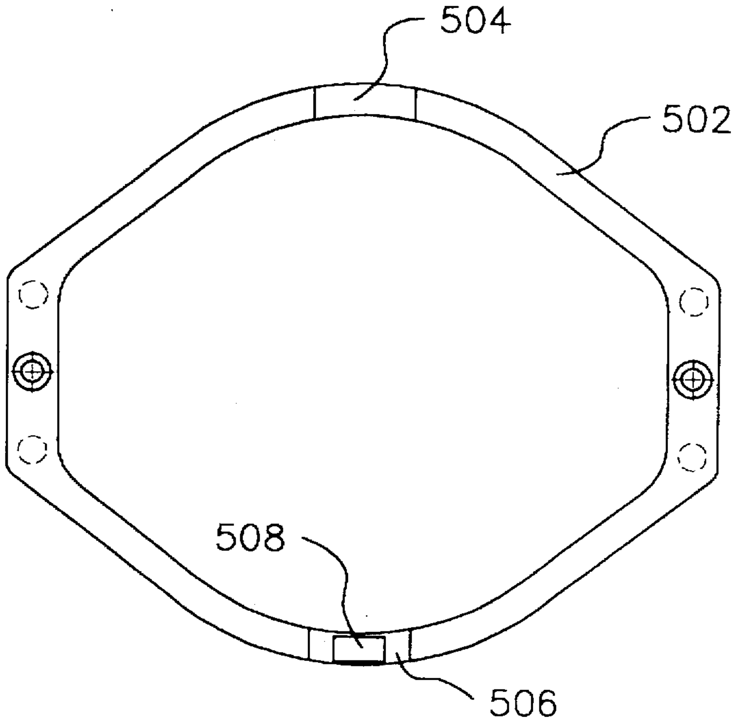

FIGURE 7

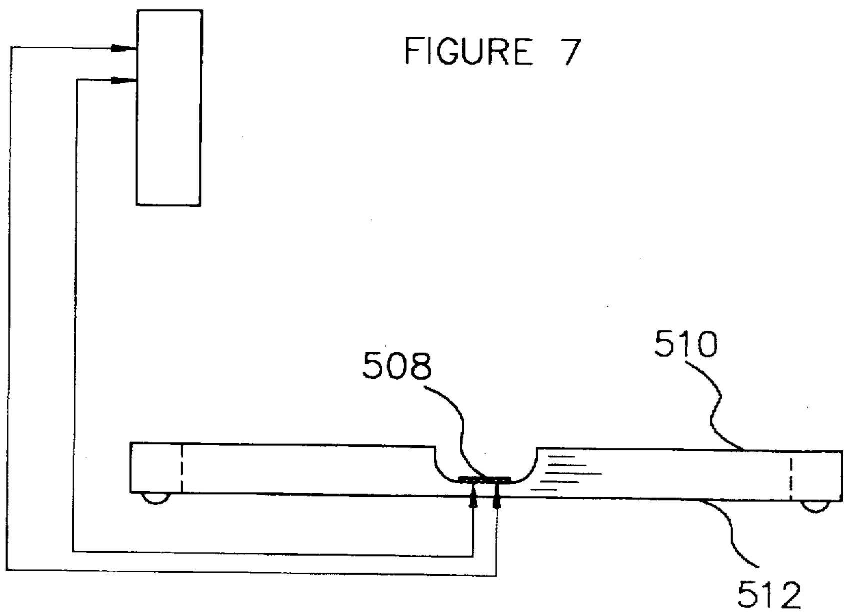

FIGURE 8

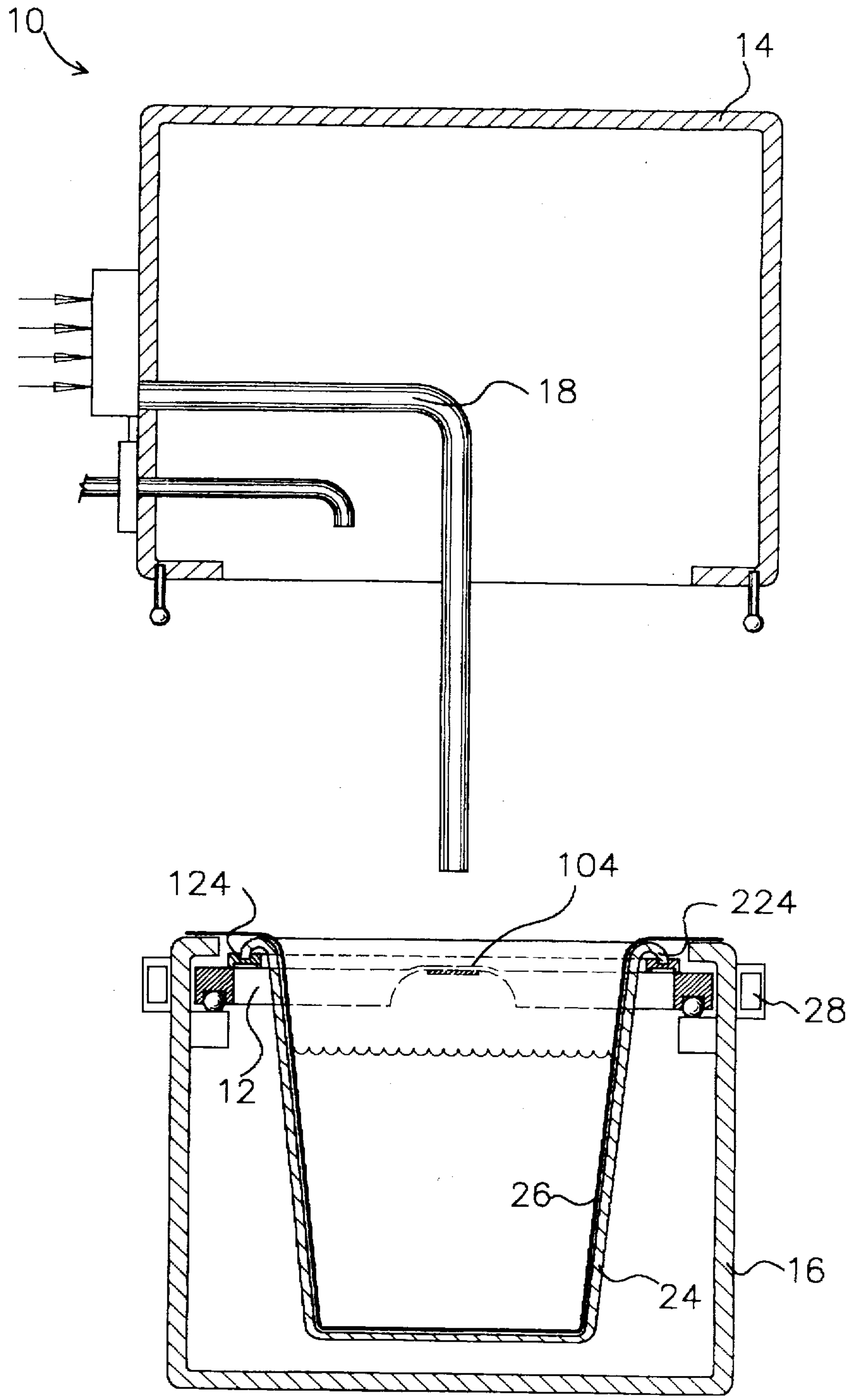

FIGURE 9

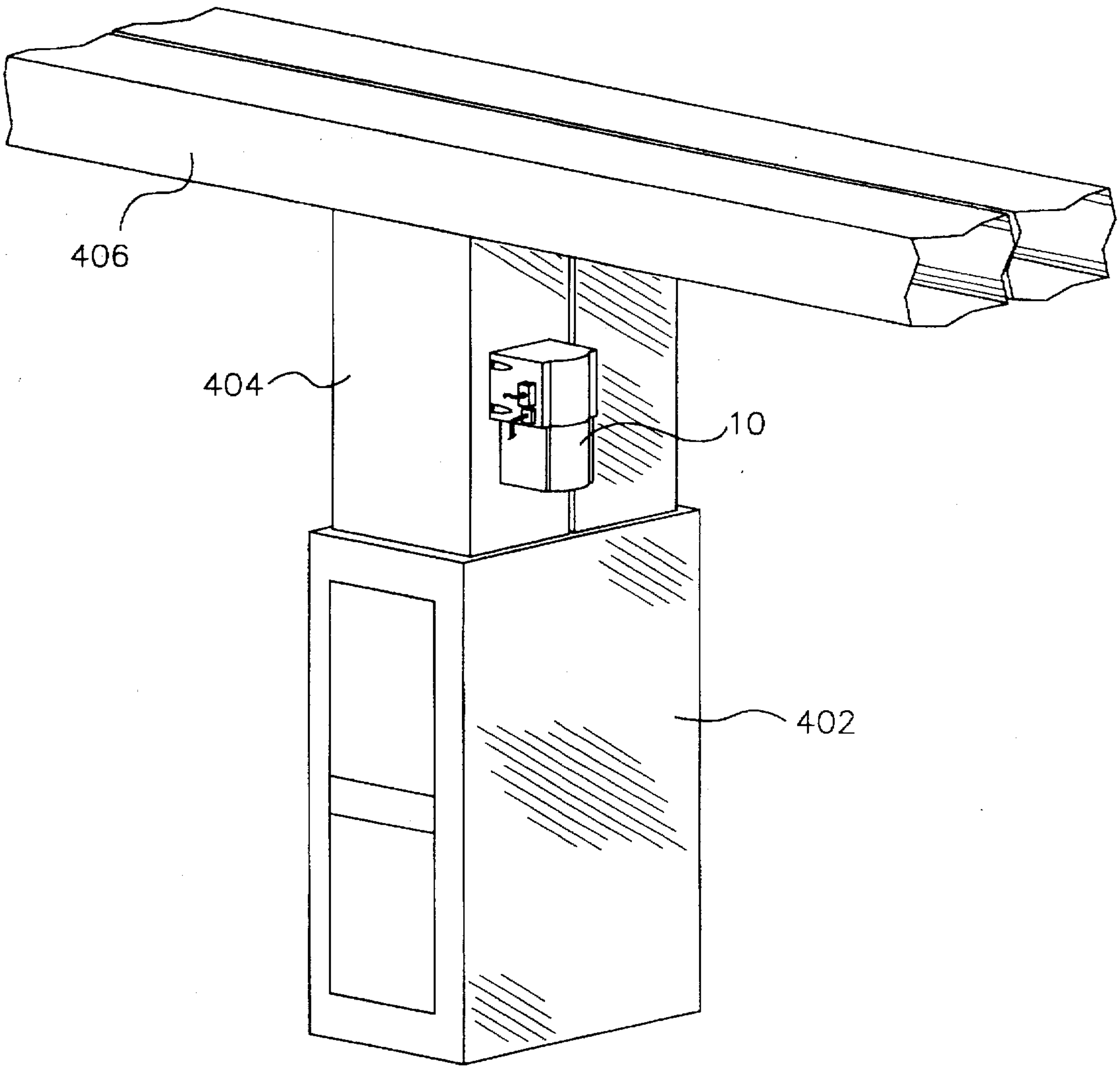

FIGURE 10

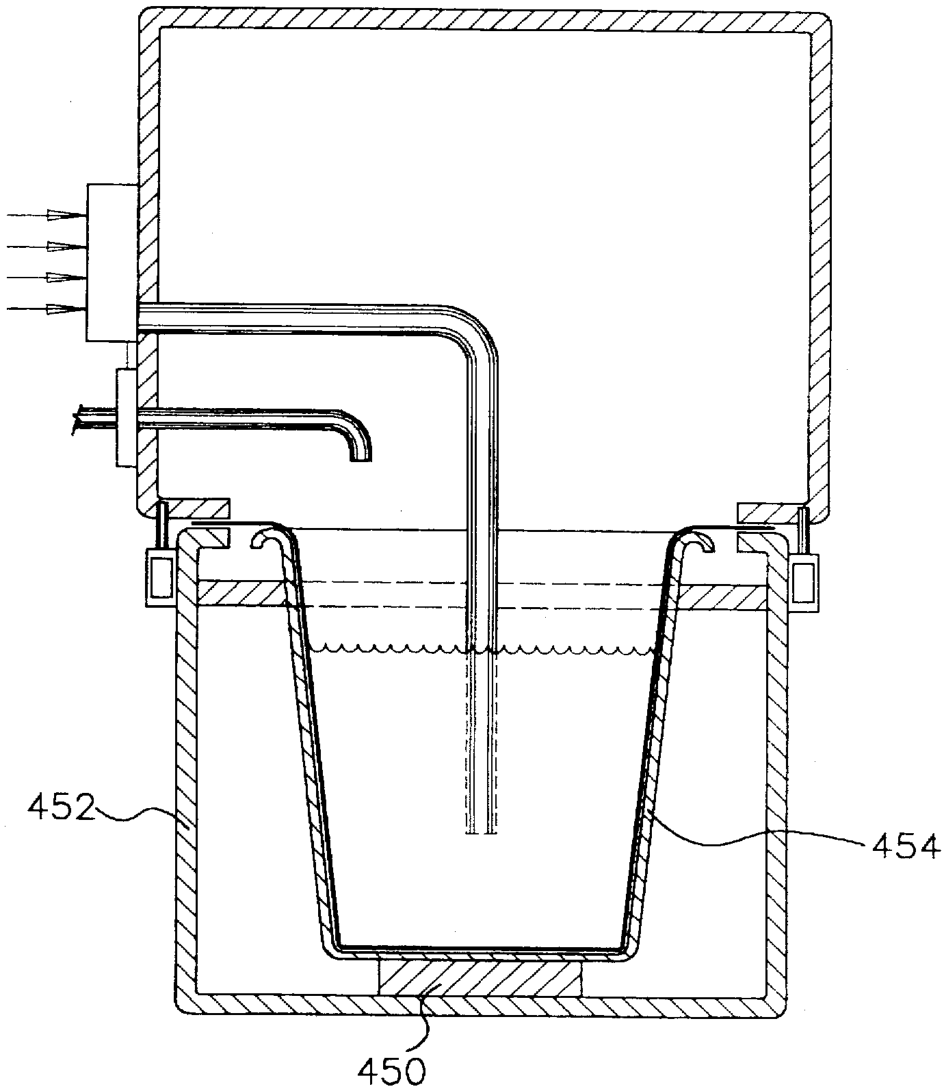

FIGURE 11

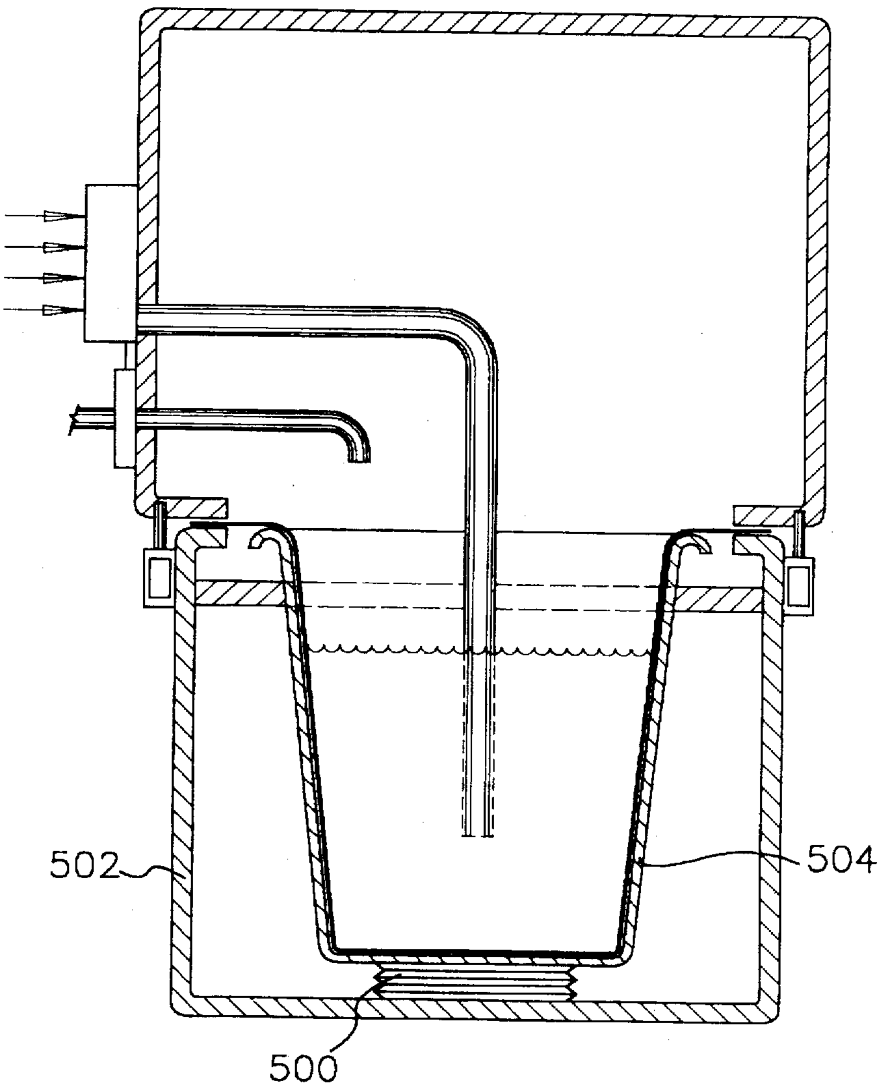

FIGURE 12

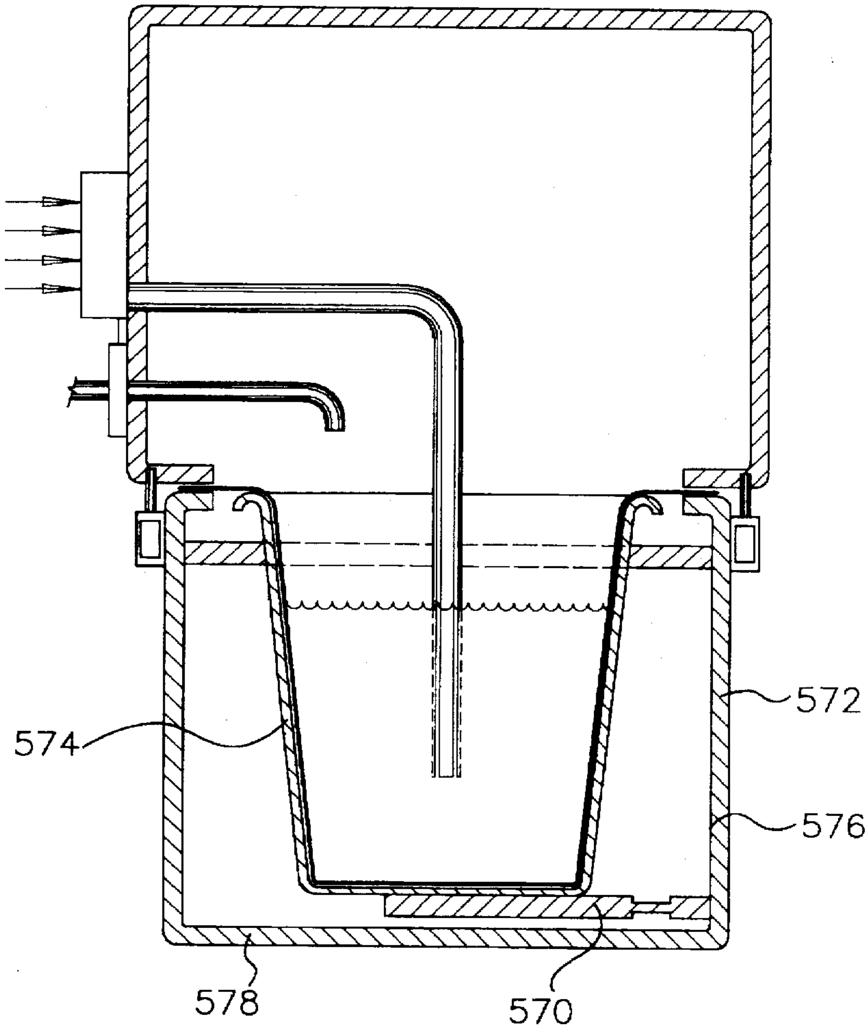

FIGURE 13

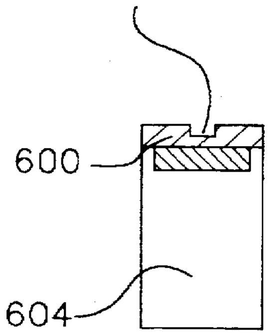

FIGURE 14

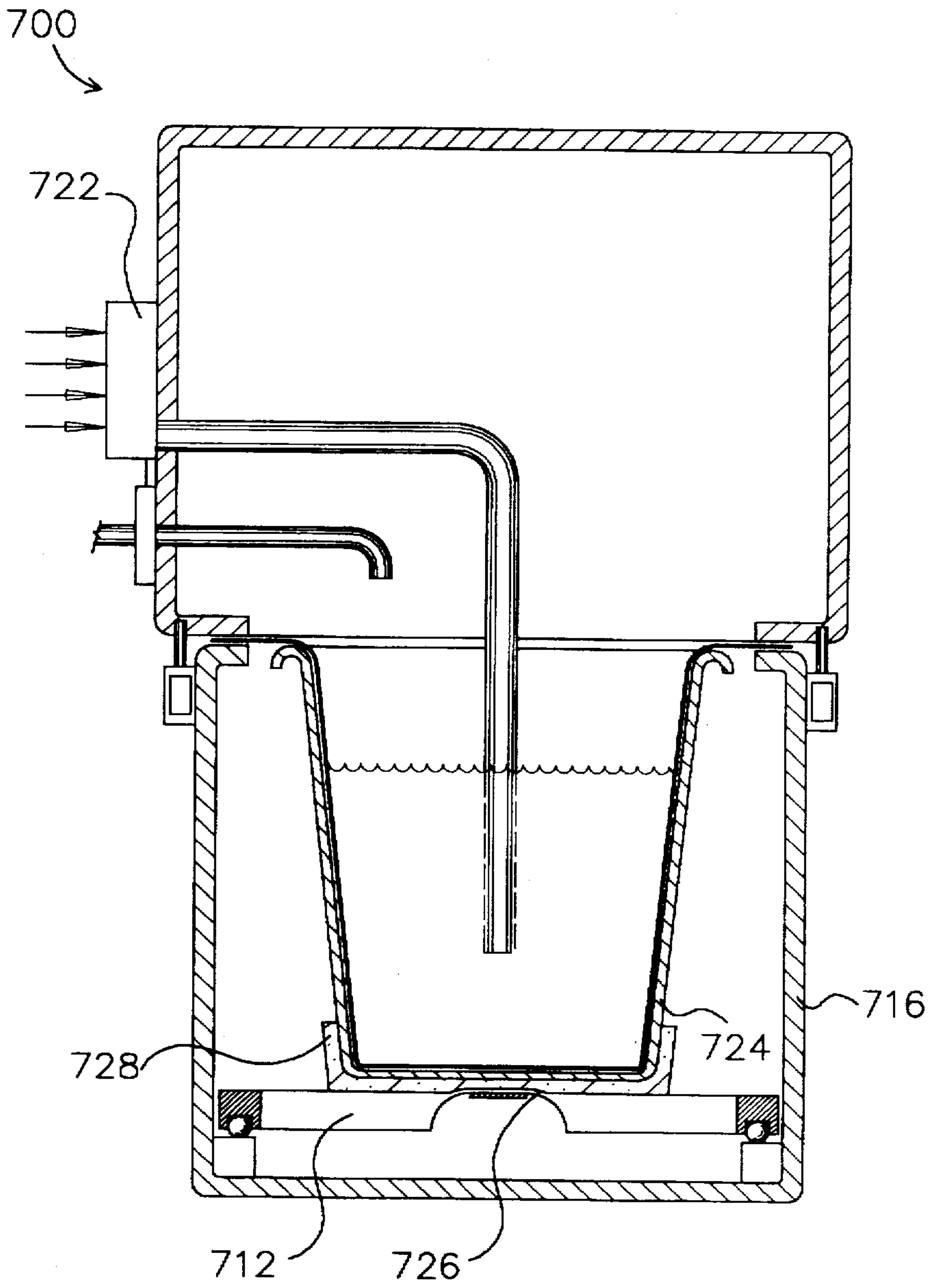

FIGURE 15

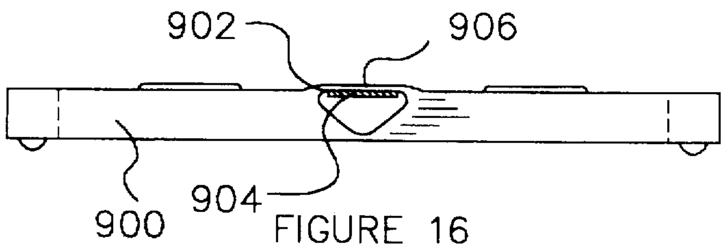

FIGURE 16

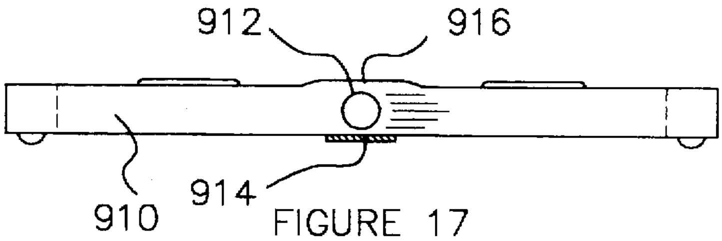

FIGURE 17

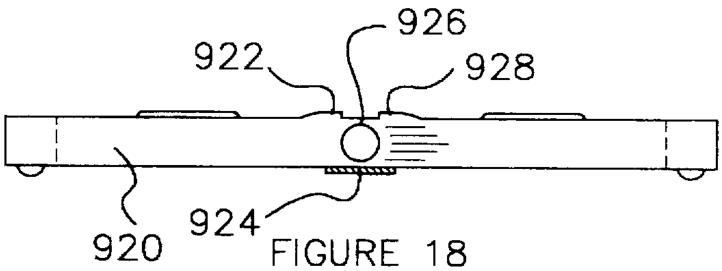

FIGURE 18

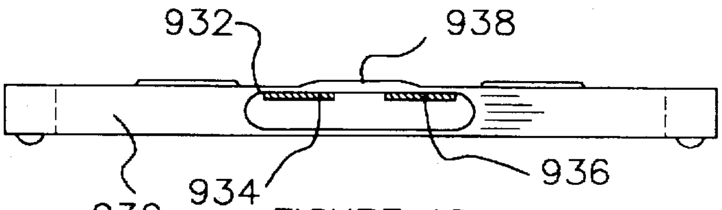

FIGURE 19

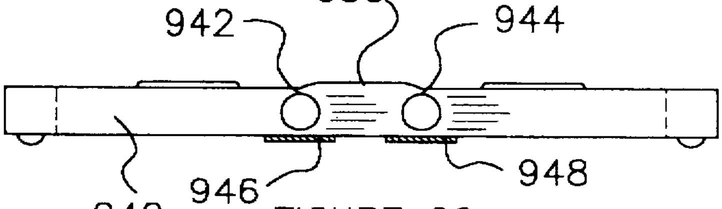

FIGURE 20

ELLIPTICAL BEAM LOAD CELL

This is a continuation-in-part of application Ser. No. 08/319,935 filed on Oct. 7, 1994 now U.S. Pat. No. 5,546,926.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention discloses an elliptical beam load cell for measuring weight increments. The use described is for measuring the change in water level in a whole house humidifying system. A removable water liner is also disclosed for use in the humidifying system to facilitate cleaning.

2. Brief Description of the Prior Art

Humidifiers are commonly used in homes during the winter to supplement the drop in humidity due to heating systems. The body is 90% water and functions best when the humidity is 50% to 55% moisture in the environment. When air drops to 30 degrees or less, the mucus membranes, such nasal passages, throat and lungs, dry out, increasing the susceptibility to bacteria related diseases. Dry skin and itching are not only uncomfortable, but in the case of skin disorders, such as psoriasis, can increase health risks.

The actual temperature, relative to our comfort level, is based on the air moisture content. In hot dry climates, a 100° F. seems comfortable because we sweat and drink liquids to replace the lost moisture. In a cold dry climate, when we sweat, the function causes a "chill" effect to the skin making us feel cold. By adding moisture to the air we "sweat" less and hence feel warmer. The actual heat (temperature setting) needed at 50% humidity is as much as 4–5 degrees lower than a 20% humidity and provides the same comfort level. Cold outside air does not hold moisture and warm forced air heating further dries the indoor air. Cold, dry weather creates a moisture vacuum that needs to be filled indoors by adding humidity that is lost. The average 2400 square foot home needs 20 gallons per day in 10 degree weather to maintain a proper humidity content.

Further advantages to maintaining a proper humidity level is in the wood products within the home. Wood products contain moisture in the 6% to 12% range, which is easily maintained when the humidity is at the 50% level. When the moisture level drops, the moldings around doors and windows will dry out and twist, crack or separate. This loss of moisture doubly causes furniture to have warped doors, drawers and frames. Maintenance of moisture preserves the life of both furniture and interior construction materials.

The addition of water to the air to bring it within balance is the solution to an unhealthy low moisture environment. The most efficient way to add humidity to a home is through the use of a whole house humidifier. Stand alone humidifiers can use 20 gallons of water per day in the cold months and keeping the units filled is a never ending task. Whole house humidifiers are only used in warm forced air systems such as electric, gas or oil furnaces and work in three different and distinct ways. Prior art humidifiers are often used in heat pump systems and work poorly or not at all. There are three types of whole house humidifiers.

Media or drum humidifiers work by some type of cloth or sponge that is constantly wetted while the hot air from the system blows over it to absorb moisture. Because the water remains luke-warm, the water particles do not merge easily with the air unless the air is hot enough to evaporate the water. In a heat pump system, with 80–90 degree air temperature, the drum humidifiers work poorly because the media remains wet and the moderate temperature is a perfect temperature for bacteria to grow. This is an excellent incubator to grow and spread germs. The second problem with media humidifiers is their maintenance. Well and public water both have "trash" particles, such as chlorine, calcium, zinc, dirt, that clog the media and coats the float and water pan. This clogging requires frequent maintenance, as often as every few weeks, and takes from one to three hours to thoroughly clean the system. Most media systems also partially block the duct work obstructing air flow through the home.

These systems have the advantage of using little energy, using tap water, and unlike impeller systems, do not spray bacteria into the air along with moisture.

In the drum type humidifier disclosed in U.S. Pat. No. 3,476,673, a chamber is provided for holding tap water or other liquid which is applied to an evaporator medium of a rotating drum. The liquid is evaporated from the evaporator medium into a hot air stream from a furnace to humidify the air stream.

U.S. Pat. No. 4,222,971 teaches the use of a liner for a drum-type humidifier which can be readily removed and replaced as needed. This, however, does not solve the problem of chemicals adhering to the wheel or other passage ways where water is in contact.

Mist or spray systems use a fine nozzle to mist water directing into the duct work to blend with the forced air. With very hot systems (oil and gas) the system works adequately, but lacks sufficient volume. Further, the trash particles clog the system and the nozzle requires frequent cleaning. In heat pump systems, the air is too cold and much of the mist water falls into the duct system causing rust.

Free standing units are also used in the home to increase humidity levels. The ultrasonic humidifiers employ a transducer and nebulizer which oscillates at about 1.7 million times a second in order to form a cool mist. While few microorganisms are released into the air, an annoying white dust is produced from the tap water.

Steamer systems provide the answer to the problems with water holding bacteria, as well as the need to provide 20 gallons per day to the forced air system. Because the steamer system heats the water to the point of evaporation prior to sending it into the heating system, the 212 degree temperature kills all bacteria. With heat pump systems, the hot steam dissipates quickly into the 80 degree air temperature.

There are about 10 steamer humidifiers around but only three main manufacturers. One commercial steamer version by Herrmidifier is about $600.00 and requires "hand cleaning", as do all prior art steam units, to remove the built-up residue which accumulates. The other two are very similar to each other in design and are generally used when a steamer humidifier is installed by professionals. Because of the inherent problems associated with residue build-up, most all furnace installers avoid sales of humidifiers. The maintenance required generally costs about $100.00 per visit and may occur 2–3 times within a winter depending on water hardness. Most steamers clog-up the first few months, shut down and the homeowner abandons it. At approximately $600.00 installed, steamer humidifiers are not a popular purchase and are an avoided product by furnace installers and knowledgeable consumers. To mount present humidifier steamers requires mounting into the duct area, thereby restricting air flow, and only mount on a horizontal duct. The maintenance on these systems is quite high due to the residue accumulation in combination with the high operating temperatures.

Impeller systems employ a fan or impeller which pumps water upwardly and slings water droplets into the air. The systems require soft water, distilled water or a demineralization cartridge rather than being a simple, tap water system.

The chemical build-ups, that is mineral deposits in units such as these, can greatly reduce the efficiency of the humidifier. In areas where there is heavy chemical content in the water, the units can require constant cleaning.

The instant invention overcomes the problems associated with the prior art by eliminating the moving parts which are susceptible to chemical accumulation and by providing an easily cleaned, low cost liner which serves to minimize the cleaning operation normally associated with humidifiers.

SUMMARY OF THE INVENTION

A humidifier for use with a hot air furnace consists of an upper and lower housing removable connected to one another. The upper housing has a heating element with a heat sensor, water refill inlet, and a control circuit which is connected to the heat sensor and water refill inlet. The lower housing contains a water retaining vessel and a water level sensor. The water level sensor is secured to a support ledge within the lower housing and positioned to receive the water retaining vessel. The water level sensor registers the minimum and maximum water weight within said water retaining vessel and is connected to the control circuit, which controls the water level based on the weight information received from the water level sensor. The control circuit controls the temperature based on information received from the heat sensor, thereby providing a constant level of evaporation within the humidifier to be drawn into the ducts of said hot air furnace. The water retaining vessel has a removable liner which is shaped to fit within the vessel. The removable liner is preferably a bacteria resistant, rigid member of semi-flexible material to allow for the removal of built up mineral residue.

In the preferred embodiment the water level sensor is a load cell having a strain gage to register the weight changes within the water retaining vessel. The preferable load cell is an elliptical beam load cell which has an open center surrounded by a rim, having a depth and a width. A pair of tab ends are along the rim opposite one another. At least one bridge is machined within the rim, reducing the depth of the rim and increasing the sensitivity to weight changes. At least one strain gage is proximate the bridge to register the strain changes placed upon the load cell. An electronic connector transfers the strain changes from the strain gage to the control circuit. The elliptical beam load cell is affixed to the lower housing in a position to support the water retaining vessel. The elliptical beam load cell has multiple steps, or raised areas, along the rim to receive the water retaining vessel. Preferably each of the steps have receiving gaskets configured to receive the receptacle and preventing the receptacle from horizontal movement. The receiving gasket is preferably an insulating material to prevent temperature transfer between the heated water and the elliptical load cell.

In one embodiment the elliptical beam load cell has balancing means consisting of a pair of bearing receiving areas within each of the tab ends and positioned to come in contact with the support ledge. Ball bearings are dimensioned to maintain friction fit within each of the bearing receiving areas. At least one screw receiving area is proximate the center of each tab ends, each having counter-bores which have a diameter greater than the screw receiving areas. A pair of screws are dimensioned to fit within the screw receiving areas, having a screw head greater than the diameter than the body of the screw. A pair of springs, with a diameter less than the screw heads, are dimensioned to fit within the counter-bores and are, with and maintained within said counter-bores by the screw heads. Each support ledge has a threaded screw engaging area threaded to receive and retain the screw. The ball bearings allow the elliptical load cell to pivot on the support ledge while the spring maintains the ball bearings in contact with the support ledge during the mounting procedure. This provides allowances for surface variations between the elliptical beam load cell tab ends and the support ledge and prevents warpage of the elliptical beam load cell.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages of the instant disclosure will become more apparent when read with the specification and the drawings, wherein:

FIG. **1** is a cutaway front view of the humidifier utilizing the load cell and liner of the instant invention;

FIG. **2** is a top view of one embodiment of the elliptical beam load cell;

FIG. **3** is a side view of the elliptical beam load cell and strain gage of FIG. **2**;

FIG. **4** is a cross section view of the elliptical beam load cell and step with gasket added;

FIG. **5** is a cutaway front view of the mounting portion of the elliptical beam load cell of FIG. **2**;

FIG. **6** is a cutaway end view of the elliptical beam load cell and support ledge;

FIG. **7** is a top view of an alternate embodiment of the instant load cell;

FIG. **8** is a side view of the load cell and strain gage of FIG. **7**;

FIG. **9** is an cutaway front view of the humidifier of FIG. **1** with the upper and lower housings separated;

FIG. **10** is a perspective view of the humidifier of the instant invention installed on a furnace;

FIG. **11** is a cutaway front view of an alternate load cell for use with the disclosed humidifier;

FIG. **12** is a cutaway front view of the humidifier of the instant invention utilizing diaphragm switch;

FIG. **13** is a cutaway front view of a straight cantilever beam load cell for use with the disclosed humidifier;

FIG. **14** is a cross sectional view of an alternate elliptical beam load cell and step;

FIG. **15** is a cutaway front view of the humidifier incorporating an alternate positioning of the elliptical beam load cell;

FIG. **16** is a side view of an alternate elliptical beam load cell with a step and strain gage bridge;

FIG. **17** is a side view of an alternate elliptical beam load cell with a step and circular strain gage cutout;

FIG. **18** is a side view of an additional elliptical beam load cell with dual steps and circular strain gage cutout;

FIG. **19** is a side view of an additional elliptical beam load cell with singular step, oval cutout and dual strain gage sets; and,

FIG. **20** is a side view of an additional elliptical beam load cell with dual cutouts and strain gage sets.

DETAILED DESCRIPTION OF THE INVENTION

The prior art problems of maintenance and bacteria growth are solved by a complete redesign of the steamer humidifier as disclosed herein. The water vessel is provided with a flexible liner, preferably silicon rubber, which can easily be replaced or cleaned. The housings have no moving parts to be clogged with mineral residue. The control regulating the humidity level is a standard humidity bulb, or other sensing means, connected to the control box. The water filler sensor is a unique load cell that maintains the appropriate water level by sensing the water weight variation. As a back-up, a standard emergency ball float resides with the filler spout activated by over fillings. The actual water valve that turns on/off is outside the steam chamber and is controlled by the load cell sensor. The heating element responds to the humidity request made through known sensing means. The heating element has a slow start system to avoid overheating and equipped with a high heat sensor to shut down if the system has emergency loss of water. The heating element is exposed when the liner is changed and can be easily replaced or cleaned. It is preferable that the heating element be a bi-metal (heating/cooling cracks scale), a split sheathing or a electro-polished sheathing design to prevent scale build-up.

The unique elliptical beam load cell disclosed can be used as a weight sensing means for detecting slight increments in weight change in devices having a low gross weight, as well as easier to measure larger weights. The load cell enables slight variations in liquid levels to be registered by weight versus prior art liquid level. The disclosed load cell is able to register the quantity of liquid within a vessel without being physically in contact with the liquid itself, thereby enabling the load cell to be used in applications where the liquid is corrosive or inhospitable to mechanical apparatus. This makes the load cell **12**, as illustrated herein, ideal for incorporation into a humidifier for use with a whole house heating system. The basic humidifying process and water retaining apparatus are described in detail in co-pending application Ser. No. 08/319,935, now U.S. Pat. No. 5,546,926 which is incorporated herein as though recited in full.

The humidifier **10**, as illustrated in FIG. **1**, comprises an upper housing **14** and lower housing **16**. The upper housing **14** contains the heating cartridge **18**, water refill pipe **20** and electrical control box **22**. The heating cartridge **18** is shown herein as an immersible unit, however any type of heating unit which will generate sufficient heat to evaporate water can be used. The heat level, as well as the automatic water refill, is controlled through the electronic controls **22**.

The lower housing **16** contains a water vessel **24**, a contoured liner **26** and and elliptical beam load cell **12**. The lower housing **16** is removably attached to the upper housing **14** through use of housing latches **28**. The housing latches **28** can be of any design which allows for ready release, and reattachment, of the lower housing **16**. A detachable bridge excitation voltage line **120** and bridge output voltage line **122** connect the load cell **12** to the electrical control box **22**. Although it is preferable that the voltage lines **122** and **120** be completely detachable, allowing the upper housing **14** and lower housing **16** to be completely separated, the arrangement is not critical. As an alternative, both voltage lines **120** and **122** can be permanently connected to each housing with sufficient length to allow for separation of the housings and removal of the liner.

The elliptical beam load cell **12** is illustrated in more detail in FIGS. **2** and **3**. The optimum material for manufacturing the load cells disclosed herein is a low-modulus material, such as the aluminum alloy 2024-T4, T351 or T81. The load cell **12** is manufactured with tab ends **108** at opposite ends of the modified ellipse. The tab ends **108** serve to support the load cell **12** on the support ledges **210**, as illustrated in FIG. **5**. Although the tab ends **108** can be either permanently or removably affixed to the lower housing **16** by various means known in the art, the preferred method is through use of ball bearings **202** and **204** in combination with screws **222** and springs **226**, as described further in FIGS. **5** and **6**. It is critical that whatever method used to secure load cell **12** to the lower housing **16**, the tab ends **108** must be secured to prevent wobbling or rotation.

Bridges **116** and **118** are machined into the under surface **112** of the load cell **12**. The bridges **116** and **118** serve to increase the sensitivity of the load cell by providing a spring element to allow for maximum strain on the metal when a load is applied. The thickness of the load cell is reduced by approximately 60–80% at the point of the bridges **116** and **118**. One of the bridges **116** is equipped with a half or full Wheatstone bridge **114**, or equivalent, to provide a read out of the amount of strain currently present on the load cell **12**. A basic Wheatstone bridge measuring circuit consists of two (half) or four (full) strain gage grids electronically connected and is recommended for use with the instant invention due to its accuracy and sensitivity with static strain circuits. Alternate bridge designs can be used and are disclosed further herein in FIGS. **16–20**.

Current is fed to the the load cell **12** through the bridge excitation voltage line **120**. The amount of load placed on the load cell **12** varies the strain of the metal, which in turn alters the current. The change in current is registered at the Wheatstone bridge **114** and fed through the bridge output voltage line **122** to the electrical control **22**. A base level strain is set at time of manufacture and a lessening of this base level indicates less weight being placed on the load cell. The electronics registering the load change, activating the water refill, etc., can be configured in any method known in the art.

To provide optimum stability, the upper surface **110** is manufactured with steps **102**, **104** and **106** to support the water vessel **24**. The steps **102**, **104** and **106** concentrate the weight contained within the cup **24** approximate the bridges **116** and **118**. The placement of the steps **102** and **106** are at approximately a 45° angle from an imaginary center line drawn between the two bridges **116** and **118**. The third step **104** is placed directly over the bridge **116** containing the strain gage **114**. The placement of the steps **102**, **104** and **106** in a triangular configuration, allows for the maximum stability and optimizes the location of the pressure placed on the load cell **12**. A further advantage to the use of the steps **102**, **104** and **106** is the increased tolerance in both cup **24** and load cell **12** manufacturing. Any surface differences between the cup **24** and the load cell **12** will result in an imbalance of pressure placement and therefore a decrease in accuracy.

To prevent slippage of the vessel **24**, a channeled gasket **124** is affixed to the steps **102**, **104** and **106** as shown in FIGS. **4** and **5**. The gasket **124** is preferable manufactured in a U-shape to fit dimensioned to form a friction fit over the steps **102**, **104** and **106**. Alternatively, the gasket **124** can be affixed through use of appropriate adhesives known in the art. The gasket **124** is provided with a channel **126** dimensioned to receive the vessel flange **128**, simultaneously cushioning the vessel **24** while preventing horizontal movement. The gasket **124** provides the additional advantage of further extending the tolerance of surface differences between the flange **128** and the load cell **12**. The gasket **124** is preferable manufactured from a insulating material to provide the advantage of avoiding heat transfer from the vessel **24** to the load cell **12**, thereby avoiding possible warpage of the load cell **12**.

In FIG. 6 the tab end **108** is shown mounted to the support ledge **210** through use of a screw **222**. The ball bearings **202** and **204** are equally spaced within the tab **108** from the screw hole **224** and receiving area **220**. The ball bearings **202** are snapped into and maintained in the bearing receiving notch **214** by a friction fit. A threaded receiving area **220** is machined into the support ledge **210** to receive the screw **222** and secure the load cell. A counterbore **206** is machined into the tab end **108** to provide a receiving area for the spring **226** and screw head **222**. The compression spring **226** has a diameter less than the machined counterbore **224** and head of the screw **222**, thereby maintaining the compression spring **226** between the head of the screw **222** and screw receiving area **224**. Tightening the screw **222** pulls the tab **108** and the support ledge **210** together until contact is made between the ball bearings **202** and the support ledge **210**. The resistance created by the compression spring **226** keeps the support ledge **210** from becoming tightly fixed to the ball bearings **202**. This allows the support ledge **210** to pivot on the ball bearings **202** so it will adjust to the wall mounting on the lower housing **16**. This floating adjustment will keep a twisting action off the load cell.

An alternate load cell **502** is illustrated in FIGS. **7** and **8**. In this embodiment, the bridges **504** and **508** are machined in the upper surface **510** of the load cell **502**. The cup **24** rests directly on the load cell **502**, spanning the bridges **504** and **506**. As stated heretofore, in this embodiment the tolerances between the load cell **502** and the cup **24** must be minimal.

In FIG. **9** the top housing **14** and bottom housing **16** are shown removed for cleaning or disposal of the liner **26**. For safety purposes, it is preferable to turn off the humidifier **10** prior to separation to allow the heating unit **18** to cool. Once both voltages lines **120** and **122** are disconnected, the lower housing **16** is completely separable from the upper housing **14**. Due to the unique design of the humidifier **10**, the lower housing **16** can be easily removed with the water vessel **24** full with little or no spillage. The water vessel **24** can be manufactured from stainless steel or any number of appropriate materials known in the art. To clean or replace the liner **26** the water vessel **24** is removed from the load cell **12** and emptied. The elliptical shape of the load cell allows the water vessel **24** to be easily grasped between the water vessel **24** rim and the tab ends **108**. The liner **26** is preferably manufactured from silicone rubber or other equivalent material, including impregnated cloth, to facilitate cleaning. The material should be inert, bacteria resistant and semi-rigid. By providing a slight degree of flexibility, the liner **26** can be "flexed" to remove the built up residue without scrubbing. It is preferable that the material of manufacture for the liner **26** be such to allow for economical disposal of the liner **26** if so desired.

The humidifier **10** is shown installed on the plenum **404** of a furnace **402** in FIG. **10**. Although the humidifier **10** can be installed on the horizontal duct work **406**, the humidification would not be as equally dispersed as the with the plenum mounting **404**. The small size of the humidifier **10** in relation to the furnace **402** is readily seen in this Figure, facilitating installation, on new or existing furnaces. The size additionally makes the unit easy to clean as it can be readily held in the user's hand.

In FIG. **11** the compression load cell **450** is placed directly on the base of the lower housing **452** and the water vessel **454** placed on top of the compression load cell **450**. The compression load cell **450** reacts to the changes in water weight as described heretofore, sending the signal through the bridge output voltage line (not shown).

FIG. **12** illustrates a diaphragm switch **500** placed at the base of the lower housing **502**. The water vessel **504** is placed directly on the diaphragm switch **500**. When the water weight in the vessel **504** becomes low, the diaphragm switch **500** will click on which transmits a signal to the electrical control box for a water refill.

In FIG. **13** a straight cantilever beam load cell is utilized to indicate the level associated weight changes in the water vessel **574**. The beam load cell **570** is affixed to the wall **576** of the lower housing **572** slightly above the base **578**. The strain placed on the floating beam load cell **570** is registered by strain gages in a Wheatstone bridge circuit design (not shown). The gages are mounted on the upper and lower spring element surfaces of the beam and transmit the load measurement to the electrical controls as described heretofore.

FIG. **14** illustrates a cross-sectional of an alternate embodiment to the steps disclosed herein. The step **600** is either machined as part of, or added to, the load cell **604**. A channel **602**, dimensioned and positioned to receive the flange of a water vessel, is machined into each of the steps **600**.

In FIG. **15** the humidifier **700** has the elliptical load cell **712** placed at the bottom of the lower housing **716**. The dimensioning of the load cell **712** has been modified to support the bottom of the water vessel **724** rather than suspend the vessel as disclosed heretofore. The steps **726** are placed as previously described, however the U-shaped gasket has been replaced with an L-shaped gasket **728**. The L-shape of the gasket **728** prevents horizontal movement of the bottom of the water vessel **724** while placing the load emphasis on the strain gages.

FIGS. **16–20** illustrate alternate configurations to the foregoing bridges, providing variations to the heretofore disclosed spring element or bridge. In FIG. **16** the elliptical beam load cell **900** has a modified inverted triangle cutout as a bridge **902**. The strain gage **904** is placed directly below the single step **906**. The elliptical beam load cell **910** of FIG. **17** uses a circular cutout for the bridge **912**. The strain gage **914** is placed at the underside of the load cell **910**, opposite the singular step **916**. The elliptical load cell **920** of FIG. **18** utilizes dual steps **926** and **928** positioned on either side of the circular cutout bridge **922**. The strain gage **924** is placed on the underside of the load cell **920** below the bridge **922**. For applications requiring extreme accuracy, such as in the medical field, dual strain gage sets are used to average the weight changes. In FIG. **19** an oval cutout is used in the elliptical load cell **930** for the bridge **932**. Dual strain gage sets **934** and **936** are placed within the bridge **932** on either side of the step **938**. Elliptical load cell **940** of FIG. **20** has dual circular cutout bridges **942** and **944** placed at either end of the step **950**. The strain gage sets **946** and **948** are placed below the bridges **942** and **944** on the underside of the load cell **940**.

The embodiments disclosed in FIGS. **16** and **19** offer the advantage of the placement of a hermetic seal for ultimate protection against moisture. FIGS. **17**, **18** and **19** provide the advantage of a lower production cost. The circular cutout designs are drilled which reduces machining time. Any of the foregoing combinations can be used in conjunction with one another to produce the optimum elliptical beam load cell for each individual application.

Since other modifications and changes varied to fit particular operating requirements and environments will be apparent to those skilled in the art, the invention is not considered limited to the example chosen for the purposes of disclosure, and covers all changes and modifications which do not constitute departures from the true spirit and scope of this invention.

What is claimed is:

1. A humidifier for use with a hot air furnace comprising:

an upper housing, said upper housing having:

heating means, said heating means including temperature sensing means and on/off means;

water refill means,

control means,

a lower housing, said lower housing being removably connected to said upper housing and containing:

a water retaining vessel;

a water level sensor means, said water level sensor means being secured to a support ledge and positioned to receive said water retaining vessel and sense the minimum and maximum water weight within said water retaining vessel;

said control means being connected to said water level sensor means, said heating means and said water refill means, wherein said control means controls the water level based on the weight information received from said water level sensor means and activates said on/off means based on information received from said temperature sensing means, thereby providing a constant level of evaporation within said humidifier to be drawn into the ducts of said hot air furnace.

2. The humidifier of claim 1, further comprising a removable liner, said removable liner being shaped to fit within the interior of said vessel.

3. The humidifier of claim 2, wherein said removable liner is a bacteria resistant, rigid member of semi-flexible material to allow for the removal of built up mineral residue.

4. The humidifier of claim 1, wherein said water level sensor means is a load cell having a strain gage to register the weight changes within said water retaining vessel.

5. The humidifier of claim 4 wherein said load cell is an elliptical beam load cell, said elliptical beam load cell having:

an open center, said open center being surrounded by a rim, said rim having a depth and a width;

a pair of tab ends, said pair of tab ends being along said rim opposite one another,

at least one bridge, said at least one bridge being machined within said rim, reducing the depth of said rim and increasing the sensitivity of said elliptical beam load cell to weight changes,

a strain gage, said strain gage being proximate said bridge to register the strain changes placed upon said load cell,

electronic connector means, said electronic connector means transferring said strain changes from said strain gage to said control means,

wherein said elliptical beam load cell is affixed to said lower housing in a position to support said water retaining vessel.

6. The humidifier of claim 5 further comprising multiple steps, said multiple steps being raised areas along said rim to receive said water retaining vessel.

7. The elliptical load cell of claim 6 further comprising receiving gaskets, said receiving gaskets being dimensioned to fit on each of said multiple step areas and configured to receive said receptacle, thereby preventing said receptacle from horizontal movement.

8. The elliptical load cell of claim 7 wherein said receiving gasket is an insulating material to prevent temperature transfer between the heated water of said water retaining vessel and said elliptical load cell.

9. The humidifier of claim 5 wherein said elliptical beam load cell further comprises balancing means, said balancing means having:

a pair of bearing receiving areas within each of said tab ends and positioned to come in contact with said support ledge;

at least two pair of ball bearings, said ball bearings being dimensioned to maintain friction fit within said bearing receiving areas;

at least a pair of screw receiving areas, said screw receiving areas being proximate the center of said tab ends and having counter-bores, said counter-bores having a diameter greater than said screw receiving areas;

a pair of screws, said screws being dimensioned to fit within said screw receiving areas and having a screw head greater than the diameter than the body of said screw;

a pair of springs, said pair of springs being dimensioned to fit within said counter-bores and having a diameter less than the diameter of said screw heads, thereby being maintained within said counter-bores by said screw heads;

a pair of threaded screw engaging areas, said screw engaging areas being threaded to receive and retain said screw in said support ledge;

wherein said ball bearings allow said elliptical load cell to pivot on said support ledge and said spring maintains said ball bearings in contact with said support ledge, during the mounting procedure thereby allowing for surface variations between said elliptical beam load cell tab ends and said support ledge and prevent warpage of said elliptical beam load cell.

10. The humidifier of claim 1, wherein said sensor means is a device for monitoring and registering weight changes within said water retaining vessel.

11. The method of maintaining a level of home humidity through furnace ducts using a hot air furnace humidifier, said humidifier having:

an upper housing, said upper housing having

control means,

heating means, said heating means incorporating heat sensing means, said heat sensing means being connected to said control means;

water refill means, said water refill means being connected to said control means,

a lower housing, said lower housing being removably connected to said upper housing and having:

a water retaining vessel;

a water level sensor means, said water level sensor means being positioned to receive said water retaining vessel and register the minimum and maximum water weight within said water retaining vessel, said water level sensor being connected to said control means;

comprising the steps of:

placing said water retaining vessel within humidifier,

activating said power source,

registering the current water weight on said water level sensor,

transmitting said water weight to said control means,

activating said water refill means to fill said vessel until the water reaches a maximum weight,

deactivating said water refill means when said water reaches said maximum weight, transmitting said upper housing's current temperature to said control means,

activating said heating means to raise said temperature in said heat chamber to a level sufficient to cause water evaporation,

allowing the moisture created through evaporation to rise through said duct into said furnace duct work,

monitoring said water and heat levels to constantly maintain a predetermined water level and temperature to cause water evaporation,

whereby said moisture is distributed throughout the house through said furnace duct work, raising the humidity level throughout the house.

* * * * *

United States Patent [19]

Cross et al.

[11] **3,841,146**

[45] **Oct. 15, 1974**

[54] **AUTOMATED VOLUME MONITORING SYSTEM**

[75] Inventors: **Newbold O. Cross,** Berkeley Heights; **Jeffrey L. Thompson,** Hopatcong, both of N.J.

[73] Assignee: **Esso Research and Engineering Company,** Linden, England

[22] Filed: **Mar. 26, 1973**

[21] Appl. No.: **344,993**

[52] **U.S. Cl.** **73/49.2**
[51] **Int. Cl.** **G01m 3/32**
[58] **Field of Search**...................... 73/40, 40.5, 49.2

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Primary Examiner—S. Clement Swisher
Attorney, Agent, or Firm—F. Donald Paris

[57] **ABSTRACT**

A system for detecting leaks in buried storage tanks by measuring change in liquid level, comprising a product containing reservoir suspended from an electronic load cell for measuring any weight loss and thermal sensor for detecting any change in average product temperature. A volume calculating circuit combines the weight change and temperature change signals to produce a temperature corrected output which may be suitably displayed. Zero change in net volume is indicated if the product level changes due only to a rise or fall in temperature. However, if the product level changes due to a leak or ground water entering the tank an accurate measurement of the volume change is obtained.

10 Claims, 4 Drawing Figures

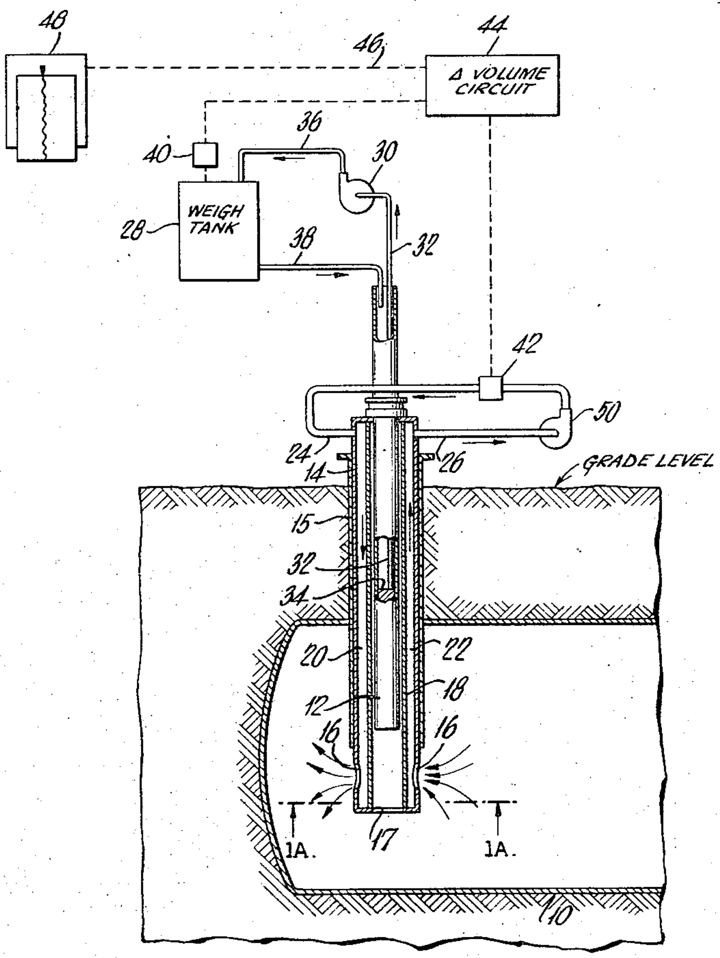
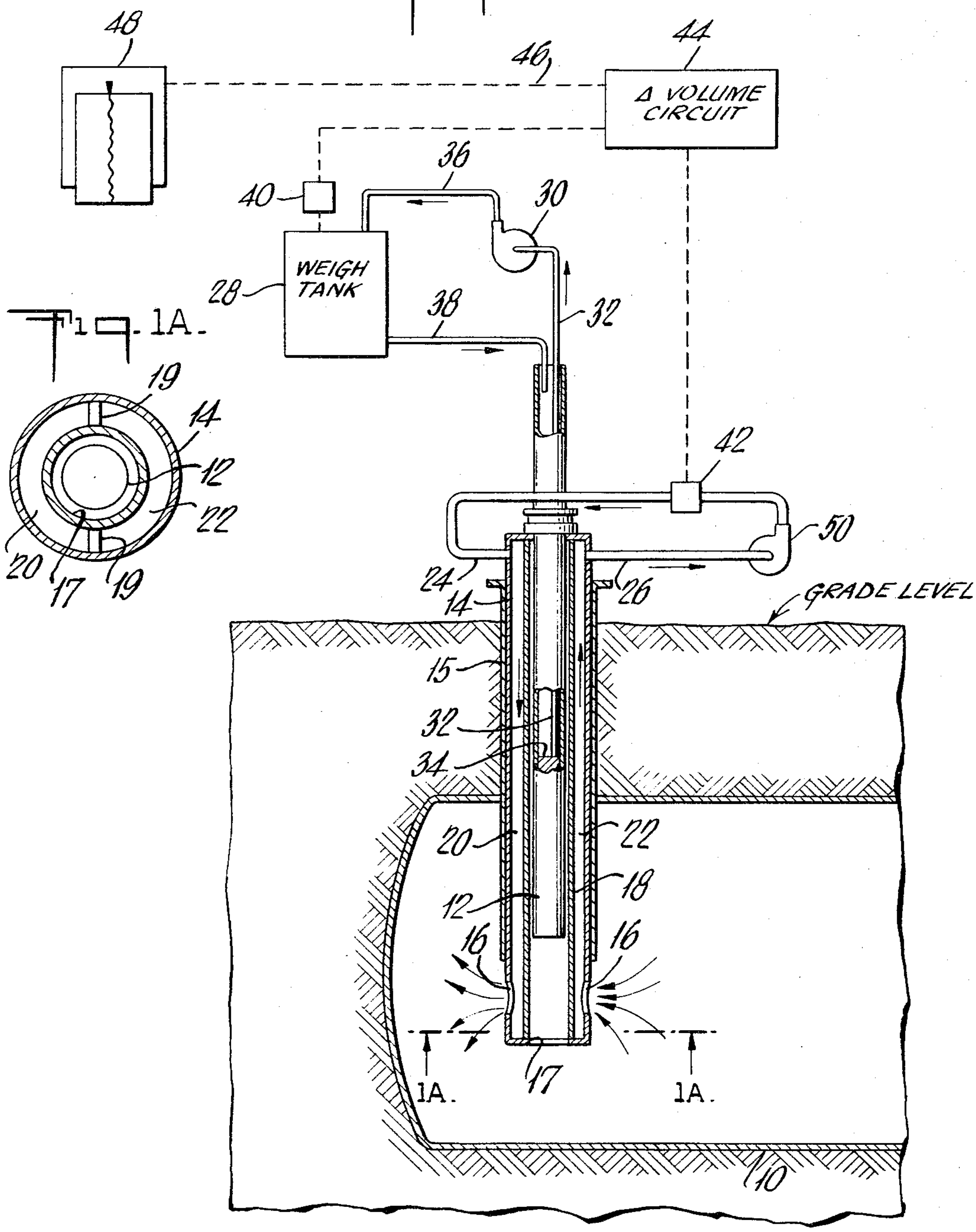


Fig. 1.


48
46
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Δ VOLUME CIRCUIT
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WEIGH TANK
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26
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GRADE LEVEL
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12
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16
17
1A.
1A.
10

Fig. 1A.

19
14
12
22
20
17
19

PATENTED OCT 15 1974 3,841,146

SHEET 2 OF 2

Fig. 2.

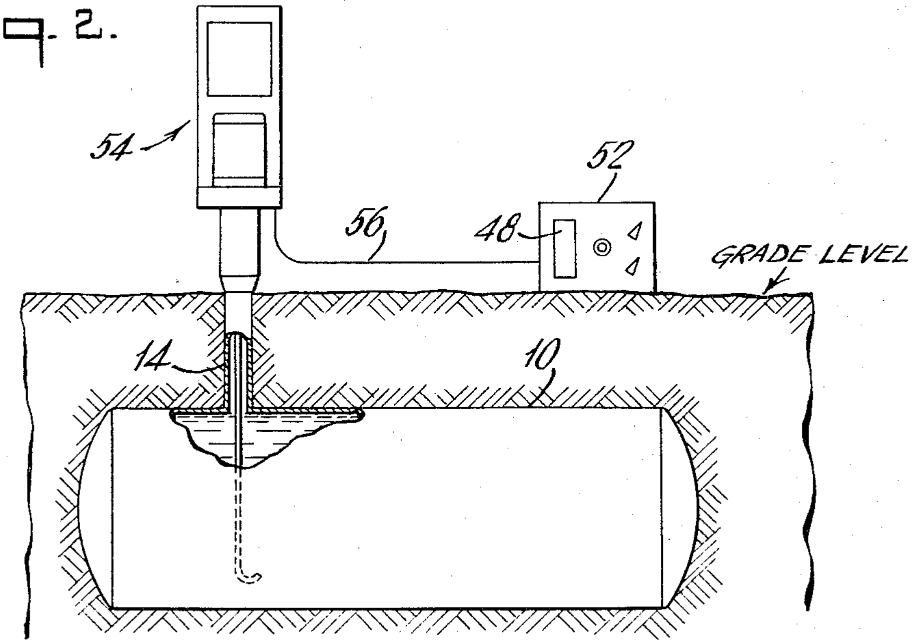
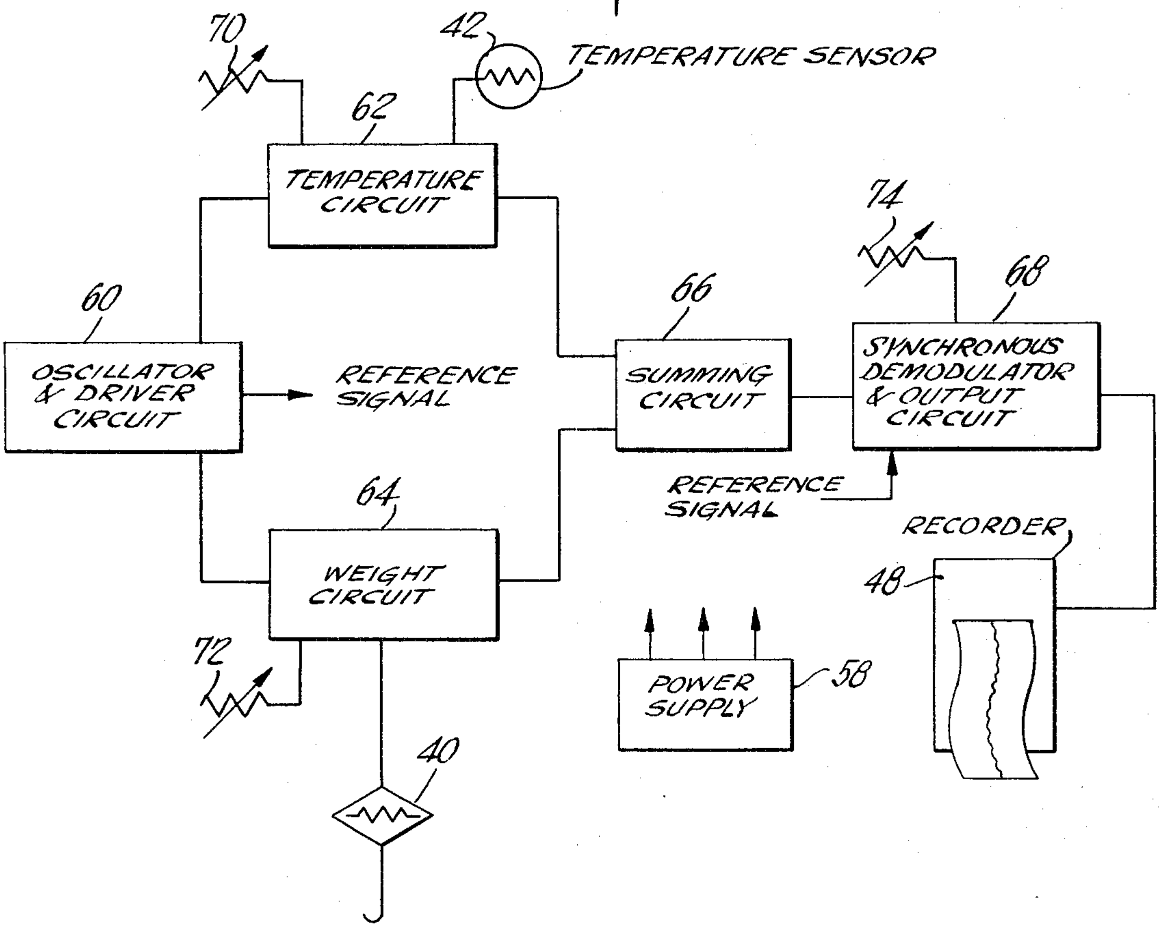


Fig. 3.



AUTOMATED VOLUME MONITORING SYSTEM

BACKGROUND OF THE INVENTION

There presently exists a need for an in-place tank inspection, particularly for underground product storage tanks, that is economical, practical and simple. Studies have shown that existing techniques for such inspection are inadequate. While there exists a variety of leak detection schemes, systems based on measuring the change in liquid level have been found to be the most sensitive, quantitative and simple.

At present there are several leak detection systems which involve the measurement of liquid level changes, the most accurate of which is commonly known as the Kent-Moore Tank Tightness Tester. Reference may be had to NFPA Publication No. 329, pp. 48–56, for details of the Kent-Moore technique. However, this technique has various disadvantages and limitations as discussed below. This technique, upon which nearly all underground storage tank integrity testing is performed, has a 0.05 gallon per hour sensitivity threshold. According to this method, the tank in question is isolated from any intertank manifolding and is completely filled with the product, such as gasoline. An approximately 4-foot clear plastic standpipe is attached to the storage tank's filler neck and filled to near the 4-foot mark. The system then is examined to ensure that there are no leaks in the dispensers or associated plumbing. The 4-foot head is maintained until there is evidence that tank end expansion into the soil has ceased, then the standpipe level is lowered about 1 foot and the actual leak test is begun. This lower standpipe level is maintained constant, and a pump simultaneously circulates the product in the tank to eliminate thermal gradients. An electronic thermometer monitors the average product temperature. This is important especially in the case of gasoline, which has a thermal expansion coefficient of 0.0006 gallons per gallon per °F. and hence a drop of average product temperature by 1°F. corresponds to an apparent "loss" of 6 gallons in a 10,000 gallon tank, which is 120 times the hourly leak threshold for this technique. About every 15 minutes, the test operator must add or subtract product from the standpipe to maintain a constant test level, read the product temperature, factor in the size of the tank under test, and then calculate the net tank contents with arithmetic accuracy to about eight decimal places. The disadvantages of this technique are readily apparent, particularly the need for the involvement of the operator in collecting data and calculating tank contents.

SUMMARY OF THE INVENTION

The present invention relates to an automated volume monitoring system and more particularly to a novel system and technique which is simple and automated, and has greater practicality and improved sensitivity and accuracy than systems heretofore available. The present invention eliminates the need for operator collection of data and calculation of net tank product volume change (Δv) by automatically compensating for product volume changes caused by differences in temperature and displaying the corrected Δv values in a suitable manner.

While the present invention incorporates the circulating pump and temperature sensing element of the prior art technique discussed above, the remainder of the system is significantly different and provides the improvements mentioned above. According to this invention a fixed test level above the tank shell is maintained in the tank under test by means of a small suction pump having its inlet positioned at the desired level. This can make any intertank manifolding, plumbing and vent piping leaks non-significant because the test level may be set as low as 1–2 inches above the top of the tank shell. In the event that detecting leaks in associated piping is of interest, the test level may be easily elevated, thus applying pressure to that piping. The small pump discharges into a 5 to 10 gallon reservoir container which is provided with a gravity drain return into the tank under test, which maintains the test level. The weight of the reservoir is measured by an electronic load cell and is a measure of product mass lost or gained due to leakage or temperature expansion. The reservoir weight and average product temperature are operated upon in an electronic circuit to derive any actual tank loss. The circuit output may be displayed in a suitable manner such as on a strip chart recorder.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates an automated leak volume monitoring system according to the present invention;

FIG. 1A is a cross-sectional end view taken substantially on the line 1A—1A of FIG. 1;

FIG. 2 schematically illustrates a typical commercial embodiment of the automated leak volume monitoring system of FIG. 1 for underground storage tanks; and

FIG. 3 is a block diagram of the weight and temperature tank leak detector circuit.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Having reference to the drawings wherein like parts are designated by the same reference numeral throughout the several views, FIG. 1 schematically illustrates a system according to the present invention for detecting a leak in a conventional underground storage tank **10.** A removable assembly comprises variable height metal tube **12,** circulation pipe **14,** and central tube **18** which are inserted into a standard fill pipe **15** of the storage tank. The tube **12** is adjustable to permit variations in head height of the product and is inserted into the pipe **14.** This adjustability facilitates testing at lower liquid heads such as when a separate test is to be conducted to determine whether an indicated leak is in interconnecting piping or the tank and is advantageous because excavation and disconnection of the interconnecting piping is eliminated. The bottom end of the pipe **14** is provided with two openings **16** to create a circulation swirl in the product contained in the tank **10,** which ensures thorough product mixing. The pipe includes a centrally disposed, isolated coaxial chamber **18,** connected to the tank contents via orifice **17,** which slidably receives the tube **12** therein and peripheral circulation pump inlet and outlet chambers **20, 22.** In order to separate the suction from discharge flow in the annular space between the pipe **14** and the chamber **18,** two vertically extending sealing strips **19** are incorporated to isolate the chambers **20** and **22.** At the upper end of the pipe (above grade level) are inlet conduit **24** and outlet conduit **26** which connect together and with chambers **20** and **22** provide, respectively, to provide a continuous flow channel for the product, the purpose of which will be explained in detail hereafter. A reservoir container **28**, which preferably may have a 5 to 10 gallon capacity, is connected via a standard self-priming suction pump **30** having an inlet **32** located at about the desired product test level **34** and an outlet **36** for discharge into the reservoir. A gravity feed line **38** drains from the reservoir, at a rate less than pump **30** capacity, back to the tank to maintain the product test level at the desired height above the top of the shell.

In operation if product leakage or thermal contraction causes a drop in the test level **34** in tube **12**, the suction inlet **32** of pump **30** will lose contact with the liquid surface. The gravity drain **38** from the reservoir **28** will continue to supply product to tank **10** via tube **12** until the end of the suction inlet which is at the desired test level is reached, whereupon pump rate exceeds gravity feed rate, thus maintaining the desired level **34**. Similarly, should ground water in-leakage or thermal expansion cause a rise in test level **34**, pump **30** will transfer the excess product to reservoir **28** until the suction inlet **32** is again just exposed at the test level **34**. A conventional electronic load cell **40** from which the reservoir container **28** is suspended measures any weight loss, which corresponds to a volume change in product in the tank, and a conventional thermal sensor **42**, which is interposed between the lines **24**, **26**, detects any change in the average product temperature. A volume calculating circuit **44** receives signals from the weight load cell **40** and the temperature sensor **42** which are a function of weight and temperature changes and combines these signals to produce a temperature corrected output signal at **46** which may be displayed on a strip chart recorder **48**. The circuit **44** is designed so that if the product level change is due only to a rise or fall in temperature, the recorder will indicate zero net volume change. If, however, product is being lost through a leak or ground water is entering the tank, an accurate measurement of volume change will be indicated on the chart. A standard circulation pump **50** is connected in the flow channel including lines **24**, **26** to eliminate or at least minimize thermal variations in the contents of the tank under test and to provide ample product flow past the thermal sensor **42**.

A typical application of this leak test technique is for leak testing buried gasoline storage tanks such as are found in service stations and garages. FIG. 2 is a schematic illustration of a typical commercial design for the subject automated leak monitoring system. Basically, this system comprises two functional units - one generally designated **52** and comprising the control and display unit and the other generally designated **54** comprising the pumps, reservoir, and load cell. The control and display unit **52** typically may include the tank volume and product density controls for calibration of the test constants, a function selection switch, a temperature difference zero adjustment and a weight zero adjustment for initial setting up of the test. This unit also contains the strip chart recorder **48** which provides a continuous display or readout of time rate of temperature corrected volume (that is, leak rate) in the weigh tank. Obviously other suitable recording means may be employed. The unit is adapted for connection to a standard 110 volt power supply. The other functional unit **54** typically may be attached to a standard quick connect coupling which fits into the tank fill pipe **14**, and includes the weigh tank or reservoir **28** and the load cell **40** which constantly monitors change in weight of the liquid in the reservoir which represents any change in liquid level, and the motor driven centrifugal pump **50** which circulates the entire volume of the storage tank to achieve uniform temperature as well as the suction pump **30**. This unit **54** is electrically coupled to the control and display unit **52** via line **56**. It is preferred to vertically mount the circulating pump and the motor concentric with the tank fill pipe **14** in order to eliminate the need for separate suction and discharge lines. Also, the weigh tank preferably should be mounted on top of the pump-motor combination in order to reduce the number of separate components at the test site.

FIG. 3 is a block diagram of the volume measurement circuit which comprises the weight and temperature sensing elements **40** and **42**. For simplicity, stability and resistance to electrical interference it is preferable to employ a synchronous alternating current system although conventional AC or direct current can be employed. The basic system comprises five functional blocks and a standard power supply **58**. An oscillator and driver circuit **60** supplies like constant amplitude signals to the temperature circuit **62** and the weight circuit **64** each of which comprises a standard bridge-amplifier circuit for deriving product temperature and reservoir weight change signals and a reference for the synchronous demodulator **68**, a summing circuit **66** to combine the weight change and temperature change signals so that apparent volume changes due only to temperature changes are eliminated, and the synchronous demodulator circuit **68** to convert the AC signal to a DC signal suitable for driving the recorder **48**. The weight sensing cell **40** which may comprise a commercial strain gauge load cell and temperature sensor **42** which may comprise a temperature sensitive resistor (i.e., thermistor) are connected into bridge circuits as shown.

In the temperature circuit **62** a potentiometer **70** is used for making the appropriate adjustment for tank size and is calibrated directly in thousands of gallons. Similarly, potentiometer **72** in the weight circuit is set at the beginning of a leak test to correspond to the actual capacity or volume of the tank under test.

In the summing circuit **66** the weight change in the reservoir is compensated by removing that part of the weight change caused solely by thermal expansion (or contraction). The volume change in the reservoir (i.e., the uncompensated leak volume) is the density of the liquid times the sensed change in weight. Liquid density is taken into account by means of a density adjustment. This volume change signal is temperature compensated by subtracting an amount equal to the volume change due only to thermal expansion. This amount is the thermal coefficient of expansion per gallon (which for gasoline is 0.0006/gal/gal/°F.) times the number of gallons in the tank (actual tank volume) times the amount of temperature change in the tank contents. The proper weight change and temperature change signals are then algebraically summed to provide a net output. This output signal which is a temperature compensated volume signal is fed into the demodulator which produces a DC voltage, proportional to the amplitude of the input signal, that drives the recorder. The demodulator is provided with a potentiometer **74** for calibrating the recorder sensitivity in gallons/inch of pen travel.

In general, the test procedure for the automated leak volume monitoring system initially is similar to the operating procedure employed by the Kent-Moore technique. Thus, the tank must be filled before the test and product added to allow for increased volume due to the tank ends bulging into the surrounding earth or backfill. A period of time is required to circulate the contents of the tank to achieve uniform product temperature. The actual time required depends upon the difference in temperature between the tank contents and added product as well as the tank volume. After uniform product temperature conditions are achieved, actual calculation and data display are automatic. In reference to FIG. 2 after the tank is filled with product, the pump and weighing assembly constructed according to the present invention is attached to the neck of the standard tank fill pipe. Then, the pumps are started and product is added or withdrawn from the reservoir to maintain the level approximately 50 percent full. The control unit is connected to a suitable power supply and the power is turned on. On the control unit the function selector switch is alternately positioned between "weight" and "temperature" positions and the weight and temperature zero controls are adjusted so that the strip chart recorder pen is maintained in a central location. The appropriate tank volume for the tank being tested is selected. After this is done the function selector switch is set at the temperature position and, if necessary, circulation of the product should be continued until the strip chart shows no more than about ±.01 gal. variation. Product density is then measured and the product density control is set at this value. Then the strip chart is observed for a period of time sufficient to determine if a leak is present. The presence of a leak is revealed by a constant negative slope of the chart trace; indicating product out leakage or a positive slope indicating ground water in-leakage.

There has been described an automated leak volume monitoring system for the leak testing of storage tanks. This novel system has the advantages of saving time which results from the automated plotting of data; reduced possibilities for human error due to miscalculations when making corrections for product temperature variations; the total test period is reduced since false leak indications caused by tank end bulging are minimized by employing a reduced test head; and leaks in attendant piping can be separated from tank leaks by lowering the test head after a leak indication is found.

It will be understood that various changes in the details, arrangement of parts and operating conditions which have been herein described and illustrated in order to explain the nature of the preferred embodiment of this invention may be made by those skilled in the art within the principle thereof and that reference should be made to the following appended claims which determine the scope of this invention.

What is claimed is:

1. An automated volume monitoring system for a product storage tank comprising:
a. a vertically adjustable tube for containing product at a predetermined test level and adapted to be disposed in the fill pipe of said storage tank;
b. thermal sensor means for sensing the average temperature of said product;
c. suction means operably disposed for contact with said product surface substantially at said predetermined test level within said tube;
d. a reservoir for containing a predetermined amount of said product;
e. level maintenance means connected to said suction means and said reservoir operable in response to a change in said predetermined test level so as to maintain said test level substantially constant;
f. drain means connected between said reservoir and said tube for supplying product from said reservoir to said tube when said suction means loses contact with said product surface until said predetermined test level is obtained; and
g. load cell means operably associated with said reservoir for measuring any weight change of the product therein.

2. An automated volume monitoring system according to claim 1 including volume calculating means operably connected with said thermal sensor means and said load cell means for producing a temperature corrected output signal representative of any change in volume of said product in said reservoir.

3. An automated volume monitoring system according to claim 2 including recorder means connected to said volume calculating means for displaying said temperature corrected output signal whereby product-out leakage is indicated by a constant negative slope and ground water in-leakage is indicated by a constant positive slope.

4. An automated volume monitoring system according to claim 2 wherein said volume calculating means comprises an electronic circuit including circuit means for providing signals corresponding to product temperature and weight change in said reservoir, and a summing circuit connected for combining said signals to provide said temperature corrected output signal so that changes in product volume due only to temperature are eliminated.

5. An automated volume monitoring system according to claim 1 including pump means for continuously circulating a sample flow of the product past said thermal sensor and minimizing thermal variations within the product contained in said storage tank.

6. An automated volume monitoring system according to claim 5 wherein said tube is coaxial with said fill pipe and said fill pipe includes separate annular peripheral inlet and outlet chambers in operable communication with said pump means.

7. An automated volume monitoring system according to claim 1 wherein said level maintenance means comprises a pump for maintaining said test level so that when said test level drops said pump transfers additional product to said tube and when said test level rises said pump transfers excess product to said reservoir.

8. A volume monitoring system for a product storage tank comprising:
a. tube means for containing said product at a predetermined head height;
b. reservoir means separate from said storage tank for containing a predetermined amount of said product; and
c. means operably connected between said tube means and said reservoir means for maintaining said predetermined head height substantially constant.

9. A volume monitoring system according to claim 8 wherein said tube means is adjustable to permit variation in the head height of said product.

10. A method for determining a change in volume of a product in a storage tank as a result of leakage comprising the steps of

a. establishing in a tube within said storage tank a substantially constant test level of said product at a height above the tank casing;
b. providing a reservoir of said product separate from said storage tank;
c. obtaining uniform temperature of the product in said tank;
d. transferring sufficient product between said tube and said reservoir in response to changes in said head height in order to maintain said predetermined head height substantially constant;
e. weighing the change in volume of product in said reservoir which change corresponds to a volume change in product in said storage tank; and
f. determining the amount of product volume change in said storage tank as a function of the product volume change in said reservoir due only to leakage.

* * * * *

US005633809A

United States Patent [19]

Wissenbach et al.

[11] Patent Number: 5,633,809

[45] Date of Patent: May 27, 1997

[54] MULTI-FUNCTION FLOW MONITORING APPARATUS WITH AREA VELOCITY SENSOR CAPABILITY

[75] Inventors: **Richard Wissenbach**, Brockport; **Anthony Tavano**, Niagara Falls, both of N.Y.

[73] Assignee: **American Sigma, Inc.**, Medina, N.Y.

[21] Appl. No.: **635,054**

[22] Filed: **Apr. 19, 1996**

Related U.S. Application Data

[63] Continuation of Ser. No. 547,718, Oct. 26, 1995, abandoned, which is a continuation-in-part of Ser. No. 219,097, Mar. 29, 1994, Pat. No. 5,506,791, which is a continuation-in-part of Ser. No. 954,288, Sep. 30, 1992, Pat. No. 5,299,141, which is a continuation-in-part of Ser. No. 612,832, Nov. 13, 1990, Pat. No. 5,172,332, which is a continuation-in-part of Ser. No. 455,981, Dec. 22, 1989, Pat. No. 5,091,863.

[51] **Int. Cl.**[6] **G06F 17/00**

[52] **U.S. Cl.** **364/510**

[58] **Field of Search** 364/509, 510; 73/863.01, 863, 863.02, 863.03, 864.34, 515; 141/1, 89, 91, 94, 130; 422/82.11, 98; 385/12; 367/13

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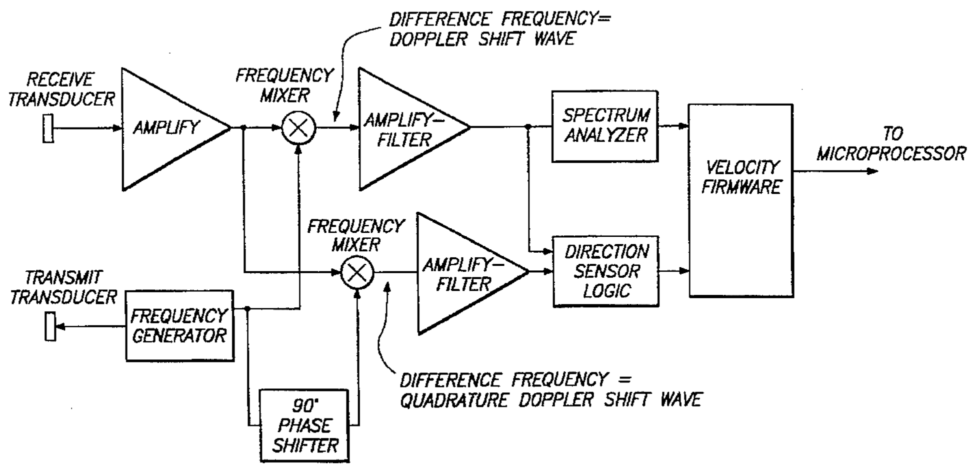
Primary Examiner—Ellis B. Ramirez
Attorney, Agent, or Firm—Weiner, Carrier & Burt, P.C.; William F. Esser; Irving M. Weiner

[57] **ABSTRACT**

A multi-function fluid flow monitoring apparatus capable of measuring fluid flow-related variables of fluid in a channel on the basis of signals from any one or more of a plurality of different types of flow sensors. Such different types of flow sensors may include, for example, a bubbler-type pressure sensor, a submerged pressure transducer, an ultrasonic transducer, and/or a velocity sensor forming part of an area-velocity sensor system, each of which sensors may be selectively connected to the apparatus as needed to accommodate various monitoring conditions. The apparatus is further capable of monitoring various conditions of fluid in the channel, such as pH level, ORP, temperature, solution conductivity, dissolved oxygen, and the like. In addition, the apparatus may be selectively linked with one of a variety of operational devices, such as an automatic sampling apparatus, a rain gauge, or a pump, so as to selectively initiate desired actions by such external device(s) or to otherwise operably cooperate with such external device(s). The integral operating unit includes a computer control system including a microprocessor, program memory, and data memory. External connectors are provided for selective connection to one or more different flow sensors, fluid condition sensors, and/or external devices. The apparatus further includes a display screen, controlled by the computer control system, which selectively displays data in either text or graphics formats. Data including flow-related data, fluid condition data, as well as data from external devices, may be transferred from the data memory of the apparatus to an external computer, printer, or the like by use of a hand-held data transfer unit or a modem integrally provided in the apparatus. The apparatus includes a liquid velocity measurement unit based upon Doppler technology, comprising a spectrum analyzer for calculating average fluid velocity, a mechanism for calculating maximum fluid velocity, and a means for verifying the calculated average fluid velocity based upon the calculated maximum fluid velocity value.

27 Claims, 24 Drawing Sheets



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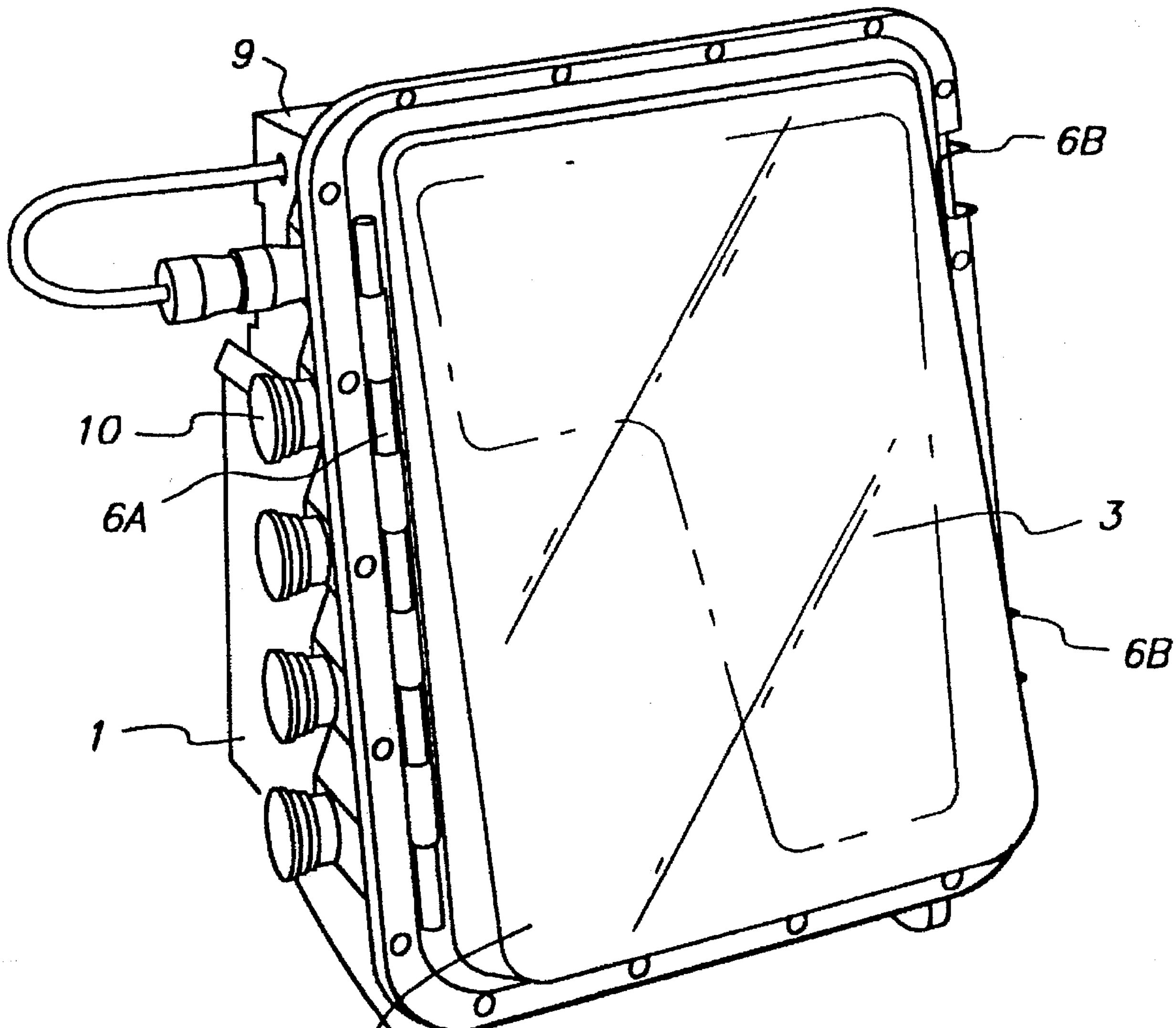


FIG. 1

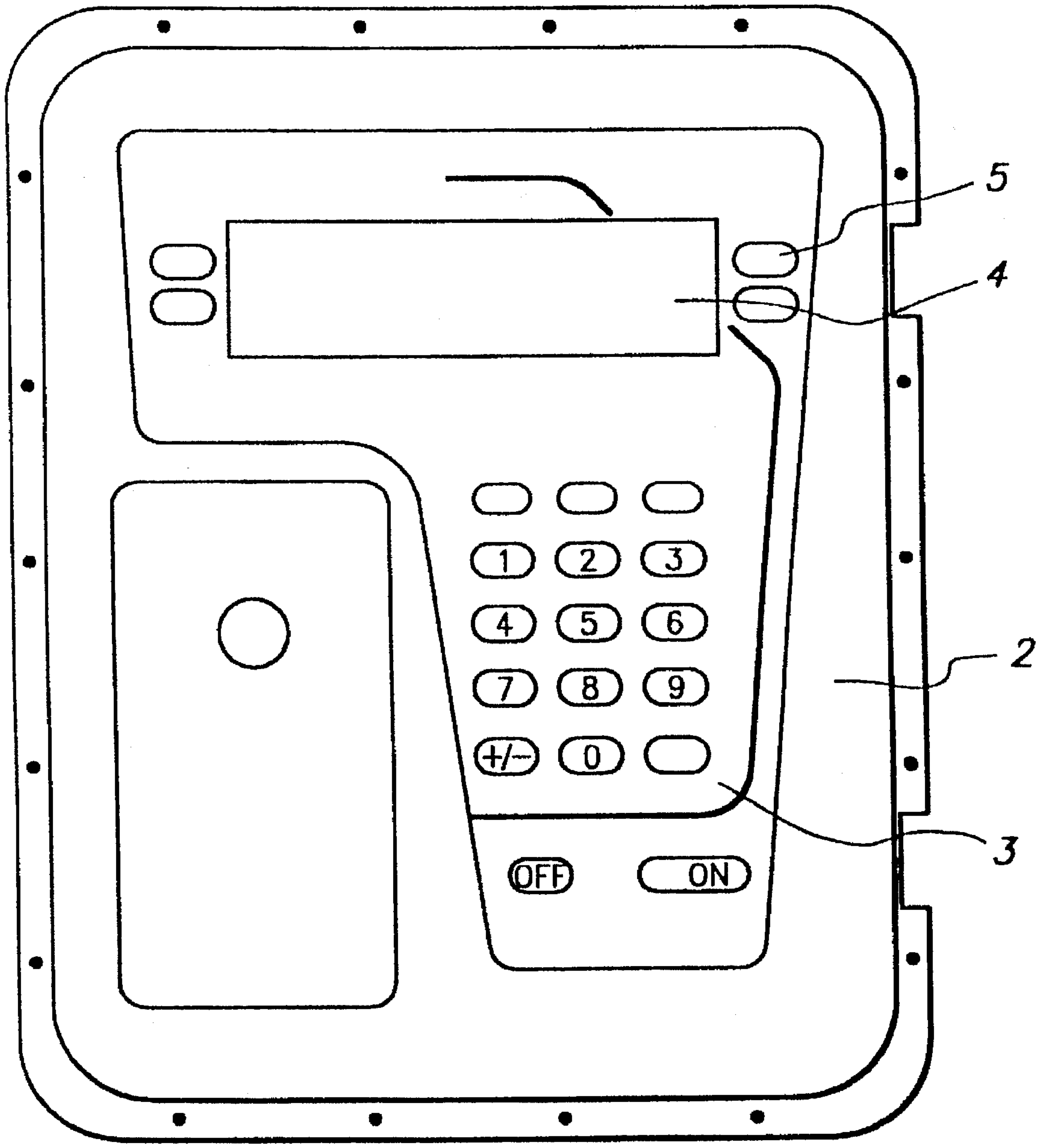


FIG. 2

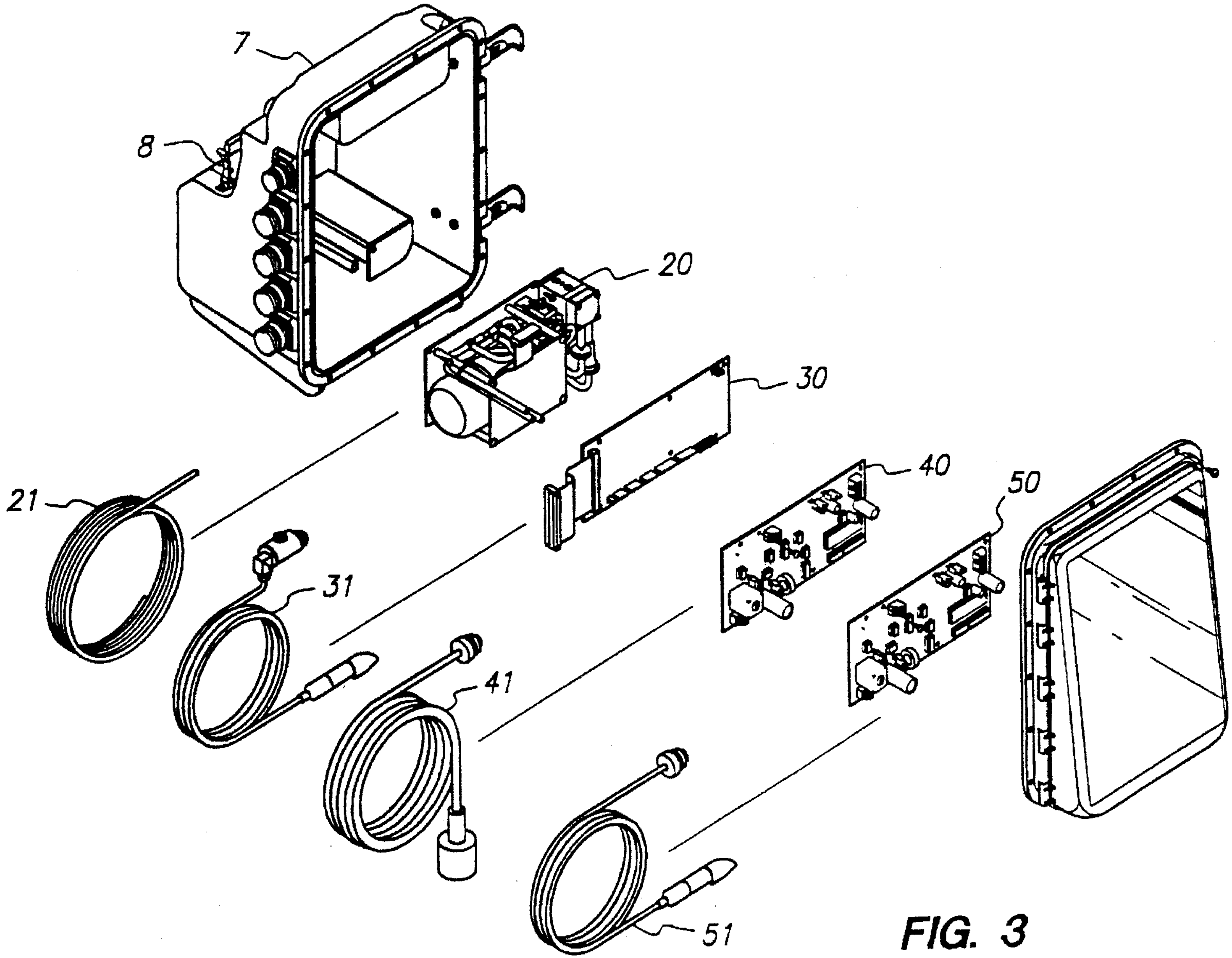


FIG. 3

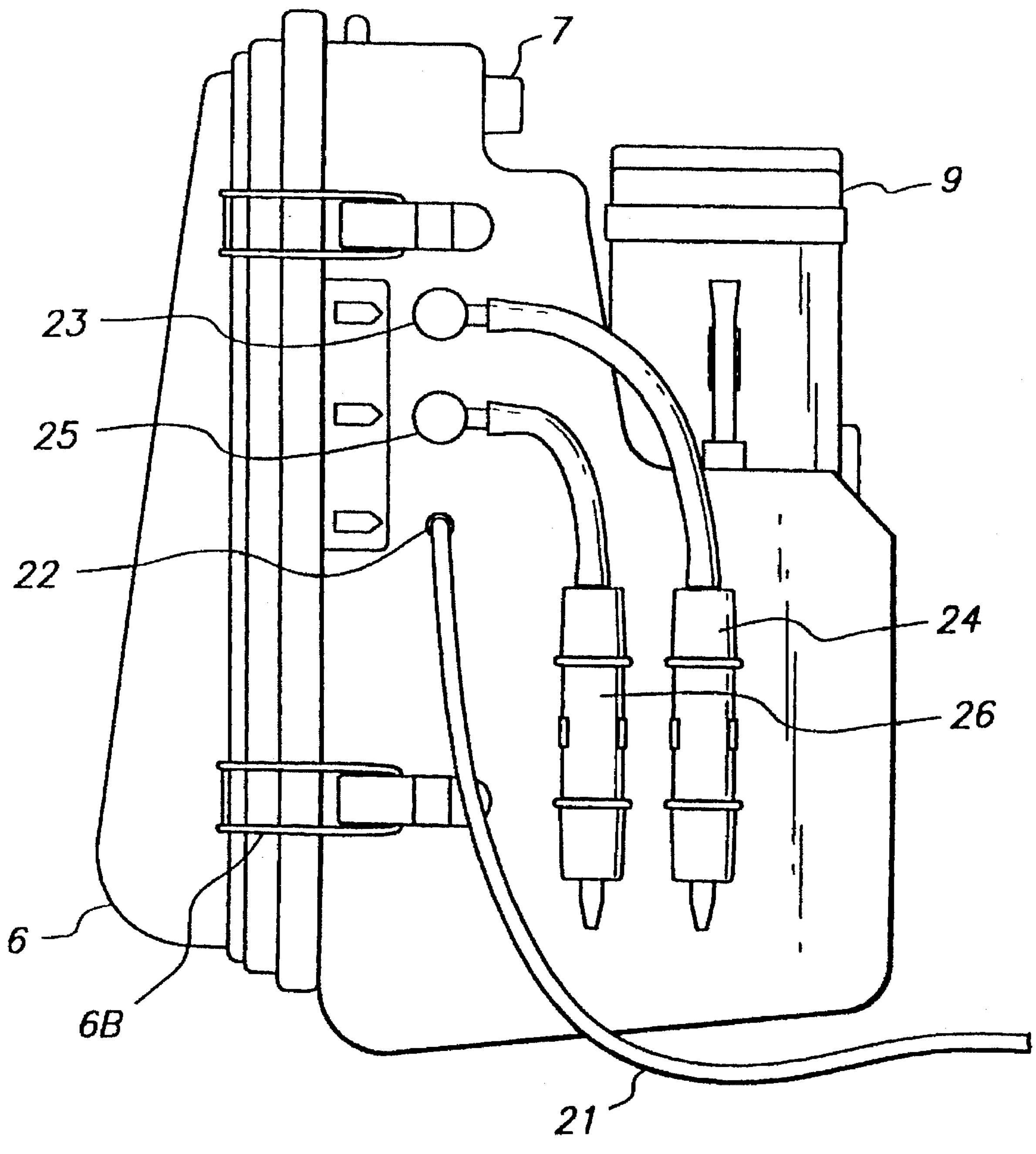
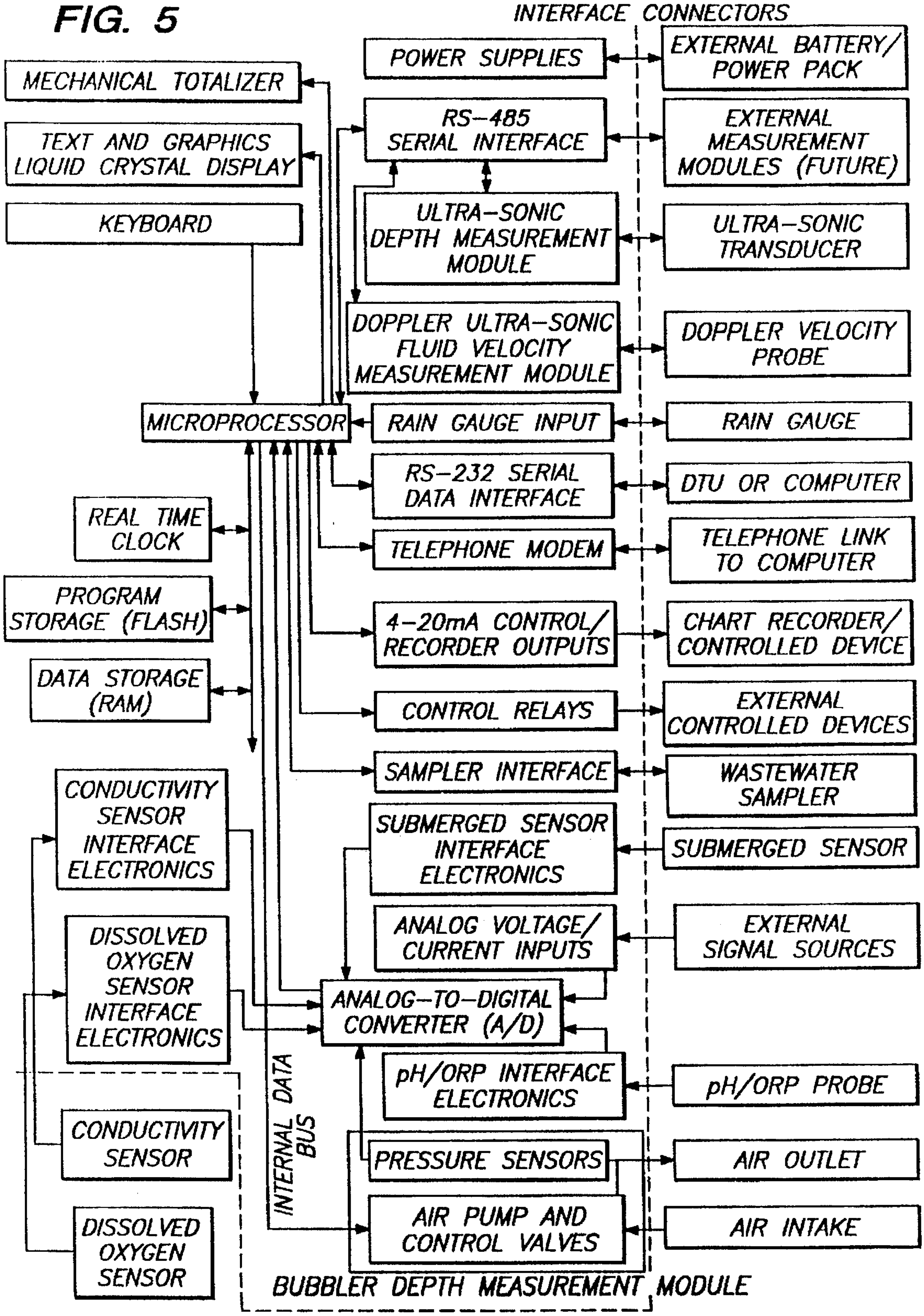


FIG. 4

FIG. 5


INTERFACE CONNECTORS
POWER SUPPLIES
EXTERNAL BATTERY/ POWER PACK
MECHANICAL TOTALIZER
RS-485 SERIAL INTERFACE
EXTERNAL MEASUREMENT MODULES (FUTURE)
TEXT AND GRAPHICS LIQUID CRYSTAL DISPLAY
KEYBOARD
ULTRA-SONIC DEPTH MEASUREMENT MODULE
ULTRA-SONIC TRANSDUCER
DOPPLER ULTRA-SONIC FLUID VELOCITY MEASUREMENT MODULE
DOPPLER VELOCITY PROBE
MICROPROCESSOR
RAIN GAUGE INPUT
RAIN GAUGE
RS-232 SERIAL DATA INTERFACE
DTU OR COMPUTER
REAL TIME CLOCK
TELEPHONE MODEM
TELEPHONE LINK TO COMPUTER
PROGRAM STORAGE (FLASH)
4-20mA CONTROL/ RECORDER OUTPUTS
CHART RECORDER/ CONTROLLED DEVICE
DATA STORAGE (RAM)
CONTROL RELAYS
EXTERNAL CONTROLLED DEVICES
SAMPLER INTERFACE
WASTEWATER SAMPLER
CONDUCTIVITY SENSOR INTERFACE ELECTRONICS
SUBMERGED SENSOR INTERFACE ELECTRONICS
SUBMERGED SENSOR
ANALOG VOLTAGE/ CURRENT INPUTS
EXTERNAL SIGNAL SOURCES
DISSOLVED OXYGEN SENSOR INTERFACE ELECTRONICS
ANALOG-TO-DIGITAL CONVERTER (A/D)
pH/ORP INTERFACE ELECTRONICS
pH/ORP PROBE
INTERNAL DATA BUS
CONDUCTIVITY SENSOR
PRESSURE SENSORS
AIR OUTLET
AIR PUMP AND CONTROL VALVES
AIR INTAKE
DISSOLVED OXYGEN SENSOR
BUBBLER DEPTH MEASUREMENT MODULE

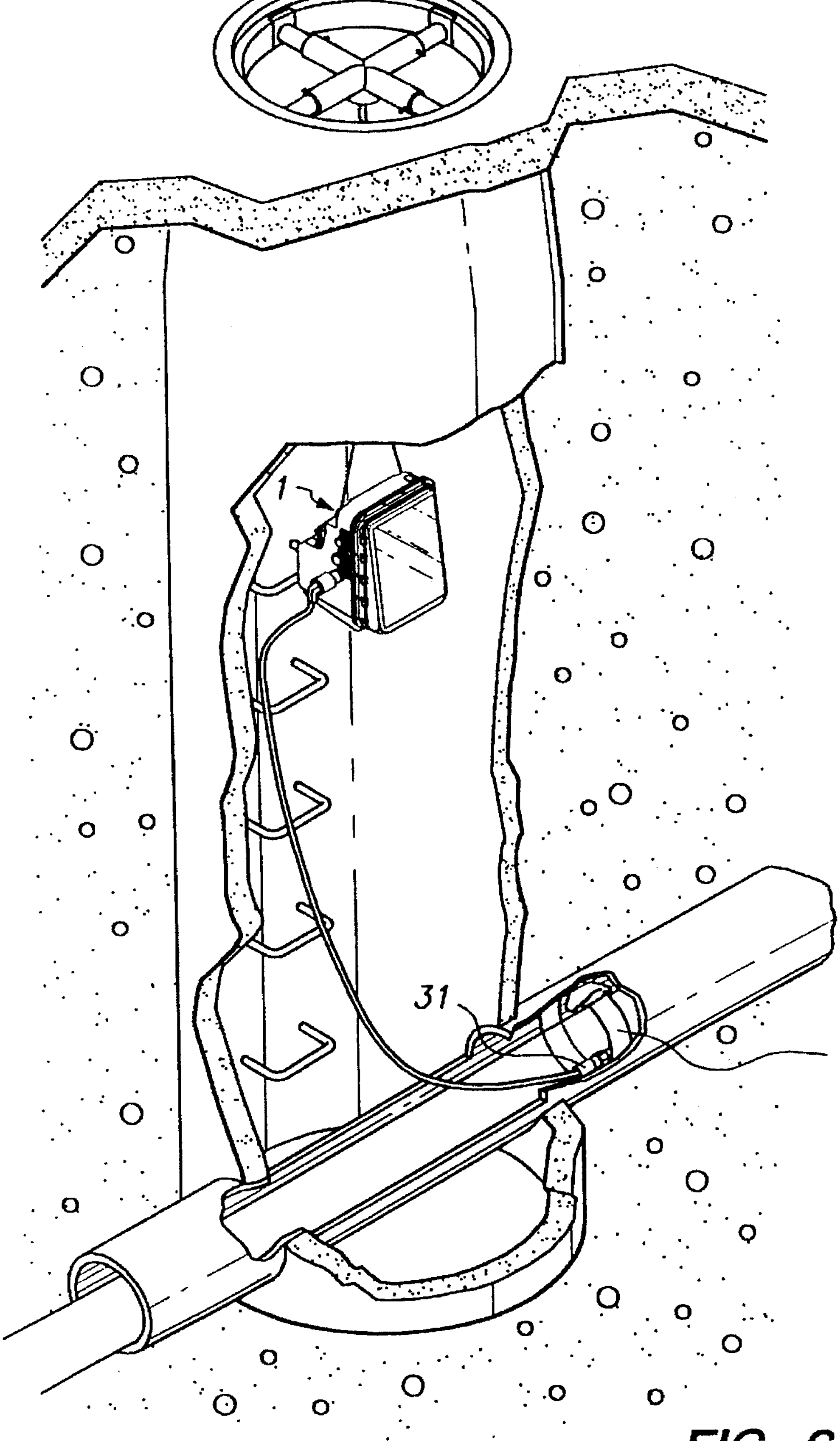


FIG. 6

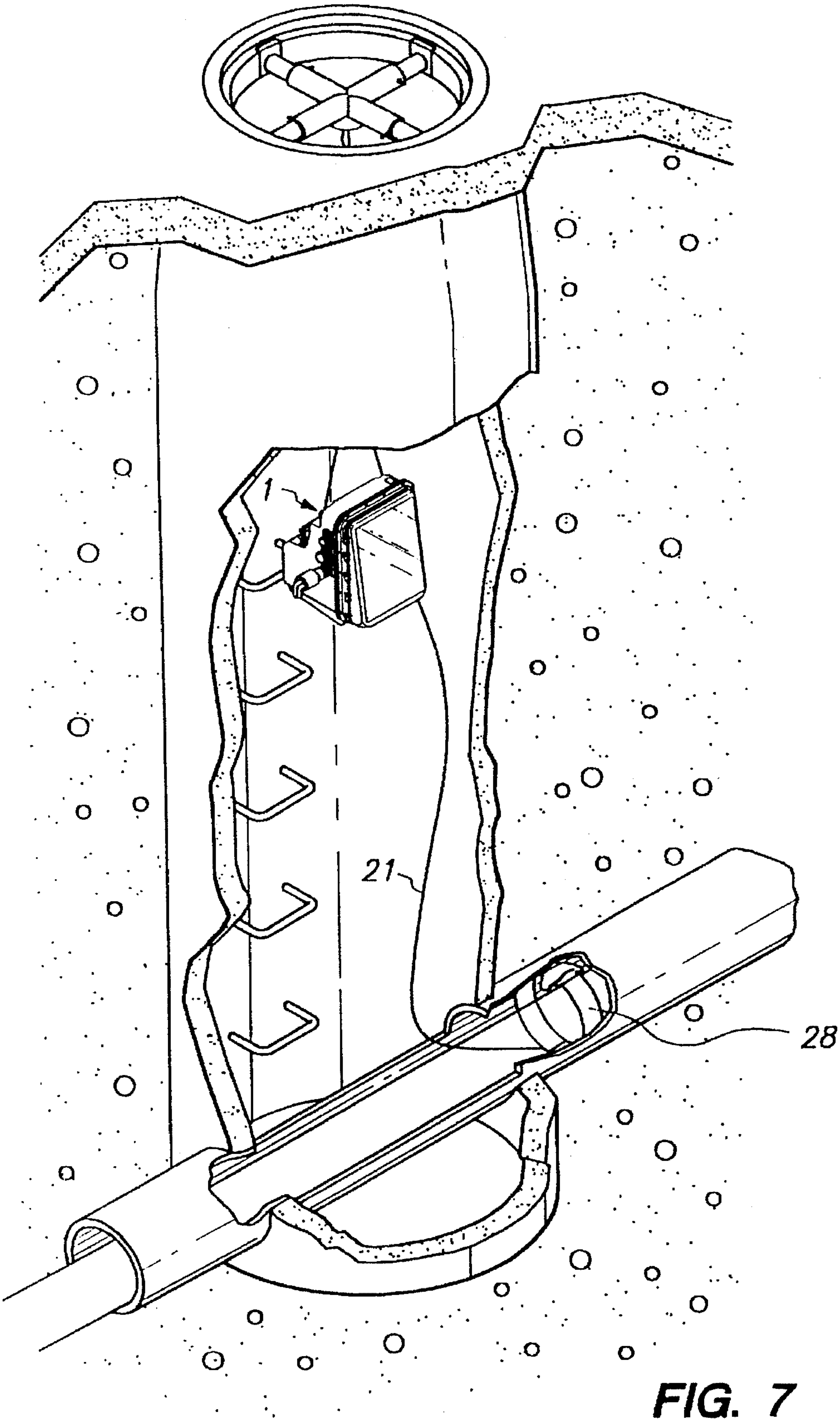


FIG. 7

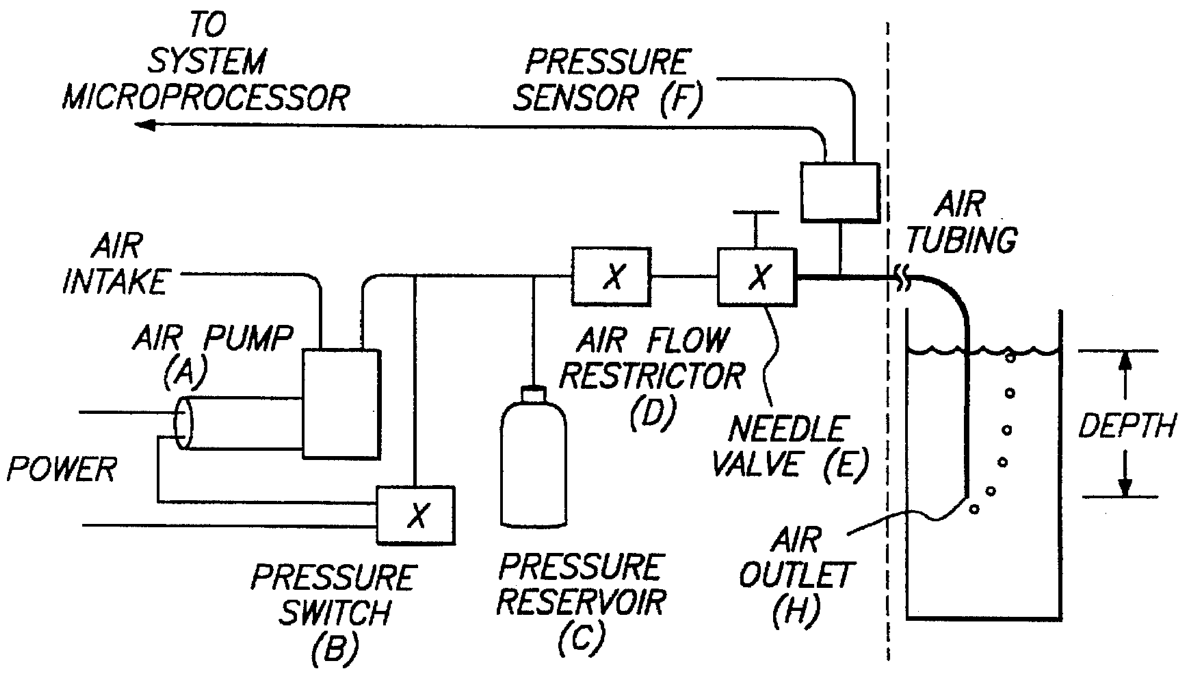


FIG. 8
PRIOR ART

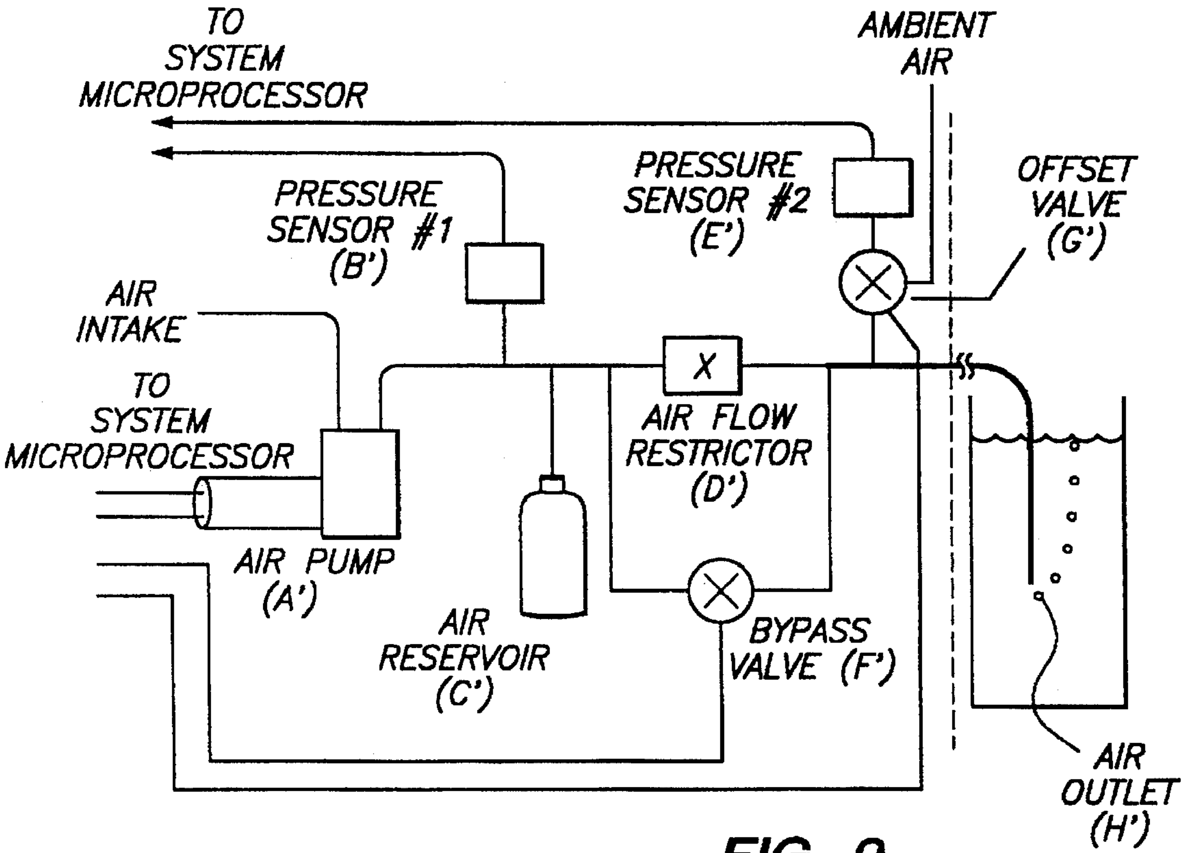


FIG. 9

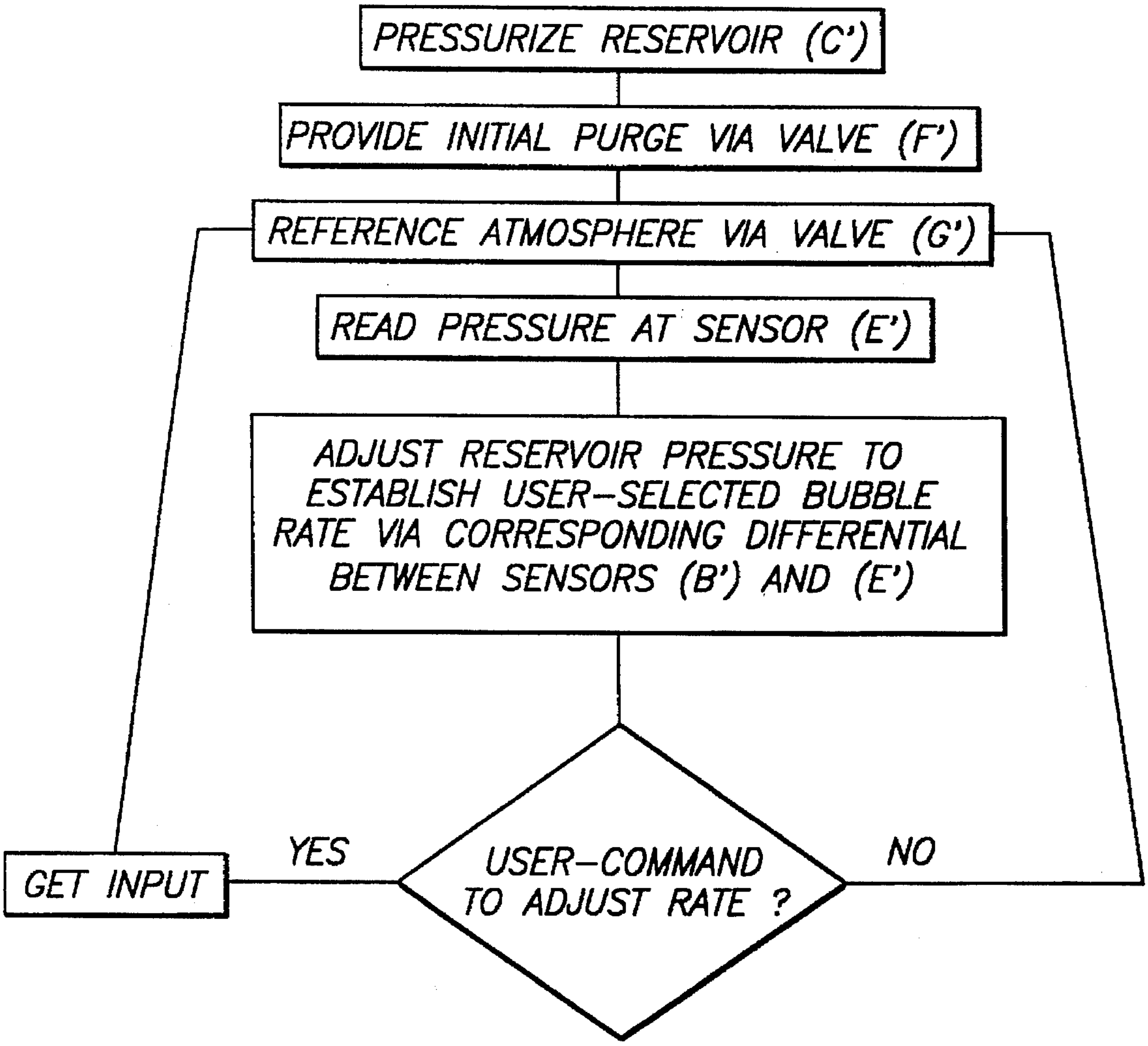

PRESSURIZE RESERVOIR (C')
PROVIDE INITIAL PURGE VIA VALVE (F')
REFERENCE ATMOSPHERE VIA VALVE (G')
READ PRESSURE AT SENSOR (E')
ADJUST RESERVOIR PRESSURE TO ESTABLISH USER-SELECTED BUBBLE RATE VIA CORRESPONDING DIFFERENTIAL BETWEEN SENSORS (B') AND (E')
USER-COMMAND TO ADJUST RATE ?
YES
NO
GET INPUT

FIG. 10

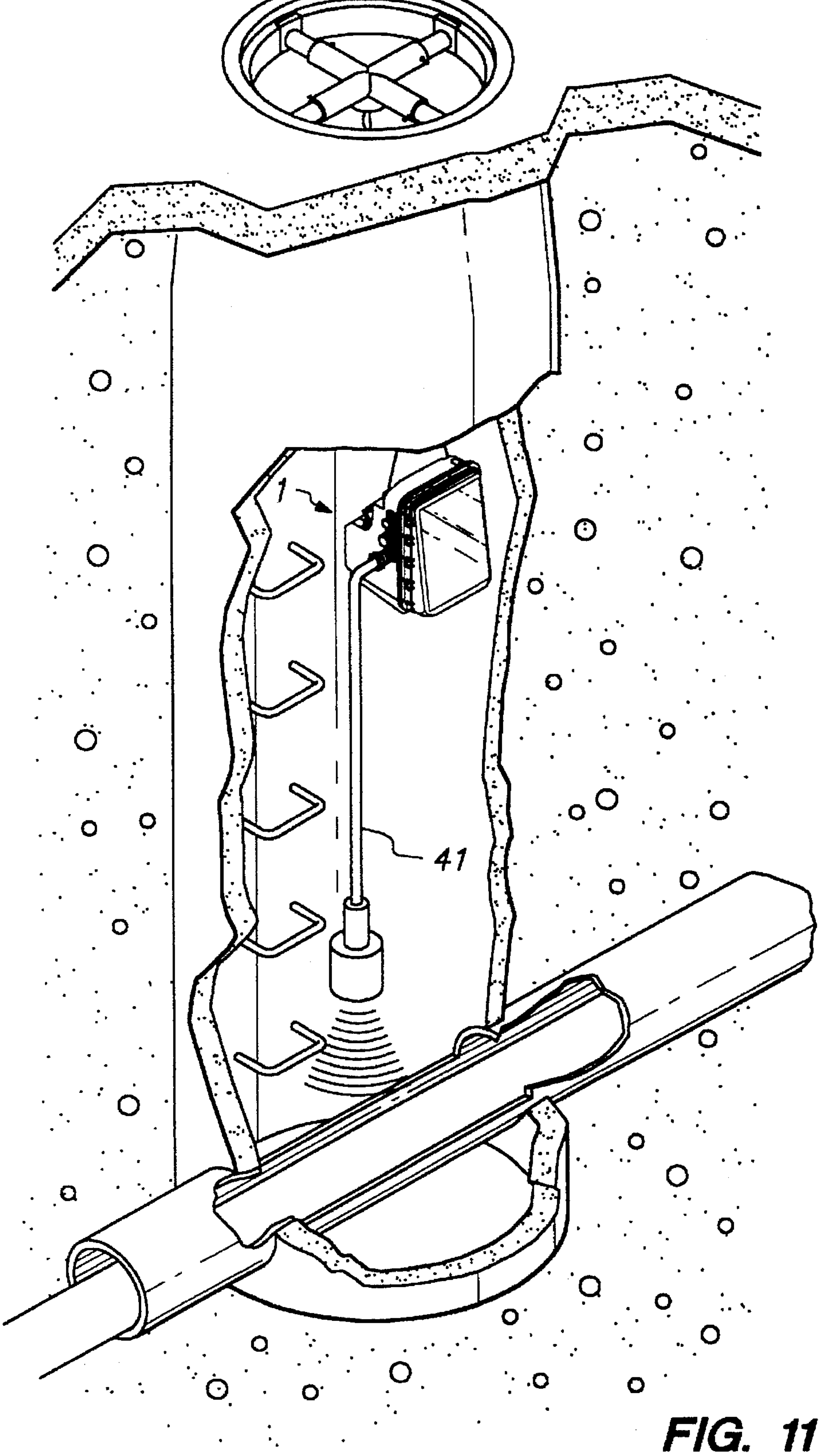


FIG. 11

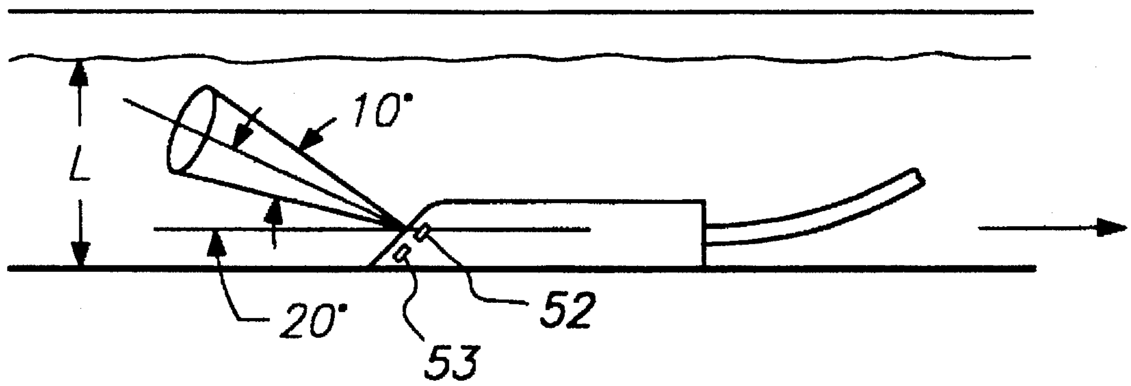


FIG. 12

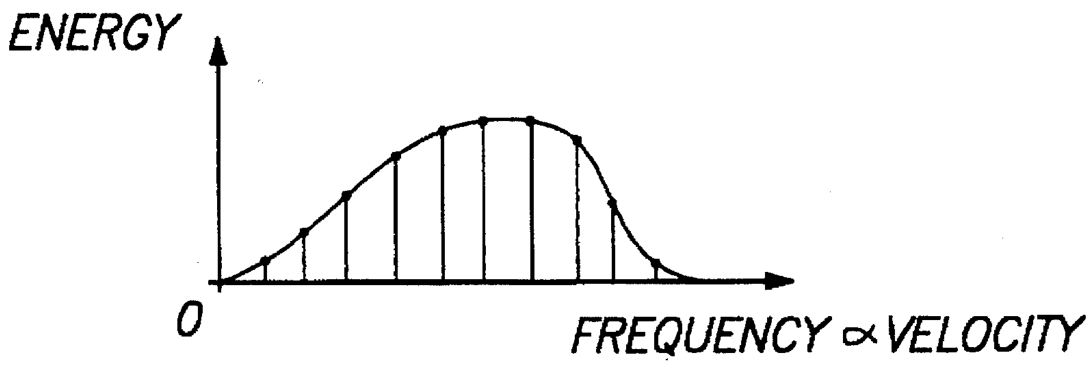


FIG. 13

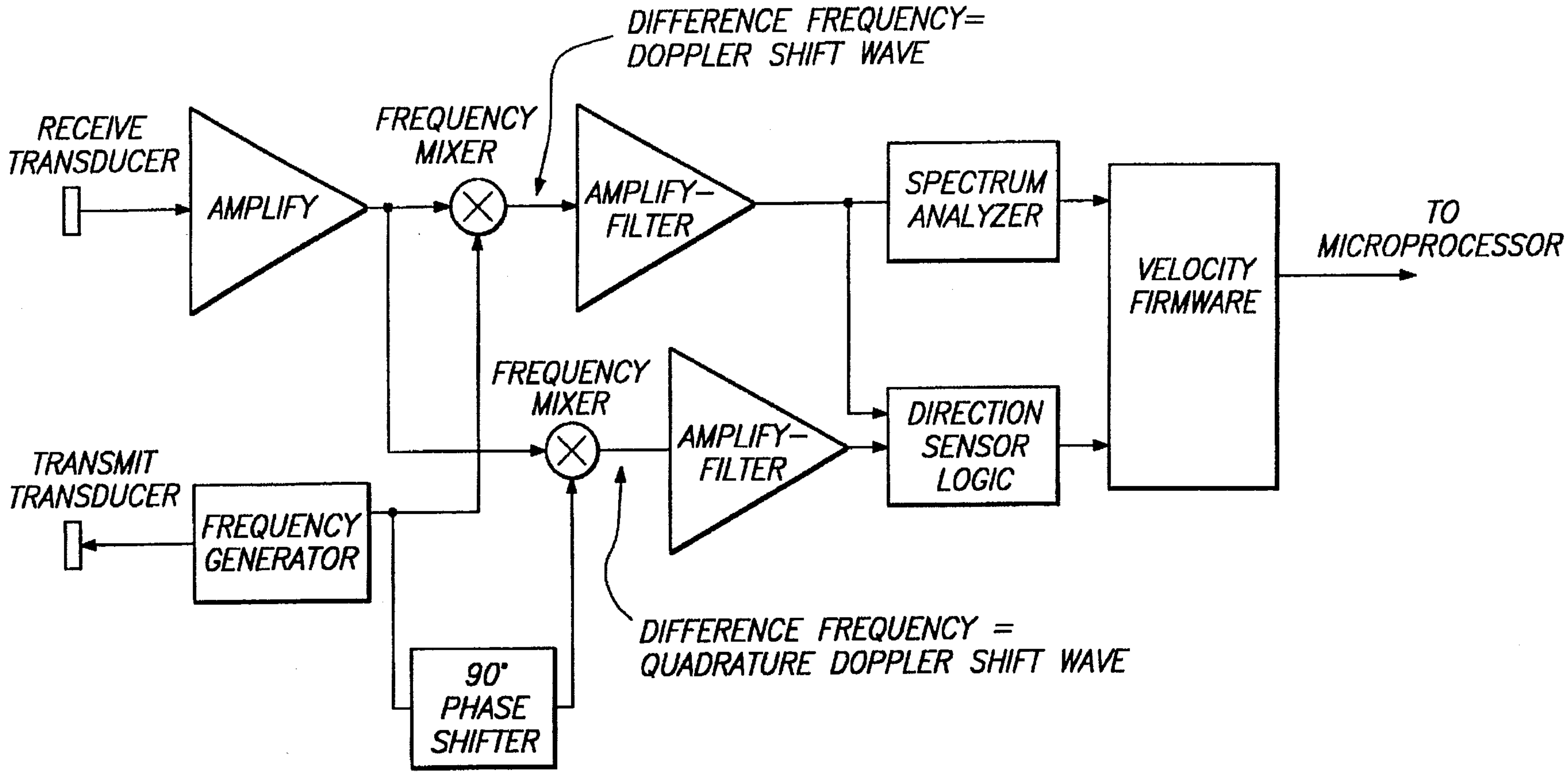

DIFFERENCE FREQUENCY=
DOPPLER SHIFT WAVE
RECEIVE TRANSDUCER
AMPLIFY
FREQUENCY MIXER
AMPLIFY–FILTER
SPECTRUM ANALYZER
VELOCITY FIRMWARE
TO MICROPROCESSOR
FREQUENCY MIXER
AMPLIFY–FILTER
DIRECTION SENSOR LOGIC
TRANSMIT TRANSDUCER
FREQUENCY GENERATOR
90° PHASE SHIFTER
DIFFERENCE FREQUENCY =
QUADRATURE DOPPLER SHIFT WAVE

FIG. 14

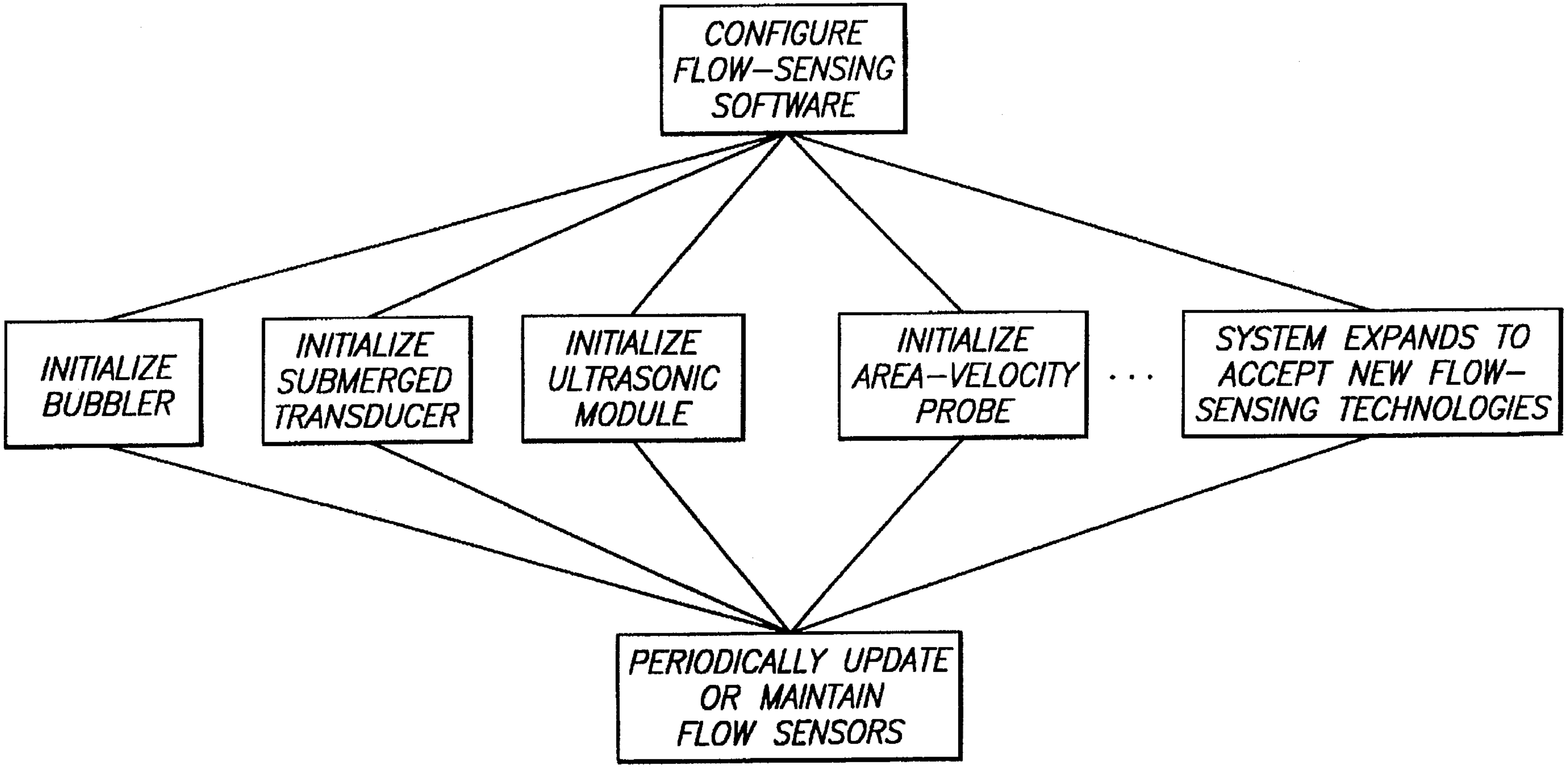

CONFIGURE FLOW-SENSING SOFTWARE
INITIALIZE BUBBLER
INITIALIZE SUBMERGED TRANSDUCER
INITIALIZE ULTRASONIC MODULE
INITIALIZE AREA-VELOCITY PROBE
. . .
SYSTEM EXPANDS TO ACCEPT NEW FLOW-SENSING TECHNOLOGIES
PERIODICALLY UPDATE OR MAINTAIN FLOW SENSORS

FIG. 15

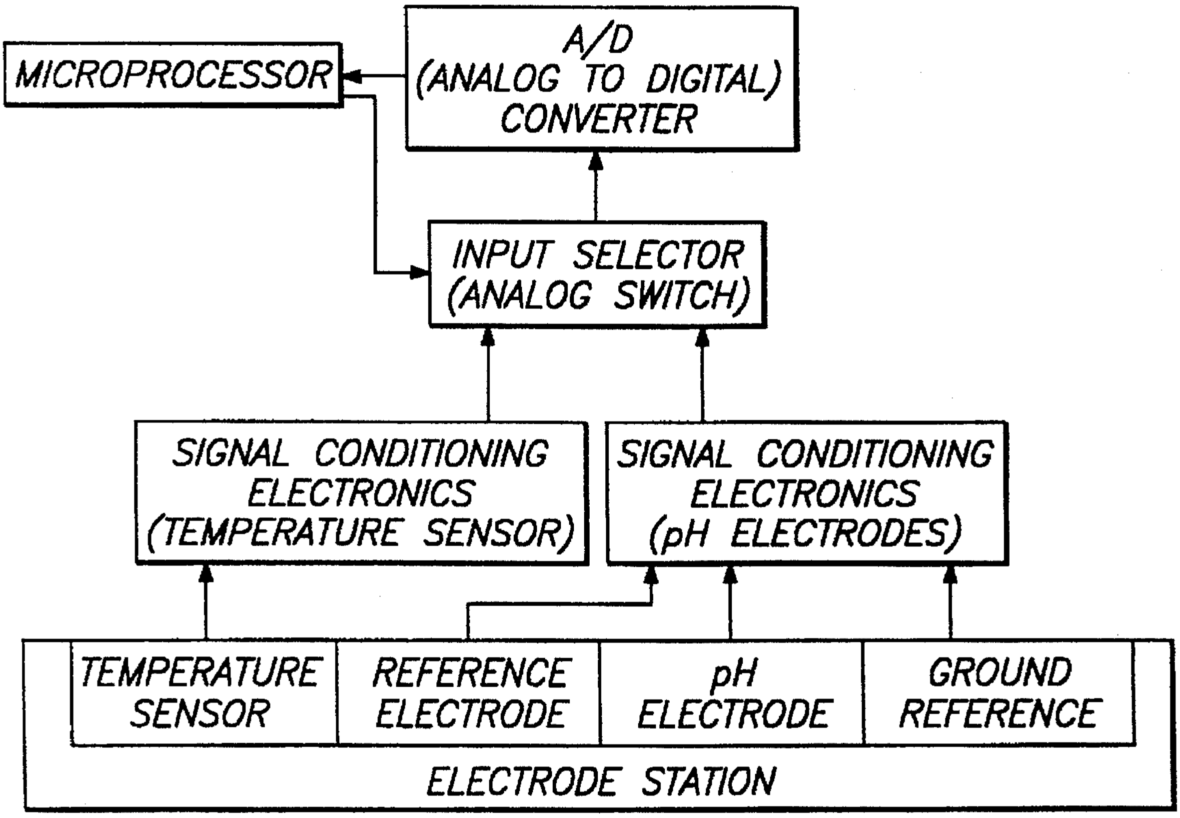

MICROPROCESSOR
A/D (ANALOG TO DIGITAL) CONVERTER
INPUT SELECTOR (ANALOG SWITCH)
SIGNAL CONDITIONING ELECTRONICS (TEMPERATURE SENSOR)
SIGNAL CONDITIONING ELECTRONICS (pH ELECTRODES)
TEMPERATURE SENSOR
REFERENCE ELECTRODE
pH ELECTRODE
GROUND REFERENCE
ELECTRODE STATION

FIG. 16

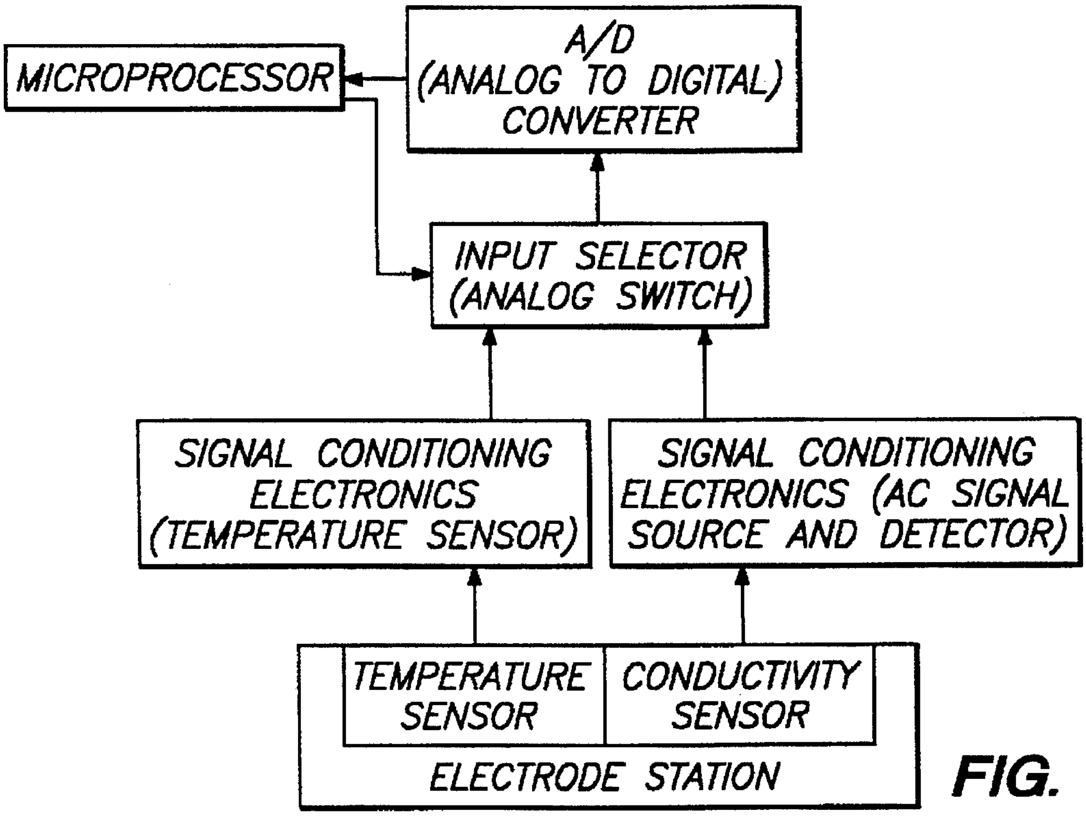

MICROPROCESSOR
A/D (ANALOG TO DIGITAL) CONVERTER
INPUT SELECTOR (ANALOG SWITCH)
SIGNAL CONDITIONING ELECTRONICS (TEMPERATURE SENSOR)
SIGNAL CONDITIONING ELECTRONICS (AC SIGNAL SOURCE AND DETECTOR)
TEMPERATURE SENSOR
CONDUCTIVITY SENSOR
ELECTRODE STATION

FIG. 17

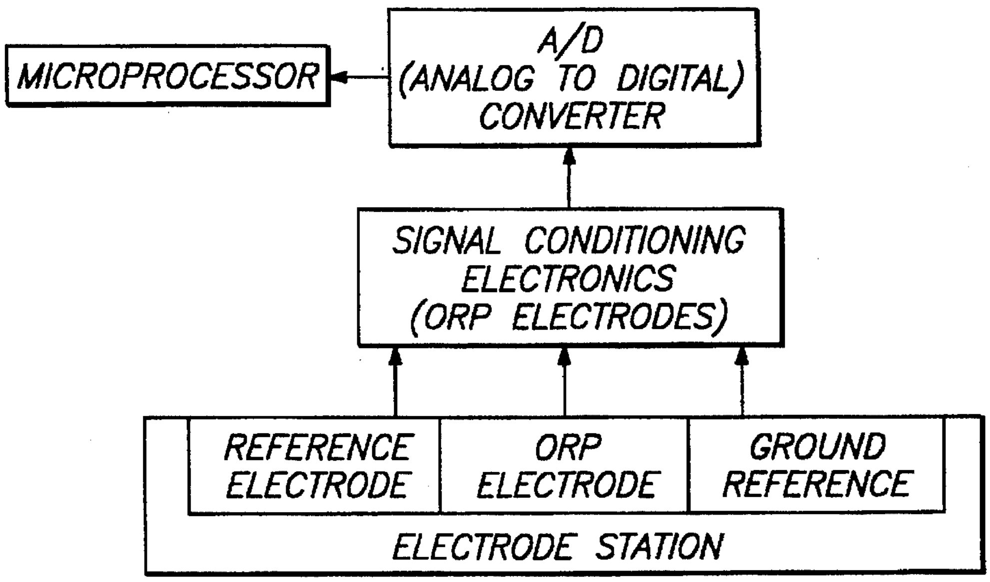

MICROPROCESSOR
A/D
(ANALOG TO DIGITAL)
CONVERTER
SIGNAL CONDITIONING
ELECTRONICS
(ORP ELECTRODES)
REFERENCE
ELECTRODE
ORP
ELECTRODE
GROUND
REFERENCE
ELECTRODE STATION

FIG. 18

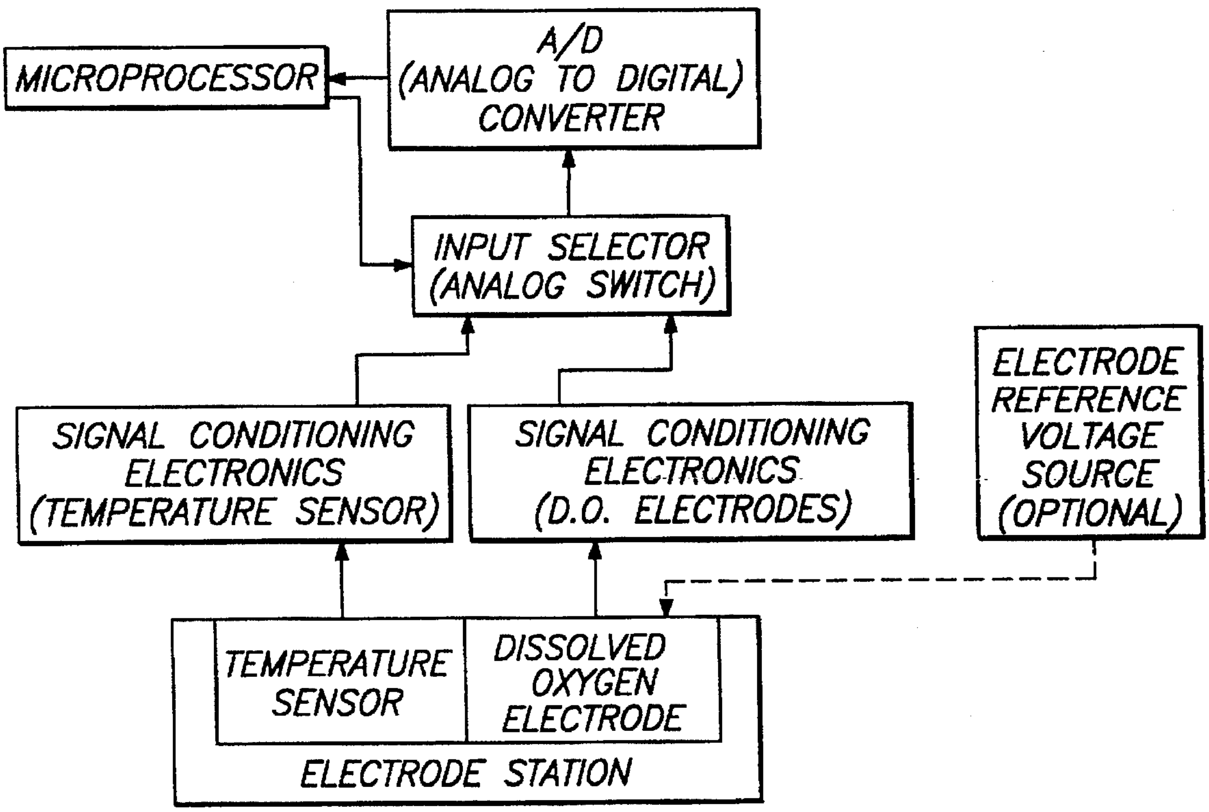

MICROPROCESSOR
A/D
(ANALOG TO DIGITAL)
CONVERTER
INPUT SELECTOR
(ANALOG SWITCH)
SIGNAL CONDITIONING
ELECTRONICS
(TEMPERATURE SENSOR)
SIGNAL CONDITIONING
ELECTRONICS
(D.O. ELECTRODES)
ELECTRODE
REFERENCE
VOLTAGE
SOURCE
(OPTIONAL)
TEMPERATURE
SENSOR
DISSOLVED
OXYGEN
ELECTRODE
ELECTRODE STATION

FIG. 19

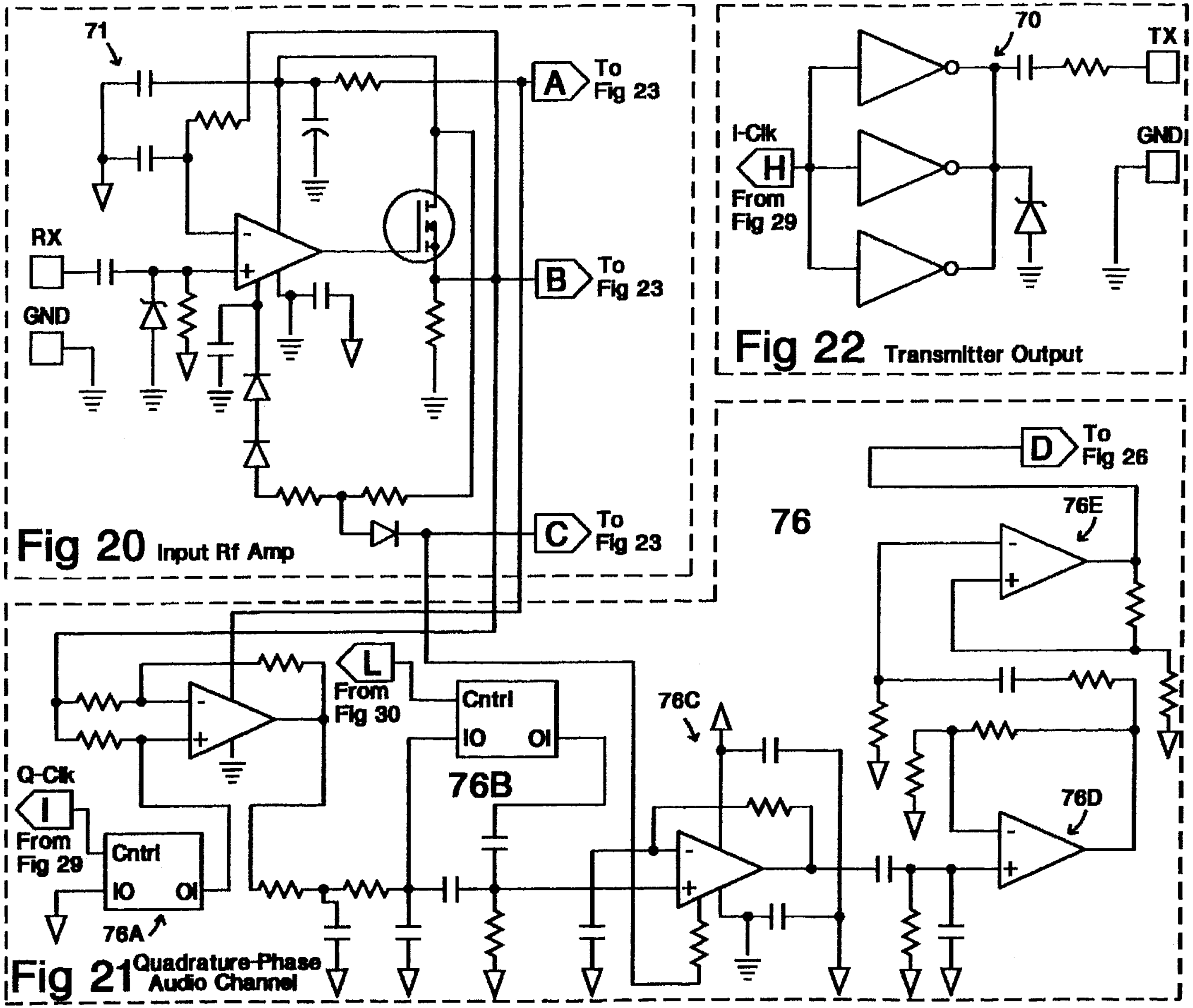
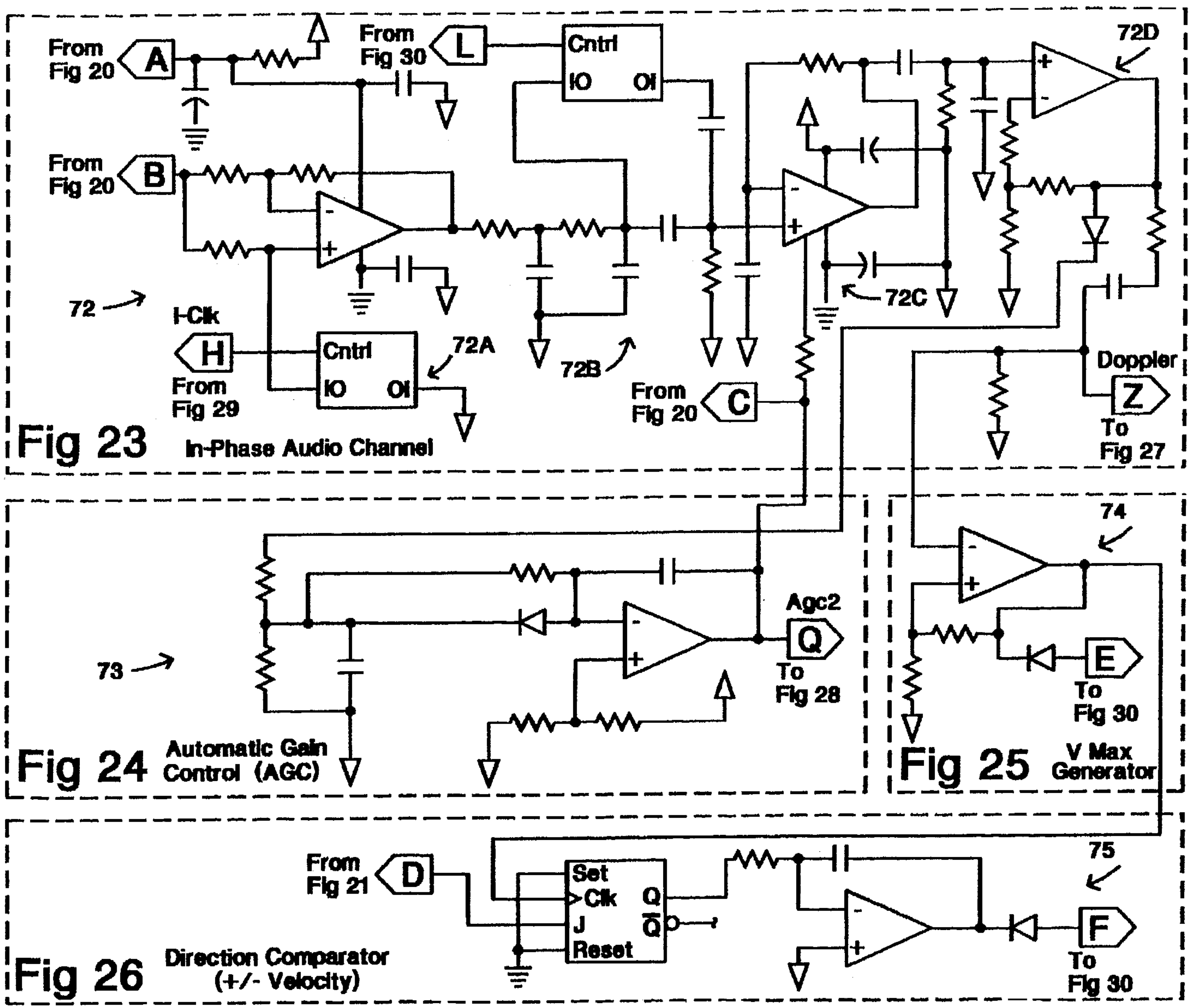


Fig 20 Input Rf Amp

Fig 22 Transmitter Output

Fig 21 Quadrature-Phase Audio Channel


From Fig 20
A
From Fig 30
L
Cntrl
IO OI
72D
From Fig 20
B
72
I-Clk
H
From Fig 29
Cntrl
IO OI
72A
72B
72C
From Fig 20
C
Doppler
Z
To Fig 27
Fig 23 In-Phase Audio Channel
73
Agc2
Q
To Fig 28
Fig 24 Automatic Gain Control (AGC)
74
E
To Fig 30
Fig 25 V Max Generator
From Fig 21
D
Set
Clk
J
Reset
Q
Q̄
75
F
To Fig 30
Fig 26 Direction Comparator (+/- Velocity)

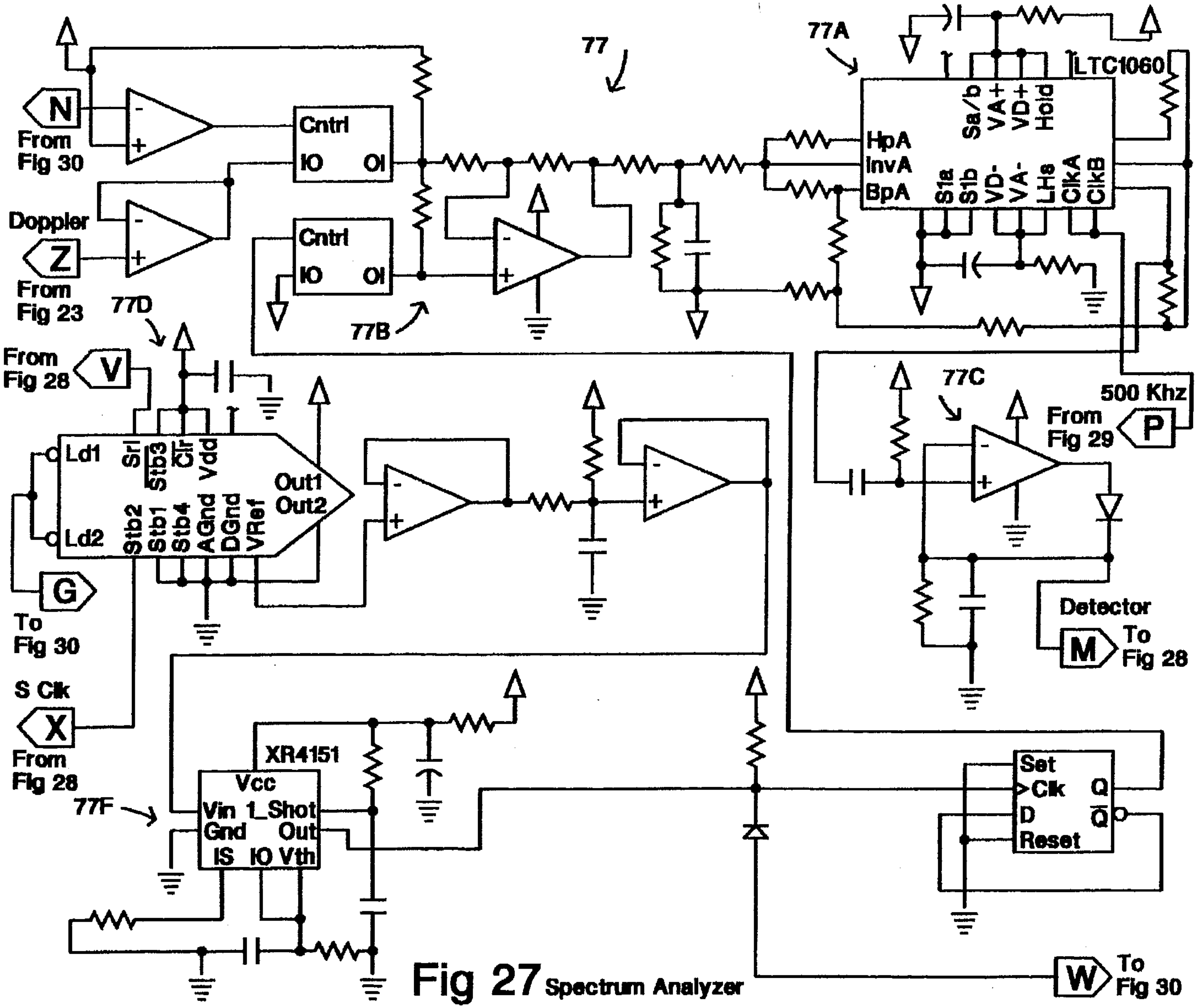


Fig 27 Spectrum Analyzer

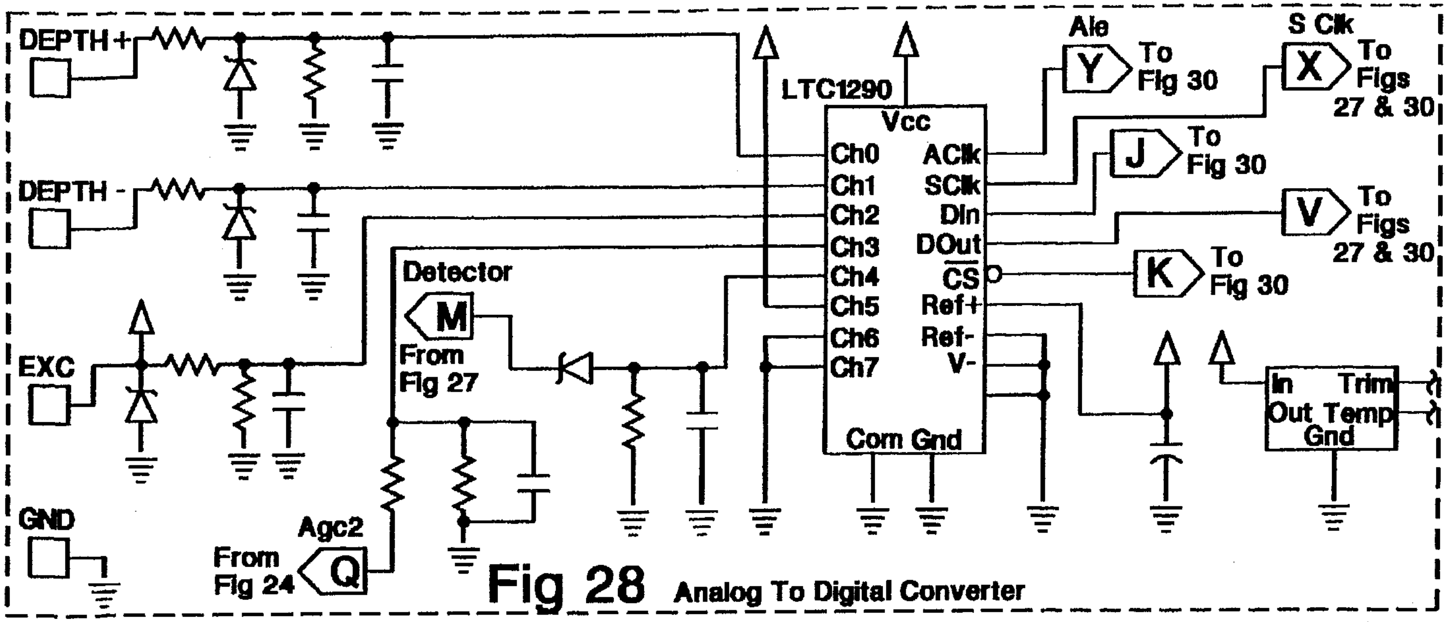


Fig 28 Analog To Digital Converter

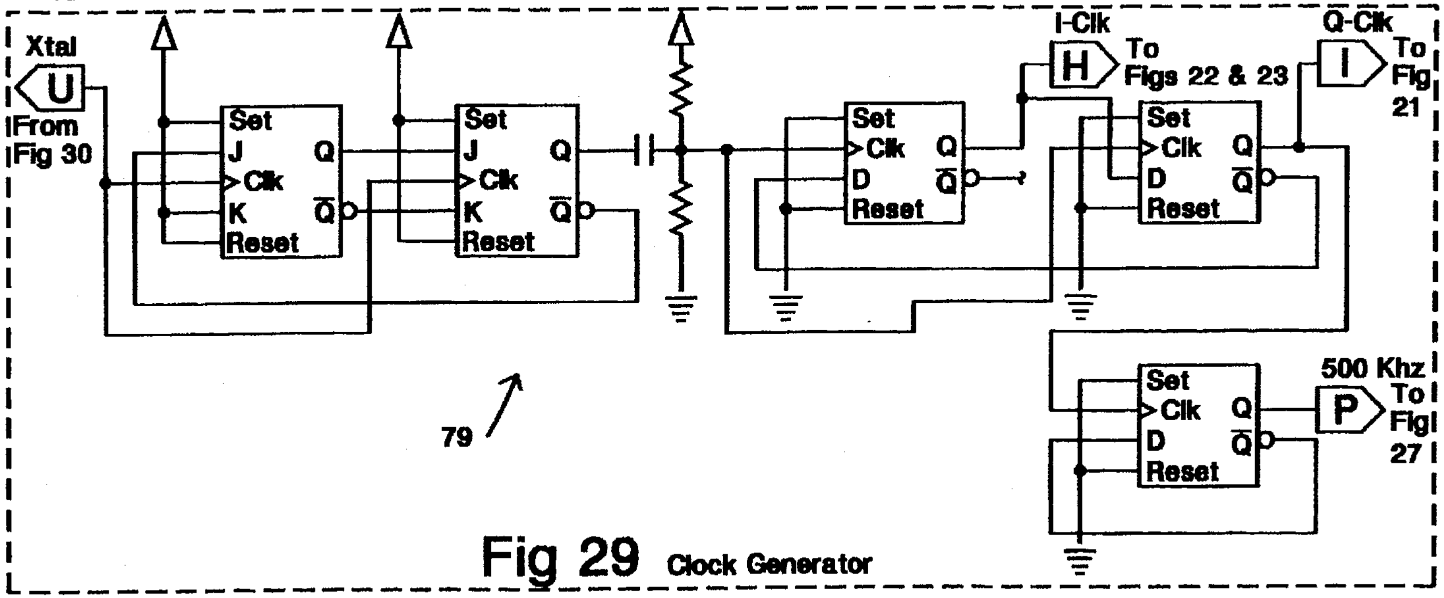
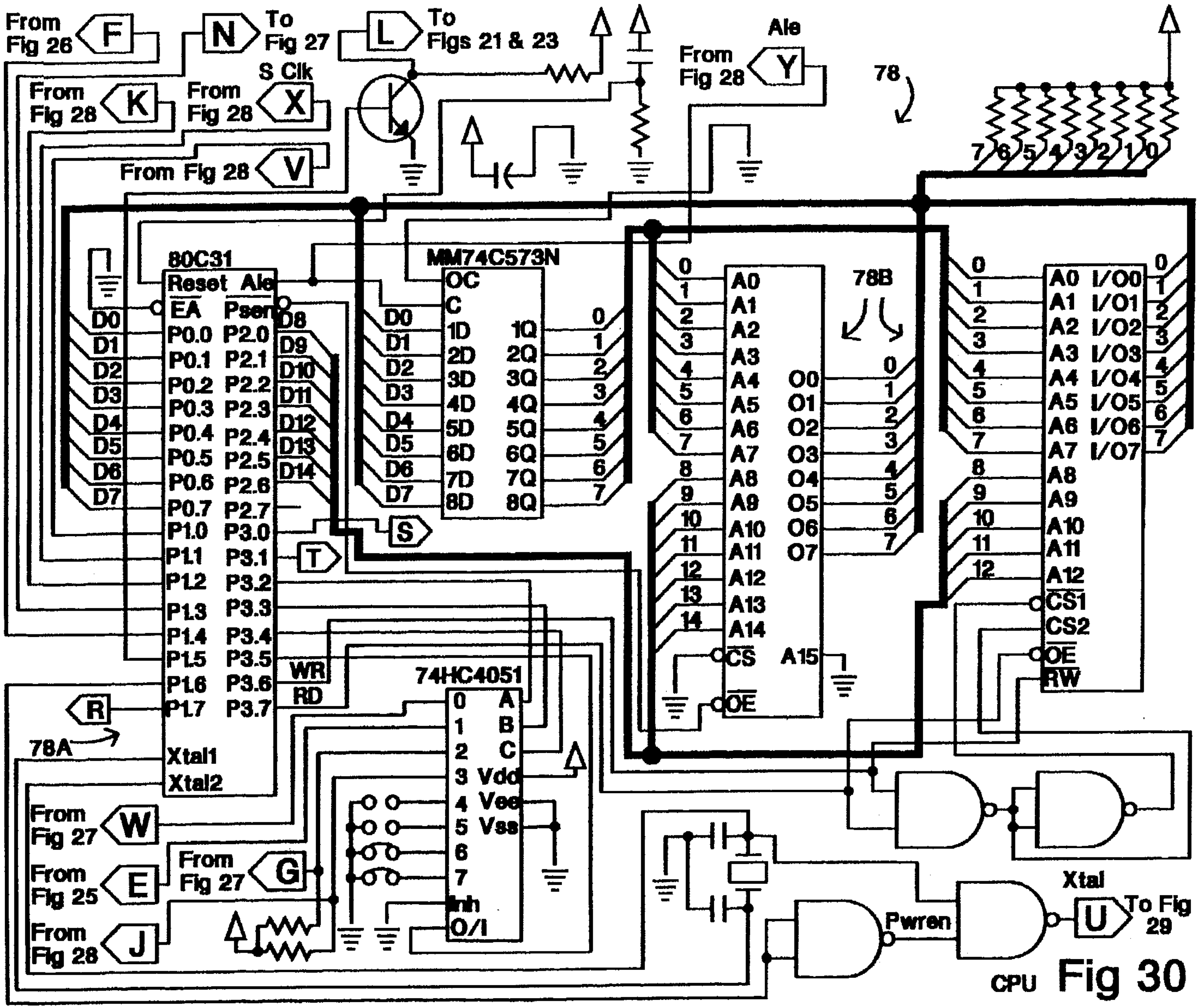


Fig 29 Clock Generator


From Fig 26
F
N
To Fig 27
L
To Figs 21 & 23
S Clk
From Fig 28
K
From Fig 28
X
From Fig 28
V
From Fig 28
Y
Ale
78
80C31
Reset
Ale
EA
Psen
P0.0
P0.1
P0.2
P0.3
P0.4
P0.5
P0.6
P0.7
P1.0
P1.1
P1.2
P1.3
P1.4
P1.5
P1.6
P1.7
P2.0
P2.1
P2.2
P2.3
P2.4
P2.5
P2.6
P2.7
P3.0
P3.1
P3.2
P3.3
P3.4
P3.5
P3.6
P3.7
Xtal1
Xtal2
D0 D1 D2 D3 D4 D5 D6 D7
D8 D9 D10 D11 D12 D13 D14
WR
RD
S
T
R
78A
MM74C573N
OC
C
1D 2D 3D 4D 5D 6D 7D 8D
1Q 2Q 3Q 4Q 5Q 6Q 7Q 8Q
78B
A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12 A13 A14 A15
O0 O1 O2 O3 O4 O5 O6 O7
CS
OE
I/O0 I/O1 I/O2 I/O3 I/O4 I/O5 I/O6 I/O7
CS1
CS2
RW
74HC4051
A
B
C
Vdd
Vee
Vss
Inh
O/I
From Fig 27
W
From Fig 25
E
From Fig 27
G
From Fig 28
J
Pwren
Xtal
U
To Fig 29

CPU Fig 30

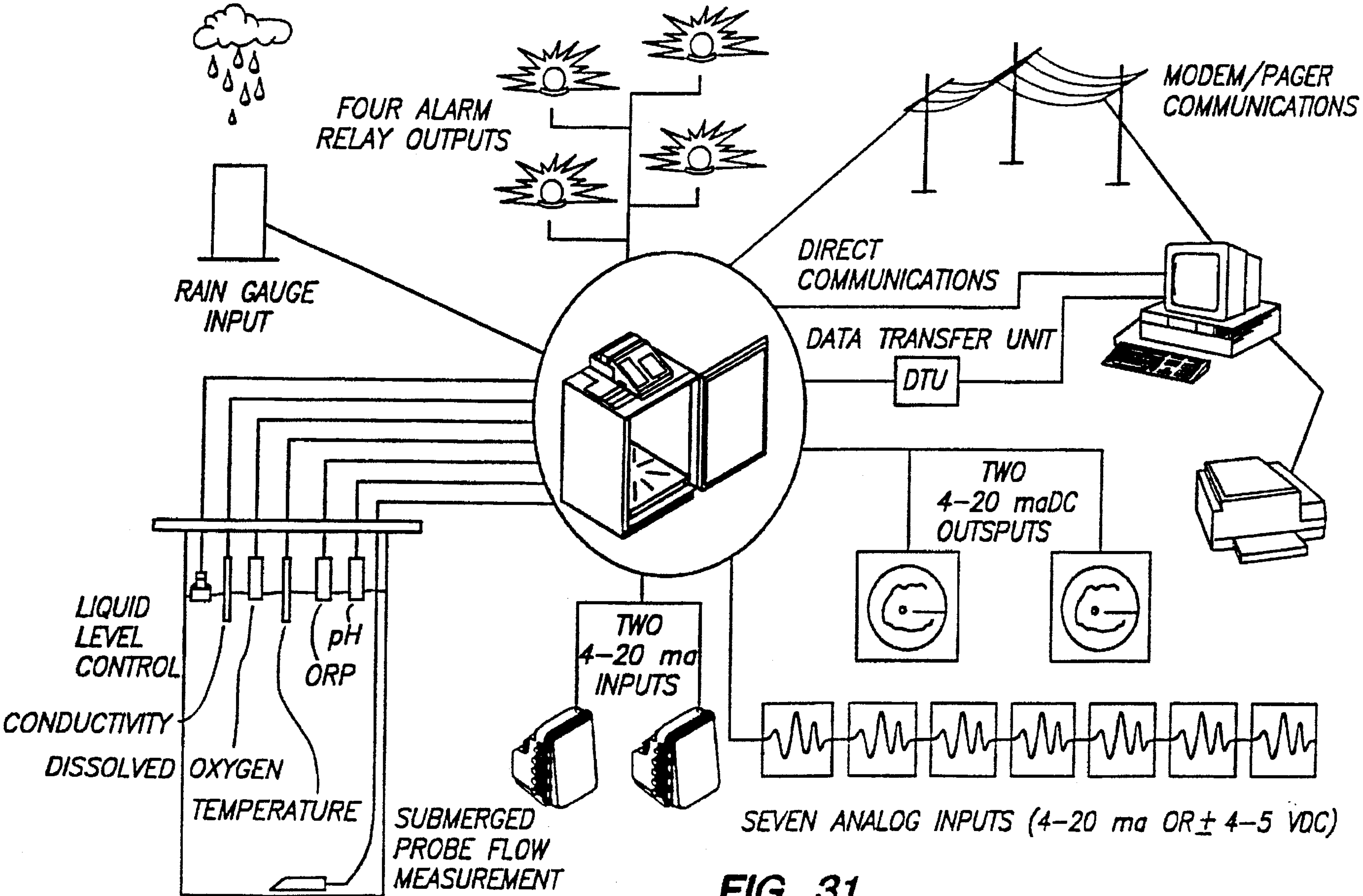

FOUR ALARM RELAY OUTPUTS
MODEM/PAGER COMMUNICATIONS
RAIN GAUGE INPUT
DIRECT COMMUNICATIONS
DATA TRANSFER UNIT
DTU
TWO 4-20 maDC OUTSPUTS
LIQUID LEVEL CONTROL
pH
ORP
CONDUCTIVITY
DISSOLVED OXYGEN
TEMPERATURE
SUBMERGED PROBE FLOW MEASUREMENT
TWO 4-20 ma INPUTS
SEVEN ANALOG INPUTS (4-20 ma OR ± 4-5 VDC)

FIG. 31

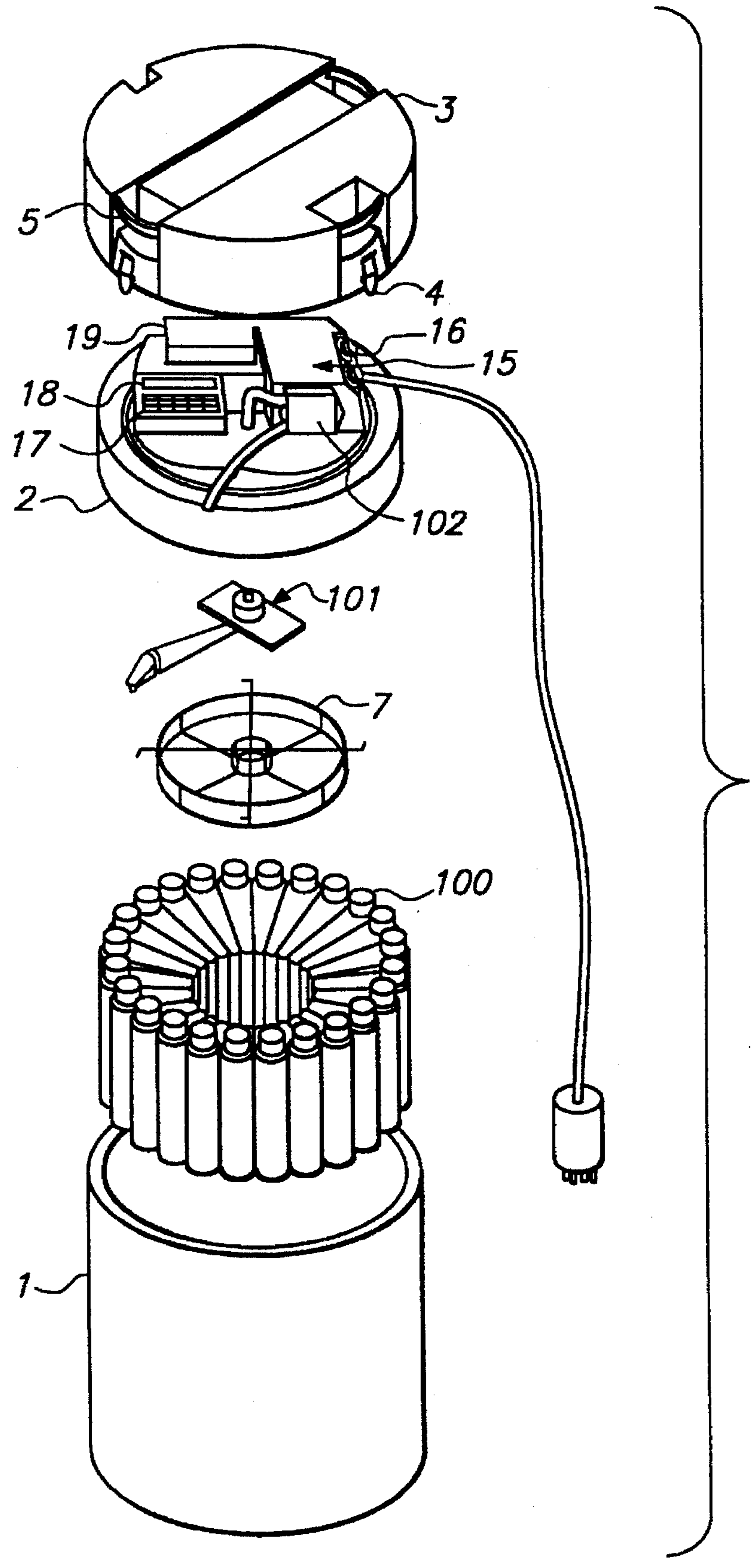


FIG. 32

FIG. 33A

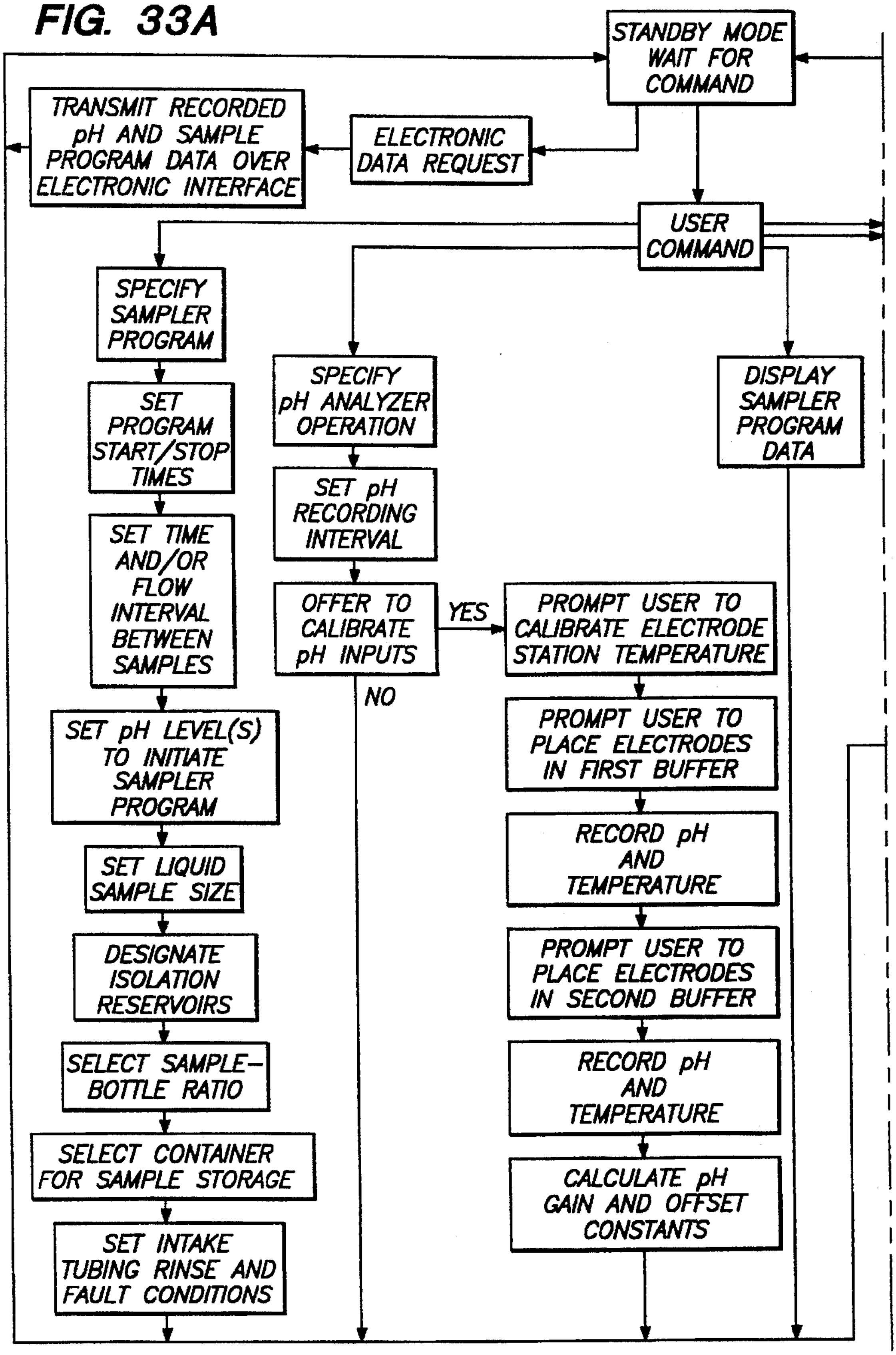
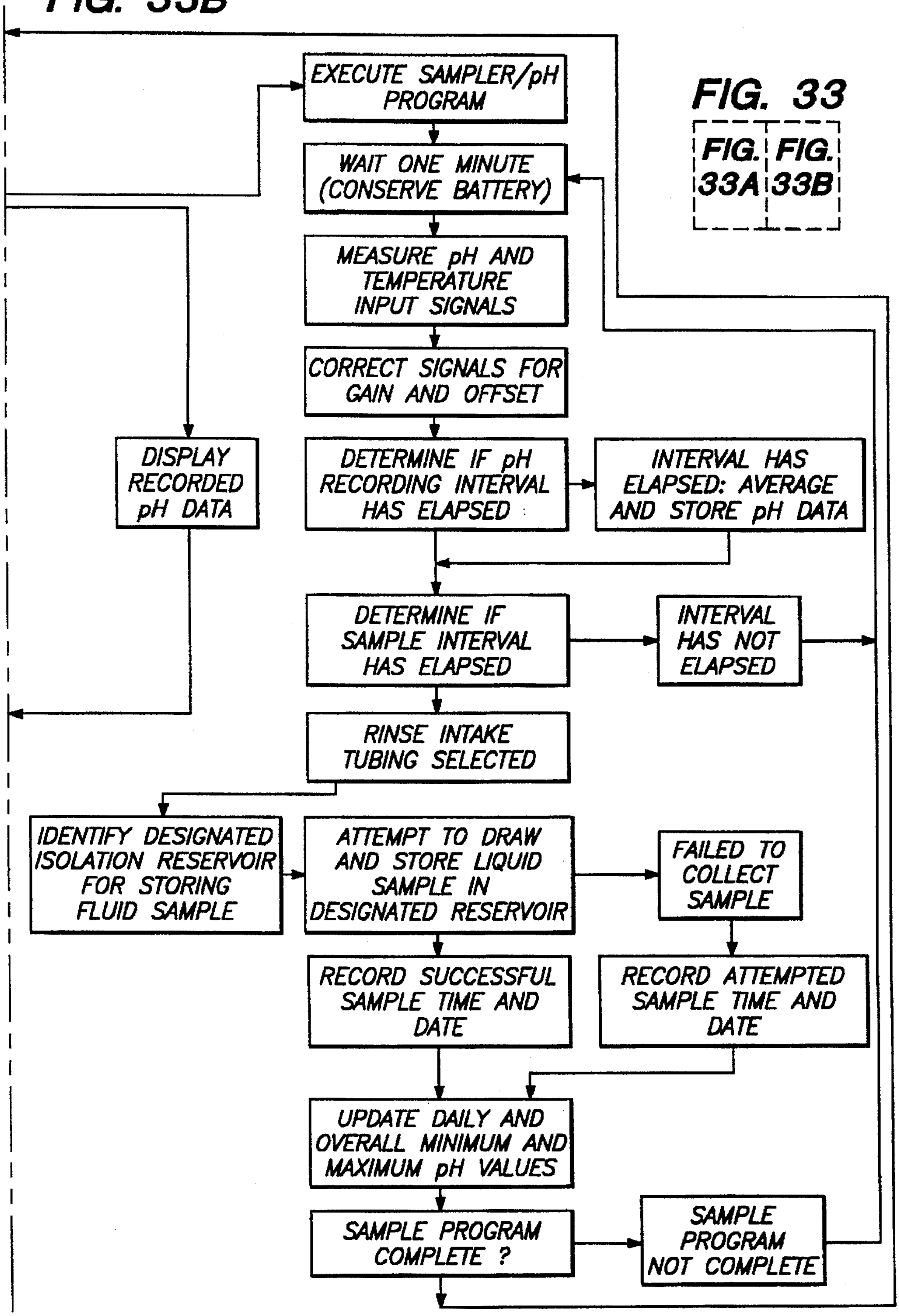

STANDBY MODE WAIT FOR COMMAND
TRANSMIT RECORDED pH AND SAMPLE PROGRAM DATA OVER ELECTRONIC INTERFACE
ELECTRONIC DATA REQUEST
USER COMMAND
SPECIFY SAMPLER PROGRAM
SET PROGRAM START/STOP TIMES
SET TIME AND/OR FLOW INTERVAL BETWEEN SAMPLES
SET pH LEVEL(S) TO INITIATE SAMPLER PROGRAM
SET LIQUID SAMPLE SIZE
DESIGNATE ISOLATION RESERVOIRS
SELECT SAMPLE-BOTTLE RATIO
SELECT CONTAINER FOR SAMPLE STORAGE
SET INTAKE TUBING RINSE AND FAULT CONDITIONS
SPECIFY pH ANALYZER OPERATION
SET pH RECORDING INTERVAL
OFFER TO CALIBRATE pH INPUTS
YES
NO
PROMPT USER TO CALIBRATE ELECTRODE STATION TEMPERATURE
PROMPT USER TO PLACE ELECTRODES IN FIRST BUFFER
RECORD pH AND TEMPERATURE
PROMPT USER TO PLACE ELECTRODES IN SECOND BUFFER
RECORD pH AND TEMPERATURE
CALCULATE pH GAIN AND OFFSET CONSTANTS
DISPLAY SAMPLER PROGRAM DATA

FIG. 33B


EXECUTE SAMPLER/pH PROGRAM
WAIT ONE MINUTE (CONSERVE BATTERY)
MEASURE pH AND TEMPERATURE INPUT SIGNALS
CORRECT SIGNALS FOR GAIN AND OFFSET
DISPLAY RECORDED pH DATA
DETERMINE IF pH RECORDING INTERVAL HAS ELAPSED
INTERVAL HAS ELAPSED: AVERAGE AND STORE pH DATA
DETERMINE IF SAMPLE INTERVAL HAS ELAPSED
INTERVAL HAS NOT ELAPSED
RINSE INTAKE TUBING SELECTED
IDENTIFY DESIGNATED ISOLATION RESERVOIR FOR STORING FLUID SAMPLE
ATTEMPT TO DRAW AND STORE LIQUID SAMPLE IN DESIGNATED RESERVOIR
FAILED TO COLLECT SAMPLE
RECORD SUCCESSFUL SAMPLE TIME AND DATE
RECORD ATTEMPTED SAMPLE TIME AND DATE
UPDATE DAILY AND OVERALL MINIMUM AND MAXIMUM pH VALUES
SAMPLE PROGRAM COMPLETE ?
SAMPLE PROGRAM NOT COMPLETE
FIG. 33
FIG. 33A
FIG. 33B

MULTI-FUNCTION FLOW MONITORING APPARATUS WITH AREA VELOCITY SENSOR CAPABILITY

This is a file wrapper continuation of application Ser. No. 547,718, which was filed Oct. 26, 1995 now abandoned; which in turn is a continuation-in-part of application Ser. No. 219,097, which was filed Mar. 29, 1994, now U.S. Pat. No. 5,506,791; which in turn is a continuation-in-part of application Ser. No. 954,288 filed Sep. 30, 1992 which issued as U.S. Pat. No. 5,299,141; which is in turn a continuation-in-part of application Ser. No. 612,832 filed Nov. 13, 1990 which issued as U.S. Pat. No. 5,172,332; which is in turn a continuation-in-part of application Ser. No. 455,981 filed Dec. 22, 1989 which issued as U.S. Pat. No. 5,091,863. The disclosure of each of such applications and patents is incorporated herein by reference thereto.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a multi-function fluid flow monitoring apparatus having the unique capability of measuring fluid flow-related variables on the basis of outputs from any one or more of a plurality of different types of flow sensors. In accordance with the multi-functional features of the invention, the apparatus can also perform fluid monitoring operations and can be linked to a variety of devices, such as an automatic sampler, a rain gauge, and the like so as to operably cooperate with same. The apparatus also provides for the displaying, storing, and transferring of data relating to fluid flow measuring and monitoring operations.

More particularly, the invention relates to a compact unitary apparatus having a computer control system which calculates fluid flow-related variables on the basis of outputs from any desired one or more of a plurality of different types of flow sensors which may be selectively and interchangeably connected to the apparatus. By virtue of this multiple flow sensor capability, the user is provided with substantial flexibility in selecting a flow sensor system suitable for a given application, and then selectively switching to any desired one of a plurality of other types of sensor systems as the need arises. The user is also afforded the flexibility of investing in a basic apparatus including, for example, a single type of flow sensor, and then later expanding the range of use of the apparatus by investing in additional types of flow sensors which are all fully compatible with, and supported by, the basic apparatus.

The apparatus of the invention also comprises a text and graphics display which permits a user to selectively view stored data in either text or graphic formats. Stored data can also be transferred to a computer for manipulating data or producing hard copy reports.

The invention also provides a novel bubbler sensor type fluid flow monitoring system comprising a novel bubbler control module which overcomes power consumption and inaccuracy problems associated with conventional bubbler sensor systems. The bubbler sensor flow monitoring system according to the invention is incorporated in the multi-function flow monitoring apparatus with multiple flow sensor capability. In an alternative embodiment, the bubbler sensor flow monitoring system of the invention may be provided independently in a flow measuring device having only a single sensor capability.

The terminology "flow sensors" as used herein refers to various available types of sensors for detecting a variable related to fluid flow and producing an electrical output signal corresponding thereto. Such sensors include, but are not limited to, bubbler-type pressure sensors, submerged pressure transducers, ultrasonic sensors, area-velocity sensor systems, and the like.

The terminology "fluid flow-related variables" as used herein embraces a multitude of fluid flow parameters, including fluid level or depth, flow rate, velocity, total flow, i.e., the actual quantity of fluid discharged over a given time period, and the like.

In addition to the versatility afforded by the interchangeability of different flow sensors, the apparatus of the invention may also provide fluid monitoring capabilities similar to those described in the aforesaid U.S. Pat. No. 5,172,332, by attaching an appropriate fluid condition sensor to the fluid flow monitoring apparatus of the invention. These monitoring capabilities enable the apparatus to calculate the value of a given fluid condition on the basis of inputs from a fluid condition sensor. By way of example, such fluid conditions may include pH level, oxidation reduction potential ("ORP"), temperature, solution conductivity or resistivity, dissolved oxygen, etc.

The apparatus according to the invention may further include means for automatically sampling fluids similar to that disclosed in the aforesaid U.S. Pat. Nos. 5,091,863 or 5,172,332. The user may then instruct the apparatus to initiate sampling operations on the basis of fluid flow related variables, or on the basis of high, low, or a range of critical levels of fluid condition(s) as calculated by the apparatus. The apparatus of the invention also automatically calculates and stores fluid flow-related variables and levels of fluid conditions to permit tracking of the history of the fluid conditions in a process stream. In a preferred embodiment, the present invention is selectively capable of isolating collected samples pertaining to a fluid flow variable or a critical fluid condition as calculated and/or detected by the apparatus, so as that collected samples representing a problem or out-of-limit condition can be quickly identified, thereby reducing laboratory analysis and analysis costs.

The apparatus according to the invention may also initiate desired actions based on fluid flow-related variables or fluid condition(s) values calculated by the apparatus. For example, the apparatus may activate a pump so as to initiate a pumping operation when water level rises above a predetermined level. It is further contemplated that the apparatus according to the invention may be selectively connected to other external devices, such as a rain gauge, so as to log data therefrom.

2. Description of the Relevant Art

Under current governmental statutes and regulations, municipal agencies and private organizations are required to carefully monitor fluid waste. Monitoring is also conducted for pollution research purposes and the like. By way of example, monitoring is typically conducted in the following applications: monitoring for compliance with NPDES permits; POTW compliance monitoring; storm water run-off monitoring; combined sewer overflow ("CSO") monitoring; pretreatment compliance; WWTP process control; and infiltration and inflow studies.

In these and similar monitoring applications, one of the principal devices used on-site is a flow meter. In addition to monitoring various fluid flow-related variables, the flow meter may also be used for pacing sampling operations in proportion to flow rate, i.e., in conjunction with a sampling apparatus which repeatedly collects samples for subsequent laboratory analysis. A separate analytical meter is also often used for on-site monitoring of critical fluid conditions, such as pH level or ORP, to alert the user in a relatively immediate fashion to an upset in the process stream. Because flow meters, analytical devices and samplers are regularly transported to and mounted at remote field sites, it is desirable for each piece of equipment to be as compact, versatile, and easy to use as possible.

The present inventors, in the apparatus disclosed in their aforesaid U.S. Pat. No. 5,091,863, have overcome many of the problems associated with using separate samplers and flow meters by providing an integrated, compact automatic sampling and flow measuring apparatus capable of pacing sampling in proportion to flow rate, and of storing sample collection and flow data for retrieval in hard copy form.

In the apparatus disclosed in their aforesaid U.S. Pat. No. 5,172,332, the present inventors have also overcome the problems associated with separate automatic sampler and analytical meter devices. The apparatus combines a sampler and analytical meter in a single unitary structure, with the sampler and analytical meter sharing the same computer control means, digital display, keyboard, circuitry, etc. The computer control means of the apparatus automatically calculates the values of fluid condition(s) such as pH level, and controls sampling operations on the basis of time and/or fluid condition(s). The apparatus also stores sample collection and fluid condition(s) data for later retrieval by the user.

The multi-function apparatus of the present invention is particularly directed to solving problems associated with transporting and using flow meters at remote monitoring sites. Technicians in the field encounter a variety of different conditions at different sampling sites, sewer manholes, and other monitoring environments, so that different types of flow sensors are required to accommodate varying open channel flow applications. Heretofore, it has been necessary to use different flow meter devices, each adapted to operate with only a single sensor type, to accommodate varying field conditions. For example, where an ultrasonic flow sensor would be best suited for a particular application, the user would have to acquire and transport a separate flow meter having an ultrasonic flow sensor. Subsequently, if the user were to encounter field conditions for which a bubbler-type flow sensor would be most suitable, the user would have to acquire and transport a different flow meter having a bubbler-type sensor.

The expense and inconvenience entailed by the use of different flow meters is eliminated by the present invention, in which the same compact apparatus accommodates a variety of interchangeable flow sensors. The multi-function fluid monitoring apparatus of the present invention has a compact, unitary structure incorporating a microprocessor which is programmed to automatically calculate and store data, as well as to perform other functions. A principal advantage afforded by the present invention is that the same compact fluid monitoring apparatus accommodates a plurality of different types of interchangeable flow sensors. Other advantages afforded by the invention include the selective graphic or tabular display of stored data in a convenient form for the user, the capability of monitoring various fluid conditions in addition to fluid flow-related variables, and features such as automatic fluid sampling. These and other features of the apparatus according to the invention render it multi-functional and highly versatile in use, while providing a structure which is very compact, conveniently transportable, and minimizes expense.

SUMMARY OF THE INVENTION

The invention provides an apparatus for monitoring at least one flow-related variable of fluid flow in a channel, comprising an integral operating unit provided in a unitary case, the integral operating unit including computer means for controlling the apparatus and input means for receiving detected signals related to fluid flow in the channel. The input means is selectively connectable to any selected one or more of a plurality of different types of flow-sensing means for producing signals related to the fluid flow in the channel. The integral operating unit further includes means for processing the signals from each of the plurality of different types of flow-sensing means, for input to the computer control means. The apparatus is also provided with power means for supplying power to each element of the apparatus. The computer control means comprises a microprocessor, program memory, and data memory. The data memory stores user-selected input parameters including at least one fluid flow-related parameter, and may further store fluid flow-related data. The microprocessor receives the signals related to fluid flow from the processing means and calculates values of at least one flow-related variable based on the signals, the user-input fluid flow-related parameter, and a selected one of a plurality of equations for computing values of the flow-related variable. Preferably, the plurality of equations are stored in the program memory of the computer control means.

In a preferred embodiment, a plurality of flow sensor control modules incorporate the signal processing means and other interface means, with each control module being associated with a particular type of flow sensor. The plurality of flow sensors may preferably include at least a bubbler sensor, a submerged sensor, an ultrasonic sensor, and a velocity sensor.

The bubbler sensor control module of the invention comprises, in addition to the signal processing means, an air pump operatively connected with an air reservoir so as to pressurize same, air flow restriction means connected to the reservoir, first pressure sensing means connected between the air flow restriction means and the reservoir, and second pressure sensing means connected downstream of the reservoir. The external connector associated with the bubbler sensor is connected to the air pump downstream of the second pressure sensing means. The microprocessor receives signals from the first and second pressure sensing means, and calculates the difference in pressure between the first and second pressure sensing means. The microprocessor is connected to the air pump so as to operate the pump to maintain a predetermined pressure difference between the first and second pressure sensing means. By virtue of this arrangement, the pressure across the air flow restrictor is kept constant, so that a nearly constant air flow or bubble rate is maintained in the fluid channel. The arrangement results in decreased power consumption and increased accuracy relative to known arrangements. In an alternative embodiment, the novel bubbler flow sensing system of the invention may be incorporated in a single-sensor type flow meter.

It is an object of the invention to provide a fluid flow monitoring apparatus which is completely contained in a compact, unitary case and which has the capability of measuring fluid flow-related variables on the basis of outputs from any one or more of a plurality of different types of flow sensors. The invention thus eliminates the expense and inconvenience associated with having to employ a number of different flow meters which each support only a single type of flow sensor.

In accordance with another important object of the invention, the flow monitoring apparatus is integrally provided with one or more fluid condition monitoring assemblies or modules which are connected with the microprocessor of the apparatus so as to input signals thereto from one or more fluid condition sensors, such as a pH sensor, ORP sensor, dissolved oxygen sensor, solution conductivity sensor, and/or other fluid condition sensors. The apparatus is thus provided with multi-functional capabilities to monitor fluid flow and fluid condition variables either independently or simultaneously, as desired.

According to yet another object of the invention, the multi-functional apparatus may be selectively linked with a variety of external devices, including a rain gauge, a pump, and the like, utilizing suitable interface electronics integrally connected with the microprocessor of the apparatus. The apparatus is thus able to transmit control signals to the external device(s), and to receive and record data from same. The additional capabilities include, for example, the capability to automatically sample fluid on the basis of either fluid flow related variables or critical level(s) of fluid condition(s).

It is another object of the invention to substantially isolate fluid samples pertaining to a flow-related variable or to a fluid condition variable so as to substantially reduce laboratory analysis costs.

Another object of the invention is to provide a fluid flow monitoring apparatus which determines and reports average fluid velocity throughout a channel utilizing Doppler technology.

The above and further objects, details, and advantages of the invention will become apparent from the following detailed description, when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a multi-function flow monitoring apparatus according to a preferred embodiment of the invention.

FIG. 2 is a front view of the operating panel of the apparatus of FIG. 1.

FIG. 3 is a partially disassembled view of the multi-function flow monitoring apparatus of FIG. 1, showing four interchangeable flow sensors accommodated by the apparatus together with their respective control modules.

FIG. 4 is a side view of the apparatus of FIG. 1, showing externally mounted components forming part of the bubbler sensor system of the apparatus.

FIG. 5 is a block diagram of the various components of a preferred embodiment of the invention, as controlled by the computer control means of the apparatus.

FIG. 6 is a perspective view of the apparatus according to the invention having a submerged sensor connected thereto, shown in a mounted position within a sewer manhole.

FIG. 7 is a perspective view of the apparatus according to the invention having a bubbler sensor connected thereto, shown in a mounted position within a sewer manhole.

FIG. 8 is a diagrammatic view of a prior art bubbler flow sensor system.

FIG. 9 is a diagrammatic view of a bubbler flow sensor system according to the invention, as incorporated within the multi-function flow monitoring apparatus.

FIG. 10 is a flow chart showing operational sequences of the bubbler flow sensor system of the invention.

FIG. 11 is a perspective view of the apparatus according to the invention having an ultrasonic flow sensor connected thereto, shown in a mounted position within a sewer manhole.

FIG. 12 is a side elevational view of a velocity sensor forming part of an area-velocity sensor system according to the invention, as mounted in an open fluid channel.

FIG. 13 shows a typical frequency distribution of signals from the velocity sensor of FIG. 12.

FIG. 14 is a block diagram showing the processing circuit for signals received from the velocity sensor of FIG. 12.

FIG. 15 is a flow chart showing operational sequences of the apparatus according to the invention.

FIG. 16 is a partial block diagram showing a fluid condition monitoring assembly with an associated pH electrode station, with other system components omitted for ease of illustration.

FIG. 17 is a partial block diagram showing a fluid condition monitoring assembly with an associated conductivity electrode station, with other system components omitted.

FIG. 18 is a partial block diagram showing a fluid condition monitoring assembly with an associated oxygen reduction potential ("ORP") electrode station, with other system components omitted.

FIG. 19 is a partial block diagram showing a fluid condition monitoring assembly with an association dissolved oxygen electrode station, with other system components omitted.

FIGS. 20–30 are schematic diagrams of a preferred embodiment of the average fluid velocity computation unit of the present invention.

FIG. 31 is a perspective view of a preferred embodiment of the present invention.

FIG. 32 is an exploded perspective view of a preferred embodiment of the present invention showing an automatic sampling unit assembly thereof.

FIGS. 33A and 33B are flow charts showing operational sequences of the apparatus according to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With reference to FIGS. 1–4, there is shown a preferred embodiment of the multifunction flow monitoring apparatus according to the invention. The apparatus includes a compact case 1 which houses the various electronic, microprocessing, and mechanical components of the invention. Case 1 is preferably fabricated of a rugged thermoplastic material, such as ABS plastic, which is impact resistant and capable of withstanding the stresses of mounting and use under harsh conditions. The front portion of case 1 includes an operating panel 2 provided with a sealed membrane switch numeric keypad 3 for user input, a liquid crystal graphics/alphanumeric display 4, push buttons 5 for selectively operating display 4, and ON/OFF switches. A door 6, fabricated of a rugged thermoplastic material which is transparent, protectively covers the operating panel 2 when it is not being used. Door 6 is hingedly secured at 6A to one side of the front case portion, and is retained in a closed position by a pair of stainless steel lockable latches 6B at the opposite side. The case 1 including operating panel 2 is completely sealed so as to be watertight, with added protection of operating panel 2 being afforded by fastening door 6 in a closed position. However, even when door 6 is open, the case 1 with the components mounted therein is submersible, watertight, dust-tight, and corrosion resistant, conforming to NEMA 4X, 6 standards. In an alternative embodiment, case 1 is integrally formed with a housing for performing additional operations, such as performing fluid sampling operations, as shown in FIG. 32.

As shown in FIG. 3, the rear top portion of case 1 may be provided with an integrally molded handle portion 7. Below the handle portion is an integrally molded recessed pocket portion 8 adapted to securely hold a power source for the apparatus, such as a battery 9, an A/C power converter, or the like.

Mounted on a side portion of case 1 is a plurality of external connectors 10 which preferably are each provided with a removable cap to protect same when not in use, although the connectors 10 are sealed in a watertight manner even without the caps. As described in greater detail below, connectors 10 are adapted to have various devices connected thereto, including any one of a plurality of interchangeable flow sensors, fluid condition monitoring sensor(s), a power source such as a battery, a data transfer unit, etc. It will be understood in this respect that the number of connectors 10 may be varied as desired to accommodate a desired number and/or types of sensors and external devices. In the embodiment shown in FIGS. 1–3, the uppermost connector 10 is adapted to receive one end of an electrical connector for connection to rear-mounted battery 9, which in a preferred embodiment provides a power source for the apparatus.

A principal feature of the multi-function fluid flow monitoring apparatus of the invention is its ability to calculate fluid flow-related variables on the basis of outputs from any one of a plurality of interchangeable flow sensors. In effect, the multiple flow sensor capability of the invention renders the apparatus equivalent to a plurality of different types of flow meters all integrated in a single unit. The user is thus able to adapt the apparatus for use in a wide variety of different site conditions simply by selecting a type of flow sensor which is suitable for the conditions at a given monitoring site, instead of having to switch to an entirely different flow meter. In the preferred embodiment described below, the apparatus is adapted to measure fluid flow-related variables on the basis of outputs from at least four different types of sensors, i.e., a bubbler-type pressure sensor, an ultrasonic type sensor, a submerged type sensor, and a velocity sensor forming part of an area-velocity sensor system. It will be understood, however, that the apparatus is capable of accommodating additional and alternative types of sensors by means of suitable control modules which may be integrally connected with the computer control means of the apparatus as desired.

As shown in FIG. 5, the apparatus according to the invention includes computer control means in the form of a microprocessor which performs all mathematical and control functions required to operate the apparatus, a keyboard (keypad 3 in FIG. 1) defining the interface to the user which allows the user to program the apparatus and monitor its operation, and a real-time clock. The real-time clock provides the computer control means with access to current time and date information, so that events occurring during program execution may be recorded with corresponding time and date of occurrence.

As shown in FIG. 3, four control modules 20, 30, 40, 50 are provided for the four interchangeable flow sensors 21, 31, 41, 51, respectively, with each module being integrally connected with the microprocessor within case 1 in the assembled state. Control module 20, which operatively cooperates with a bubbler type sensor in the form of bubbler tubing 21, includes an air pump and various mechanical and electronic circuitry components, including signal processing means, of a bubbler depth measurement system described in detail below. Control module 30, in the form of an electronic circuitry board, includes signal processing means and interface means for submerged sensor 31 as described in detail below. Likewise, control modules 40 and 50, each in the form of an electronic circuitry board, define signal processing and interface means for ultrasonic sensor 41 and a velocity sensor 51, respectively, as also described in detail below.

Submerged Sensor

With reference to FIGS. 1–3, 5 and 6, the operating characteristics of the invention will first be described with respect to sensor 31, which comprises a submerged pressure transducer.

By way of example, submerged pressure transducer or submerged sensor 31 is suitable for use in monitoring conditions where floating oil, grease, foam, steam, silt, solids, or turbulence are present. The sensor 31 is selectively connected with one of the connectors 10 on case 1, which is in turn connected with the microprocessor of the apparatus via control module 30. The interface means incorporated in module 30 are defined by signal conditioning electronics and an analog to digital ("A/D") converter, as represented in the lower portion of FIG. 5 by labelled blocks. The circuitry provided in control module 30 operates to transmit a precision voltage level to the sensor 31, as well as to condition and convert signals detected from sensor 31 for input to the computer control means. The detected signals are amplified and smoothed (filtered for noise), and then converted to digital form by an A/D converter (FIG. 5) for input to the microprocessor.

With reference to FIG. 6, the apparatus with submerged sensor 31 connected thereto is shown in a mounted position in a sewer manhole. As shown, the apparatus may be suspended by a plurality of lines attached to case 1 and extending from a cross-bar support provided at the upper end of the manhole. Sensor 31 is shown as installed in an open flowing sewer passage, secured in position by a stainless steel mounting band 32 such that the sensor is positioned directly in the flow stream. The pressure over the sensor 31 changes with changes in fluid level. The microprocessor of the apparatus, on the basis of inputs from sensor 31 processed by control module 30, converts the level reading to a flow rate based on the level-to-flow relationship of the channel configuration. The flow rate relationship is determined on the basis of the dimension, declination, and inside roughness of the pipe.

Submerged sensor 31, like the other interchangeable sensors described in detail below, may alternatively be installed in a fluid flow restricting or primary device which is in turn installed in an open flowing sewer passage to define a fluid channel for measuring fluid flow rate. Such a primary device may take the form of a weir, such as a V-notch weir, a contracted or non-contracted rectangular weir, a Cipolletti weir, a Thelmar weir, or a compound V-notch and rectangular weir. Alternatively, the primary device may comprise a flume, such as an H, HL or HS flume; a Parshall flume; a trapezoidal flume; a Palmer-Bowlus flume, or a Leopold-Lagco flume. The primary device may also take the form of a nozzle, such as a Kennison or parabolic nozzle.

Each of the foregoing primary devices is adapted to restrict fluid flow in an open passage so as to increase the fluid depth upstream of the device. The upstream fluid depth or "head" of each such device has a known mathematical relationship with the rate of flow through the channel of the device. This head vs. flow rate relationship is available in published form for various different sizes of each type of device.

When the sensor **31** is submerged upstream of one of the above-described flow restriction or primary devices, the voltage output from sensor **31** will be directly related to the "head" value used to calculate the flow rate. Typically, the sensor **31** will be mounted at a low point in a primary device so that it will remain submerged. Processing of the signals from sensor **31** and calculation of the flow rate is performed by the apparatus including the computer control means as described below.

The computer control means according to the invention comprises a microprocessor, and preferably has program storage firmware in the form of FLASH memory which permits software enhancements without replacing E-PROM chips. In addition to program storage memory, the computer control means is also provided with data storage memory in the form of random access memory (RAM) which stores specific details of operation set by the user and records flow and other data as described below. The RAM is backed-up by its own battery, e.g., a lithium battery, so that data will remain stored therein even when the overall power source of the apparatus is turned off.

Program Storage Memory.

The program storage memory of the computer control means according to the invention implements all of the functions required to read and process data from submerged sensor **31**, as well as any other interchangeable sensor being used, and to operate the text and graphics display **4** and keypad **3**. The program storage memory may include the following programming:

Interface Programming;

Flow Measuring Programming; and

Fluid Condition Monitoring Programming.

The Interface Programming allows the microprocessor to control the user input keypad **3**, the text/graphics display **4**, the real-time clock, and to access the active interface devices including the interchangeable sensors and any external devices connected with the apparatus. With respect to the bubbler module **20**, the computer control means is also programmed to control operation of the bubbler air pump based on inputs from pressure sensors received via an A/D converter (FIG. **5**), as described in greater detail below.

The Flow Measuring Programming allows the microprocessor to calculate the fluid depth, flow rate, velocity, and other fluid flow-related variables on the basis of processed signals received from the sensor **31** or one of the other interchangeable sensors described below. The programming includes depth vs. flow equations which characterize the relationship between the "head" and flow rate for various types and sizes of fluid flow restricting devices. Also included are equations (e.g., the Manning Equation) for calculating flow variables on the basis of sensor inputs directly from various shaped channels, such as round pipes, U channels, rectangular channels, and trapezoidal channels. While these various equations could alternatively be selectively input by the user via keypad **3**, in the preferred embodiment of the invention the equations are stored in the program memory of the computer control system of the apparatus. Floating point math algorithms are provided to enable the microprocessor to perform high precision mathematical operations required to accurately calculate the values of fluid flow-related variables. Such fluid flow-related variables include the fluid depth which is calculated from the output of a selected one of the sensors, and the fluid flow rate which is calculated from the measured fluid depth. Algorithms are included for performing addition, subtraction, multiplication, division, exponentiations, logarithms and trigonometry functions to a precision equivalent to over four significant figures.

It will be understood that the Interface Programming and Flow Measuring Programming also allow the microprocessor to perform a variety of other operations which will become apparent from the following detailed description. For example, one such operation comprises a totalizer feature in which the microprocessor calculates and keeps a running total of the fluid quantity discharged over a given time period, on the basis of inputs from a flow sensor being used with the apparatus, with the running total being displayed on display **4**. A second running total may also be provided which is re-settable by the user so as to track total flow over only a selected period of time. As shown in FIG. **5**, a mechanical totalizer operated by the microprocessor is also provided so as to ensure that a totalized value will not be erased.

The Fluid Condition Monitoring Programming comprises firmware which allows the microprocessor to calculate the values of a given fluid condition(s) on the basis of processed signals received from a fluid condition sensor via suitable interface means, as described in greater detail below.

Data Storage Memory

The data storage memory of the computer control means is preferably provided in the form of random access memory (RAM) which stores specific operational parameters set by the user, and stores data during operation. Parameters which may be set by the user include fluid flow and fluid level logging intervals, such as on the basis of time, a given depth in the fluid channel, and/or rainfall (where a rain gauge is connected with the apparatus), as well as selection of a primary device or channel configuration. The user may also select parameters for monitoring fluid conditions such as pH, temperature, ORP, rainfall, conductivity, dissolved oxygen, turbidity, etc., on the basis of inputs from external signal sources as described below. Other parameters which may be set include control parameters such as trip points based on high and/or low fluid condition levels (e.g., pH levels or water level), which trigger the operation of an automatic sampling unit, a pump, or the like. A variety of other parameters which may be input by the user will become apparent from the description below.

The invention contemplates that the computer control means be programmed to selectively prompt the user, via a series of menu screens displayed on display **4**, to enter various desired parameters via keypad **3**. Various user-keyed parameters associated with particular sensors and devices are described in detail below. In addition to user-programmed entries, all data collected during operation is stored in RAM.

Bubbler Sensor

In accordance with the interchangeable flow sensor capability of the invention, the use of the apparatus as a bubbler-type pressure sensor system including the bubbler sensor **21** (FIG. **3**) will now be described with reference to FIGS. **3–5** and **7–10**.

The bubbler sensor **21**, which comprises a length of plastic tubing, is particularly suitable for use in low or intermittent flow conditions, or where interfering conditions are present, such as floating oil, grease, foam, steam, surface turbulence, and/or excessive wind. Because only inexpensive tubing is exposed once the bubbler type sensor is mounted for operation, it is also well suited for applications in which vandalism may be a problem. The ease of installation of the bubbler sensor, described below, also makes it well suited for temporary flow applications, such as POTW monitoring or infiltration and inflow studies.

As shown in FIG. **3**, the control module **20** for bubbler sensor **21** includes an air pump and various mechanical and electronic circuitry components of a bubbler depth measurement system according to the invention, including signal processing and interface means connected with the microprocessor. The bubbler system of the invention represents a substantial improvement over a conventional bubbler depth measurement system, such as shown in FIG. **8**, as described in detail below.

With reference to FIG. **8**, the conventional bubbler system includes an air pump A which is controlled by a pressure switch B so as to maintain an approximately constant air pressure in a pressure reservoir C. Such pressure must be sufficient to force air bubbles into the maximum fluid depth which is expected to be encountered by the system, as follows:

$$P \geqq 0.03612 \times D$$

where

P=Reservoir Pressure (PSI)

D=Maximum expected water depth (inches)

In the conventional system, an air flow restrictor D and needle valve E cooperate to limit the air flow from the reservoir to some desired rate. In practice, the user adjusts the needle valve to obtain an air flow rate which yields approximately one to three bubbles per second from the air outlet H. Air outlet H is mechanically fixed in place inside a fluid channel. The fluid depth in the channel may then be determined by measuring the back pressure on the output air line by means of a pressure sensor F. Ideally, the fluid depth may be calculated as:

$$D = 27.681 \times P$$

where

D=Channel fluid depth (inches)

P=Measured Pressure (PSI).

In reality, however, the movement of air through the output tubing adds a friction term to the measured pressure. This friction or error term must be subtracted from the measured pressure in order to make an accurate depth calculation, as follows:

$$D = 27.681 \times [P - f(l,d,v)]$$

where

D=Channel fluid depth (inches)

P=Measured Pressure

f(l,d,v)=Measured Pressure Error due to air moving in output tube; a function of air tubing length (l), diameter (d), and air flow velocity (v).

The magnitude of the error term is determined by the length and diameter of the output tube, and the velocity of the air flowing through it. Two of the factors in the error term, the tubing length (l) and diameter (d), remain constant for a given installation. However, the air flow velocity is primarily a function of the position of the needle valve, and the pressure difference between the pressure reservoir and the air output. Because the air outlet is mechanically fixed inside the fluid channel, this pressure difference will be determined primarily by the fluid depth in the channel. The net result is that the fluid depth calculated by the conventional system will include an error term which is a function of the current needle valve setting, the length and diameter of the output tubing, and the current depth in the fluid channel.

When the conventional system shown in FIG. **8** is used in applications where the measured fluid depth changes only slightly, the error term [f(l,d,v)] is more or less constant, and may be compensated for when installing and calibrating the system at the site. When the conventional system is used in applications where the fluid level varies over a wide range, the error term will add significantly to worst case measurement error. In either case, any movement of the needle valve after calibration will alter the error term and thus detrimentally affect the accuracy of depth measurement.

Another problem which the conventional bubbler system of FIG. **8** suffers is excessive power consumption. When the system is adjusted to provide a suitable bubble rate at maximum fluid depth, the air flow will be substantially greater near zero fluid depth. This causes the air pump to run more frequently, thus consuming additional power. Such power consumption is particularly undesirable in battery operated systems where battery life is an important factor.

The bubbler system according to the present invention, shown in the block diagram of FIG. **9**, overcomes the various problems associated with the conventional bubbler system of FIG. **8** while maximizing accuracy and minimizing power consumption. The bubbler system according to the invention includes an air pump A' which pressurizes an air reservoir C', both of which are housed, together with other components of the bubbler system, within case **1** of the apparatus as part of the bubbler control module **20** (FIG. **3**). Unlike the conventional system, in the bubbler system according to the invention the air pump A' is controlled by the microprocessor of the apparatus. The microprocessor is programmed to determine when and for how long the air pump A' must be run by reading the two pressure sensors B' and E' shown in FIG. **9**. As shown in FIG. **5**, inputs from pressure sensors B' and E' are transmitted to the microprocessor via an A/D converter. The pressure difference between sensors B' and E' is equivalent to the pressure drop across the air flow restrictor D'. The microprocessor controls operation of pump A' so as to maintain a predetermined pressure across the air flow restrictor D'. As the fluid level in the channel changes, the pressure maintained in the reservoir C' is thus changed by a like amount.

An important advantage afforded by the bubbler system according to the invention is that the constant pressure across the air flow restrictor D' results in a nearly constant air flow or bubble rate into the fluid channel, thus virtually eliminating the depth dependency from the error term in the depth-pressure equations set out above for the conventional system. The depth-pressure relationship for the bubbler system according to the invention is as follows:

$$D = 27.681 \times [P - f(l,d)]$$

where

D=Channel depth (inches)

P=Pressure measured at pressure sensor E' (PSI)

f(l,d)=Measured Pressure Error due to air moving in output tube; a function of air tubing length (l) and diameter (d).

Because the bubbler system according to the invention effectively controls the air flow velocity, it is unaffected by the fluid depth in the channel. The tubing-based error term (f(l,d)) from which the conventional system suffers, while still present, is in the present system a function of only the output air tubing length and diameter. The error term is thus constant for a given installation and may be effectively canceled at the time the apparatus of the invention is installed and calibrated at the site.

Another important advantage afforded by the bubbler system according to the invention is that a lower pressure is maintained in the air reservoir C' when the channel fluid depth is less than the maximum. The lower reservoir pressure reduces pump run time, thus conserving power and increasing battery life. A further advantage of the present system is that the air flow or bubble rate is set by a command to the microprocessor of the apparatus which is effected via keypad **3**, rather than mechanical adjustment of a needle valve as in the conventional system. Once the bubble rate has been initially set by the user, it will remain constant even when the apparatus is moved from one installation site to another. In most cases, the bubble rate need never be changed from the original factory setting for the life of the unit.

As shown in FIG. **4**, the bubbler sensor tubing **21** is selectively connected to the apparatus via a bubbler line port connection **22** which is preferably provided on the side of case **1** opposite the side provided with connectors **10**. Also provided is an air intake port **23** with an associated dryer tube **24** for air supply to the bubbler air pump A', as well as a reference port **25** with an associated dryer tube **26**. The reference port **25** communicates with the atmosphere via an offset valve G' as shown in FIG. **9**. The microprocessor is programmed to open the bubbler port and reference port to atmosphere at regular intervals, and to electronically zero same so as to eliminate any drift due to changing barometric pressure. Further, a bypass valve F' is opened periodically by the microprocessor for a short time. The resulting burst of high velocity air through the air tube helps to dislodge any debris which otherwise might accumulate on the air outlet H' and restrict air flow.

The sequential steps of initializing and operating the bubbler system, as described above, are summarized in the flow chart of FIG. **10**.

With reference to FIGS. **4** and **7**, installation and operation of the bubbler type sensor is as follows. The bubbler sensor **21** is connected at one end to bubbler line port connection **22** and is mounted at its other end within the fluid in a channel. As shown in FIG. **7**, a stainless steel mounting band **28** may be used for securing the outlet end of sensor **21** in a channel, although it is contemplated that any suitable mounting means may be employed. The bubbler air supply arrangement described above, in cooperation with the microprocessor of the apparatus following the sequence of steps shown in FIG. **10**, communicates through the bubbler line port **22** with bubbler sensor **21** so as to direct a constant, small volume of air through the tubing of sensor **21** to the measurement point in the fluid channel. As the pressure in the sensor tubing **21** changes in proportion to fluid level, the flow measuring programming converts the level reading to flow based on the level-to-flow relationship of the channel configuration, or that of a primary device.

In accordance with another embodiment of the invention, the bubbler sensor system as described above may alternatively be provided in a single-sensor capacity fluid flow monitoring apparatus or flow meter. Such embodiment would include the bubbler control module **20**, but not the other control modules **30**, **40** and **50** shown in FIG. **3**. The bubbler type fluid flow monitoring apparatus as thus constructed may also include any one or more of the other multi-functional features of the invention, such as the ability to link the apparatus with external devices such as a rain gauge, automatic fluid sampling apparatus, and the like, as well as accommodating one or more fluid condition monitoring sensors.

Ultrasonic Sensor

In accordance with the interchangeable flow sensor capability of the invention, the use of the apparatus with the ultrasonic type sensor **41** (FIG. **3**) will now be described with reference to FIGS. **3**, **5** and **11**.

The ultrasonic transducer or sensor **41**, which functions without contacting the fluid being monitored as discussed below, is particularly suitable for use where chemicals would adversely affect a sensor located in the fluid. The ultrasonic sensor **41** is also suitable for permanent applications, particularly where silt or solids are present. Further, because ultrasonic sensor **41** is mounted above the fluid channel instead of within the channel, it is capable of accurately measuring channel depth as low as zero and is not affected by high fluid velocities in the channel.

The signal processing and interface electronics for sensor **41** are provided on control module or board **40** as shown in FIG. **3**. Ultrasonic sensor **41** uses an echo range measurement through air technique to measure the distance from a fixed point above the channel to the fluid surface. The output from sensor **41** based on such measurement, processed by control module **40** for input to the microprocessor, is then processed to calculate the depth of the fluid in the channel, and the rate of flow. Control module **40** cooperates with sensor **41** to supply a series of acoustic pulses from a high-energy, high-frequency source which are directed toward the fluid surface by sensor **41**, and echo signals are reflected back and processed in order to calculate values such as average fluid flow rate, as described below.

The operating parameters of the ultrasonic sensor system as described above are all controlled by the microprocessor of the apparatus, with which control module **40** is connected. The microprocessor performs routine optimizing operations to determine and adjust the optimal settings for pulse strength, pulse width, detector sensitivity, and frequency. For example, if the echo signal quality deteriorates below an acceptable level, the condition will be detected and automatically corrected. Because the frequency at which the ultrasonic sensor **41** is driven can be varied, while the strength of the resulting echo is monitored, the ultrasonic sensor system according to the invention effectively tunes itself to match the particular ultrasonic sensor being used. The user is thus able to replace one ultrasonic sensor with another in the field, without having to return the unit to the factory for re-tuning.

In use, ultrasonic sensor **41** is selectively connected to one of the connectors **10** on case **1** which is in turn connected with ultrasonic control module **40**. As shown in FIG. **11**, the apparatus with the sensor **41** connected thereto is installed in a sewer manhole in the manner described above with respect to the other types of sensors. As also shown in FIG. **11**, the sensor **41** is positioned above the fluid in the channel, which may be accomplished by simply allowing the sensor cable to hang from the connector **10**. It will be understood, however, that any suitable mounting means may be used for mounting sensor **41**, provided that the sensor is held in position above the fluid and out of contact therewith.

Area-Velocity Sensor System

In accordance with the interchangeable flow sensor capability of the invention, the use of the apparatus as an area-velocity sensor system (FIG. 3) will now be described with reference to FIGS. **12–14** and **20–30**.

The area-velocity sensor system according to the invention includes a fluid level measuring subsystem and a fluid velocity measurement subsystem. The fluid level measuring subsystem may take the form of any of the above-described flow sensor systems capable of measuring fluid depth, including the bubbler sensor system, the ultrasonic sensor system, or the submerged sensor system described above. The fluid velocity measurement subsystem, used in conjunction with the fluid level measuring subsystem, includes the velocity sensor **51** and associated electronic circuitry provided on control module or board **50**, with module **50** being connected with the microprocessor of the apparatus. The circuitry details of module **50** are shown diagrammatically in FIG. **14**, and discussed in detail below. When it is desired to use the velocity sensor **51**, its coaxial cable is selectively connected with the apparatus via one of the connectors **10** which is in turn connected with module **50**. Simultaneously, one of the flow sensors **21**, **31**, or **41** is connected with its associated connector **10**, so as to measure fluid level.

The velocity sensor **51** is shown in FIG. **12** as mounted on the bottom of an open channel, with fluid flowing through the channel to the right as indicated by the arrow. Sensor **51** is mounted substantially horizontally, facing in the upstream direction so as to eliminate sensor induced turbulence on the velocity measurement. It will be understood with respect to the following description of velocity measurement that free surface, open channel flow is assumed. To simultaneously measure fluid level, designated as L in FIG. **12**, one of the sensors **21**, **31**, **41**, or an alternative flow sensor capable of measuring fluid depth, is also mounted in the channel.

Provided within the plastic housing of sensor **51** is a piezoelectric transmit transducer **52** and a piezoelectric receive transducer **53**. The signal processing circuitry on board **50** of the apparatus transmits average velocity results to the microprocessor while simultaneously the microprocessor receives fluid level information from the fluid level measuring subsystem. The microprocessor then calculates average flow rate by the following equation:

Average Flow Rate=Average Velocity×Channel Cross-Sectional Area

The channel cross-sectional area is calculated by the microprocessor on the basis of channel geometry information entered by the user via keypad **3**, and fluid level information.

The fluid velocity subsystem of the area-velocity sensor system operates on the principle of the Doppler frequency shift of a transmitted electromagnetic wave. A high frequency (e.g., 1-Megahertz) ultrasonic wave is emitted from transmit transducer **52** at an angle from the long axis of the sensor (typically an angle of 15° to 35°, e.g., 20° in FIG. **12**), with the wave being emitted in the form of a cone with a 10° cone angle as shown in FIG. **12**. Relative motion between the stationary probe and moving particles in the fluid are detected by receive transducer **53**, which is manifested as a change in frequency from the transmitted wave. This Doppler shifted frequency is proportional to the speed of the moving particles in the fluid.

The signal from receive transducer **53** actually comprises a time domain sum of sinusoidal signals corresponding to packets of scattering particles in the fluid. As shown in FIG. **14**, circuitry provided on control module **50** processes the signal from receive transducer **53** by amplifying, filtering, and mixing it with the transmitter frequency, yielding the sum and difference frequencies of the inputs to the mixer. The sum frequency is filtered out and the difference frequency is the actual Doppler shifted frequency. This Doppler signal is then input to a spectrum analyzer circuit on module **50**, and a frequency scan is performed on the time domain signal over the expected full-scale range of velocities for the instrument. The output comprises a weighted frequency distribution of the input signal over discrete, evenly-spaced frequency intervals, as shown in FIG. **13**. The weighting of each frequency component corresponds to the strength of the scattered energy at each velocity interval. To obtain average velocity, the centroid of this frequency distribution is calculated and the result is used by the microprocessor for calculating the average flow rate.

The flow direction, whether downstream or upstream, is obtained by detecting the relative phase difference between the actual transmitted wave and the quadrature shifted (90°) transmit wave. This quadrature transmit wave is processed internally on module or board **50** in parallel with the actual transmitted wave to yield the actual Doppler wave and a quadrature shifted Doppler wave. The quadrature shifted Doppler wave is used only for flow direction sensing, and not in the average velocity measurement. The actual Doppler wave and the quadrature shifted Doppler wave are then input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to the microprocessor.

Referring to FIGS. **20–30**, there is shown the circuit diagrams depicting the area-velocity sensor system according to the preferred embodiments of the present invention. Clock generator circuit **79** (FIG. **29**) generates in-phase and quadrature phase clock signals running at a relatively high frequency, such as 1 MHz. Transmitter circuit **70** (FIG. **22**) accepts the in-phase clock signal and transmits the clock signal throughout the channel. The transmitted signal is reflected by particles within the fluid and the reflected (or echo) signal is received by receiver **71** (FIG. **20**) and amplified therein. The echo signal comprises a time domain sum of sinusoidal signals corresponding to packets of scattering particles in the fluid, and possesses a change in frequency from the original transmitted signal. This frequency change is the Doppler frequency shift, which is related to the velocity of the objects from which the signals are reflected.

The output of receiver circuit **71** is accepted by in-phase audio channel **72** (FIG. **23**) as well as by quadrature-phase audio channel **76** (FIG. **21**). In-phase audio channel **72** receives the amplified reflected signal and mixes it with the in-phase clock using mixer circuit **72A** so as to yield a signal having the sum and difference frequencies thereof. The component of the output signal representing the difference in frequencies between the reflected signal and the in-phase clock is the frequency shifted Doppler component.

Low-pass filter **72B** receives the output from mixer circuit **72A** and is tuned so as to select the component thereof representing the difference in frequencies between the reflected signal and the in-phase clock, which comprises the frequency shifted doppler signal in the audio band. An AGC amplifier **73** (FIG. **24**) maintains the amplified doppler signal within an acceptable amplitude range, comprising a rectifier circuit followed by an integrator amplifier. Similarly, quadrature phase audio channel **76** receives the amplified echo signal and mixes it with the quadrature phase clock using mixing circuit **76A**, and low-pass filter **76B** passes the quadrature-shifted doppler signal.

The doppler signal from the in-phase audio channel **72** is then amplified by two-stage amplifier **72C**, **72D**, the output of which drives spectrum analyzer **77** (FIG. **27**). Spectrum analyzer **77** is preferably but not necessarily a swept tuned local oscillator comprising a frequency generator having voltage controlled oscillator (VCO) **77F** which generates an oscillating signal whose frequency is microprocessor-controlled; mixer circuit **77B**, which mixes the VCO **77F** output signal with the doppler signal; bandpass filter **77A** which accepts mixer circuit **77B** output and passes a narrow band of frequencies centered at a predetermined intermediate frequency; and peak detector **77C** which receives the output of filter **77A** and generates an output representative of the peak energy level thereof. The output of peak detector **77C** is then digitized (FIG. **28**) for storage in digital memory **78B** (FIG. **30**). In this way, microprocessor **78A** (FIG. **30**) can be programmed to step the voltage control input of VCO **77F** so that VCO **77F** is swept across the desired frequency range in predetermined increments. The energy level of the doppler signal at each desired frequency can thereby be sequentially extracted by being passed through IF filter **77A**, detected by peak detector **77C** and then digitized and stored in memory **78B** together with its corresponding frequency, so that a frequency distribution of the doppler signal over discrete, substantially spaced intervals is substantially obtained. In one preferred embodiment of the present invention, the energy levels of the doppler signal are extracted at substantially evenly-spaced frequency intervals.

By way of one example, filter **77A** is a 4th-order high Q bandpass filter centered at 10 kHz and having a 3 dB bandwidth of 46 Hz; and microprocessor **78A** steps VCO **77F** over approximately a 3.5 kHz frequency range between 10 kHz and 13.5 kHz so that doppler frequencies between 0 and 3.5 kHz are passed through IF filter **77A**. These doppler frequencies correspond to fluid velocities between 0 and 10 ft/sec.

Once the frequency distribution of the doppler signal has been stored in memory **78B**, microprocessor **78A** computes the centroid thereof, which is approximately equal to average fluid velocity.

The area-velocity sensor system preferably but not necessarily includes a means for verifying the accuracy of the average fluid velocity as calculated by spectrum analyzer **77** and microprocessor **78**. The verification means preferably but not necessarily calculates a maximum velocity of fluid flow substantially concurrently with the average flow rate calculation and compares the maximum value with the average value. If the calculated average fluid velocity is not at least a predetermined percentage of the calculated maximum fluid velocity value, then the calculated average velocity value is discarded and the calculated maximum velocity value is reported as the average velocity value, following multiplication thereof by a constant. By way of one example, the calculated average flow rate is discarded unless it is at least 72% of the calculated maximum velocity value, and the reported average velocity is 90% of the calculated maximum velocity value when the computed average velocity value is less than 72% thereof.

Specifically, the verification means preferably but not necessarily comprises comparator **74** (FIG. **25**), which receives the doppler signal generated by amplifier **72D** and converts the signal into a digital square wave so as to provide a digital representation of the doppler signal; direction comparator **75** (FIG. **26**), which determines the direction of fluid flow by comparing the quadrature-phase mixed signal from audio channel **76** with the squared doppler signal from comparator **74** so as to yield the relative phase difference therebetween; timing circuitry within microprocessor **78A** which accepts the output from comparator **74** as well as the in-phase clock, measures substantially consecutive time periods of the output from comparator **74**, and stores the measured time values of consecutive time periods in memory; and arithmetic circuitry, also within microprocessor **78A**, which sorts through a predetermined number of stored time periods, selects a predetermined number of the values therefrom representing the smallest time periods (i.e., those time periods corresponding to the highest frequency), obtains a sum of the smallest time periods and normalizes the sum. The normalized sum is then multiplied by a constant in order to convert maximum frequency to maximum velocity in to units of feet/second. This result is the calculated maximum fluid velocity value which is used to verify the legitimacy of the calculated average fluid velocity value.

By way of one example, 100 consecutive time periods are measured by the verification means, and the 27 smallest measured time periods thereof are summed and normalized in computing maximum fluid velocity.

With reference to FIG. **15**, there is shown a flow chart showing the overall sequence of operation of the apparatus with respect to the four sensor systems described above. From FIG. **15** and the above detailed description of the four sensors **21**, **31**, **41**, and **51**, and their respective control modules **20**, **30**, **40**, and **50**, it will be understood that the flow monitoring apparatus of the invention essentially incorporates four different flow monitoring assemblies into a single compact unit. By employing a common microprocessor and command structure, and housing the computer control means with modules **20**, **30**, **40**, and **50** in a single case, the apparatus is able to accommodate a very wide range of monitoring needs which heretofore could be accommodated only by relying upon a number of separate flow meter devices. The case **1** which houses the microprocessor and control modules of the invention is at least as compact as commercially available flow meters which are limited to use with only a single type of flow sensor. In order to adapt the operation of the apparatus to the desired bubbler, submerged sensor, ultrasonic sensor, or area-velocity mode, the user has merely to connect the desired sensor or sensors to the appropriate connector(s) **10** and enter corresponding operating parameters via keypad **3**. The invention thus enables the user to select from a variety of flow sensor systems the particular type which will be best suited to a given monitoring application.

Multi-Functional Modes of Operation

In addition to the unique capability of the invention to selectively operate as essentially four (or more) different flow meters in accordance with the above-described embodiment of the invention, the apparatus of the invention may also be integrally provided with one or more means for monitoring various fluid conditions, such as pH, ORP, temperature, dissolved oxygen, conductivity, turbidity, and the like.

The means for monitoring a given fluid condition(s) preferably takes the form of one or more fluid condition monitoring assemblies or control modules such as those disclosed in the aforesaid U.S. Pat. No. 5,172,332, the disclosure of which is incorporated herein by reference thereto. Four such fluid condition monitoring assemblies or modules are depicted in the block diagrams of FIGS. **16–19**, i.e., for a pH sensor, a conductivity sensor, an ORP sensor, and a dissolved oxygen sensor, respectively. FIGS. **16–19** are all partial system views showing only the individual fluid condition monitoring modules and electrode stations as connected to the microprocessor of the apparatus, with the various other components of the invention shown in FIG. **5**, including the various control modules for the flow sensors, omitted for ease of illustration.

It is contemplated that each of the fluid condition monitoring assemblies or control modules of FIGS. 16–19 may desirably be provided in the form of a single board similar to the control modules 30, 40, and 50 shown in FIG. 3. As shown in FIG. 16, a control module for a pH electrode station or sensor includes signal conditioning electronics, an input selector (analog switch), and an A/D converter. These components may be provided on a single board which is integrally connected with the microprocessor within case 1, and which is also connected to one of the external connectors 10. Programming in the form of firmware is provided which allows the microprocessor to calculate the pH level on the basis of processed signals received from the fluid condition monitoring assembly or module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and to permit user selection, via keypad 3, of the time interval for recording data. A sensor in the form of a pH electrode station may be selectively connected to the corresponding connector 10, so that pH levels can be monitored along with fluid flow-related variables. A more detailed description of the structural and functional features of the pH sensor control module and the electrode station itself is set out in the aforesaid U.S. Pat. No. 5,172,332.

With reference to FIG. 17, a control module for a solution conductivity sensor includes signal conditioning electronics, an input selector (analog switch), and an A/D converter, all preferably provided on a single board connected with the microprocessor within case 1, and also connected to one of the external connectors 10. Programming in the form of firmware allows the microprocessor to calculate the conductivity level on the basis of processed signals received from the fluid condition monitoring module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and user selection via keypad 3 of the time interval for recording data. A solution conductivity electrode station or sensor is selectively connected to the corresponding connector 10 to permit monitoring of conductivity levels. A more detailed description of the conductivity sensor control assembly or module and the electrode station itself is set out in the aforesaid U.S. Pat. No. 5,172,332.

FIG. 18 shows a control assembly or module for an oxygen reduction potential ("ORP") sensor, including signal conditioning electronics and an A/D converter preferably provided on a board connected with the microprocessor within case 1, and also connected to one of the external connectors 10. Programming in the form of firmware allows the microprocessor to calculate the ORP level on the basis of processed signals received from the fluid condition monitoring module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and user selection via keypad 3 of the time interval for recording data. An ORP electrode station or sensor is selectively connected to the corresponding connector 10 for monitoring of ORP levels. A more detailed description of the ORP control assembly or module and ORP electrode station is set out in the aforesaid U.S. Pat. No. 5,172,332.

With reference to FIG. 19, there is shown a control assembly or module for a dissolved oxygen sensor of either a polarographic or galvanic type. The control module includes signal conditioning electronics, an optional electrode reference voltage source, an input selector (analog switch), and an A/D converter. The control module circuitry is preferably provided on a board, which is connected with the microprocessor within case 1 and also connected to one of the external connectors 10. Programming in the form of firmware allows the microprocessor to calculate the dissolved oxygen level on the basis of processed signals received from the fluid condition monitoring assembly or module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and user selection via keypad 3 of the time interval for recording data. A dissolved oxygen electrode station or sensor is selectively connected to the corresponding connector 10 for monitoring of dissolved oxygen levels. A more detailed description of the dissolved oxygen control assembly or module and dissolved oxygen electrode station is set out in the aforesaid U.S. Pat. No. 5,172,332.

By incorporating one or more of the fluid condition monitoring assemblies shown in FIGS. 16–19, the apparatus according to the invention may be adapted to monitor a number of different fluid conditions. To this end, the program storage memory of the computer control means of the apparatus may be programmed to perform the calculations necessary for a variety of different fluid conditions, and to allow for necessary calibration. As such, the program storage memory can be programmed to have a relatively universal capacity capable of processing inputs from a variety of different fluid condition sensors. It will be understood that the invention is not limited to the particular fluid conditions and sensors described above, and other suitable known sensors and corresponding interface electronics and programming may be employed for monitoring other conditions. With the multi-functional fluid monitoring and flow sensing capabilities of the invention, the user can choose to monitor and record data relating to a given fluid condition either independently of flow, or in conjunction with flow.

It will be further understood that the fluid flow monitoring apparatus of the invention may be selectively employed for use for flow monitoring only, for fluid condition monitoring only, or for monitoring both flow and fluid condition(s) simultaneously. These independent or dual operation modes can be effected by user input via keypad 3 to the microprocessor of the apparatus.

As shown in the diagram of FIG. 5, the multi-function fluid flow monitoring apparatus of the invention may also be capable of being linked with a variety of devices, such as an automatic sampling apparatus, a rain gauge, a pump, and the like. To this end, suitable interface electronics are provided, as shown in FIG. 5, which allow the microprocessor to operably communicate with the sampling apparatus, an external rain gauge, etc. The device interface electronics are in turn connected with the microprocessor of the apparatus, and suitable programming is provided to permit the apparatus to send control signals to the these device(s), as well as to receive and record data from same.

By way of example, the apparatus of the invention may be connected to an automatic sampler similar to that disclosed in the aforesaid U.S. Pat. Nos. 5,091,863 or 5,172,332. The user may then instruct the apparatus, via keypad 3, to initiate sampling operations by the automatic sampling unit on the basis of a fluid flow related variable, or on the basis of high, low, or a range of critical levels of fluid condition(s) as calculated by the microprocessor on the basis of inputs from one of the fluid condition monitoring modules.

The multi-function fluid flow monitoring apparatus according to the present invention may include a means for initiating a fluid sampling operation based upon at least one fluid parameter, and a means for substantially isolating one or more collected fluid samples from other collected samples. In this way, the present invention not only increases the likelihood of collecting an intermittent discharge containing a fluid flow related variable pertaining to an out-of-limit condition, but also substantially segregates the samples from other samples so as to reduce laboratory costs in analyzing numerous collected samples.

By way of one example, the apparatus collects fluid samples upon the detection of an out-of-limit condition pertaining to a first fluid variable, such as a flow related variable or a fluid condition variable, and stores the sample in a container into which samples pertaining to other fluid variables or to a timed sampling interval are prevented from being stored. Alternatively, a plurality of different fluid variables are monitored for collecting and storing fluid samples in separate isolated fluid reservoirs.

As shown in FIG. **32**, the fluid collecting means preferably but not necessarily comprises fluid reservoirs **100**; distributor mechanism **101**, which is operably pivotal about a substantially lateral axis so as to direct collected fluid into the desired reservoir **100**; and pump **102**, which is operably connected to distributor mechanism **101** so as to draw fluid therein based upon control signals generated by the apparatus microprocessor. By way of one example, there are **24** reservoirs **100**, one to four of which are dedicated for storing isolated fluid samples.

The fluid sample isolation means preferably but not necessarily includes programming means for allowing the user to designate the number of reservoirs **100** in which to store the isolated samples; to select the particular fluid variable to be monitored for the purposes of performing an isolated sampling operation, such as pH, dissolved oxygen content and conductivity; to select the control parameters or trigger point(s) pertaining to the selected fluid variable, the detection of which initiates the isolated sampling operation; and to select the ratio of collected fluid samples to designated isolated sampling reservoirs **100**, together with fluid volume setting controls for the reservoirs **100**. A representational flowchart detailing the a operational sequences is shown in FIG. **33** for the case of pH level being selected as the fluid variable which is monitored for isolation sampling.

Further, the present invention includes means for recording the time, date, and source of each isolated sample taken.

The fluid monitoring apparatus preferably but not necessarily includes means for maintaining collected samples of fluid at lowered temperatures, comprising an insulated housing; and means for cooling the housing to the desired temperature, including a thermostat, a compressor/condenser assembly and a forced air blower. Such an embodiment is substantially shown in FIG. **31**. In a second embodiment, the fluid monitoring and collecting apparatus is portable having an insulated housing for the collected samples and a space defined therein for receiving ice or other substantially frozen articles so as to maintain the collected samples at substantially refrigerated temperatures.

The apparatus according to the invention may be selectively connected to an external pump so as to initiate a pumping operation when the fluid rises above a predetermined level as input by the user via keypad **3**. It is further contemplated that the apparatus according to the invention may be selectively connected to an external rain guage. The computer control means of the apparatus may be provided with programming which permits the apparatus to initiate flow measurement based on rainfall as measured by signals received from the rain gauge, and or based on fluid depth and rainfall. Further, the apparatus is programmed to store rainfall data measured by the rain gauge in the RAM memory of the apparatus of the invention.

With further reference to FIGS. **5** and **31**, the fluid flow monitoring apparatus according to the invention is also desirably provided with at least one 4–20 mA output connection to enable the apparatus to form part of a current loop for driving a chart recorder or other external device. Preferably, an RS-232 standard type serial data interface and connection is also provided, to permit the apparatus to be connected with means for transferring recorded data as described below.

User Access to Stored Data

The user can request, via keypad **3**, that data stored in RAM, such as flow related data, fluid condition data, and/or other data gathered from external devices linked to the apparatus, be displayed on display **4** when desired. Further, the combined text and graphics display **4** permits the user to selectively view data either in graphics or tabular form.

The invention provides an alternative means for retrieving stored data in the form of a portable data transfer unit, indicated as a "DTU" in FIG. **5**. The portable data transfer unit is preferably very compact, i.e., pocket-sized, so that the user can conveniently carry same for selective use. The data transfer unit is provided with its own microprocessor, the memory of which may take the form of CMOS RAM chips powered by a lithium battery (battery backed-up RAM), or FLASH memory not requiting battery back-up. The data transfer unit is also preferably provided with its own user-input keypad and an alphanumeric display, and resembles a conventional small pocket calculator in overall appearance.

The data transfer unit is connected via a conventional connector cable (not shown) with the RS-232 serial connector. The user may then send an electronic data request command from the data transfer unit to the microprocessor of the apparatus. Upon receipt of such command, the microprocessor of the apparatus retrieves the requested data from its RAM and sends it for storage in the memory of the data transfer unit.

When it is desired to retrieve the data thus stored in the data transfer unit, the unit is in turn connected, via a standard computer or printer jack for example, to an external output device in the form of a conventional printer or computer (e.g., a personal computer). The stored data can be read out directly an a printer to produce a hard copy thereof, with the microprocessor of the data transfer unit itself operating the printer in a known manner. The user is thus able to obtain a complete and accurate hard copy record of the data. Alternatively, the stored data can be transferred to a conventional computer for manipulation using an available software program for statistical analyses, spreadsheet, etc.; for more permanent storage in a database stored in the computer's memory; and/or for printing by a printer connected to the computer.

As also shown in FIG. **5**, an alternative data transfer means may be provided in the form of a modem which is built-in to the apparatus and provided with a standard external connector. The modem may comprise, for example, an FCC approved, 2400 baud modem with X modem feature. By virtue of the built-in modem, the apparatus can be linked by telephone line to a modem in a remote computer to permit immediate, long-distance transfer of stored data from a monitoring site.

Further, the fluid monitor apparatus preferably but not necessarily includes an alarm system for alerting the user of the occurrence of any of a number of events. As shown in FIG. **31**, these alarms are preferably but not necessarily classified into two categories—alarms which are activated upon the occurrence of an out-of-range condition pertaining to one or more preselected fluid variables, and alarms pertaining to the effective operation of the apparatus. As to the latter category, an alarm may be activated upon the detection of a low battery, a modem failure, a missed sample, a purge failure, or a jammed distributor. The alarms may preferably set a relay or generate a report via the modem or RS-232 line, and may be selectively enabled.

Although it may not always be practical, the apparatus can alternatively be directly linked to a remote computer (e.g., a laptop computer) for direct transfer of the stored data from the apparatus to the computer.

It will be understood from the foregoing that the fluid monitoring apparatus according to the invention not only affords the unique capability of monitoring fluid flow on the basis of any desired one of a variety of different types of fluid flow sensor systems, but is also multi-functional in that it is capable of performing non-flow related operations such as fluid condition monitoring. The apparatus thus offers the user a wide variety of monitoring features in a single compact unit which is conveniently transported and easy to use.

While there have been described hereinabove what are at present considered to be the preferred embodiments of the invention, it will be understood that various modifications may be made therein without departing from the spirit and scope of the invention. The present embodiments are therefore to be considered in all respects as illustrative, and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description.

We claim:

1. A fluid velocity measurement device, comprising:

means for transmitting an ultrasonic signal throughout a channel in which fluid flows;

means for receiving a reflection of said ultrasonic signal, said reflected signal including signals which are shifted in frequency from said transmitted ultrasonic signal;

means for generating an electrical signal from said reflected ultrasonic signal;

first mixing means for mixing said reflected electrical signal with a signal having a frequency which is proportional to a frequency of said transmitted signal;

first filtering means for filtering an output of said first mixing means so as to pass an audio band signal representative of said frequency shifted signal;

means responsive to an output signal of said first filtering means, for substantially sequentially extracting energy levels therefrom at preselected frequencies within said audio band;

means for computing an average fluid velocity value from said extracted energy levels;

means for calculating a maximum velocity of fluid flow from said output signal of said first filtering means;

means for verifying said computed average fluid velocity value based upon said maximum fluid velocity calculation; and

means for reporting a value representing average fluid velocity in said channel based upon an output of said verifying means.

2. A device as recited in claim 1, wherein:

said reporting means reports said computed average fluid velocity value if said computed average fluid velocity value is substantially proximal to said calculated maximum velocity value, and reports substantially said maximum velocity value if said average fluid velocity value is not substantially comparable to said maximum velocity value.

3. A device as recited in claim 1, wherein:

said maximum velocity calculating means comprises a means for digitizing said output signal of said first filtering means, means for receiving an output signal of said digitizing means and for measuring a time duration of a plurality of substantially consecutive time periods thereof.

4. A device as recited in claim 3, wherein:

said maximum velocity calculating means further includes means for selecting from said consecutive measured time periods those periods having the smallest duration, means for averaging said time periods having the smallest duration and for converting said average time duration to velocity, and means for reporting said converted velocity value as said maximum fluid velocity value.

5. A device as recited in claim 1, wherein:

said average fluid velocity computing means includes a means for determining direction of fluid flow.

6. A device as recited in claim 1, wherein:

said energy level extracting means comprises a means for generating an oscillating signal having a frequency proportional to a first input thereof; second mixing means for mixing said output signal from said first filtering means with an output from said oscillating means; second filtering means for filtering an output from said second mixing means so as to pass frequencies at an intermediate frequency; processing means for providing a plurality of values substantially sequentially to said first input of said oscillating means; and means for storing an output of said second filtering means.

7. A device as recited in claim 6, wherein:

said oscillating means comprises a voltage controlled oscillator; and

said processing means comprises a software controlled microprocessor.

8. A device as recited in claim 2, wherein:

said reporting means reports said computed average fluid velocity value if said computed average fluid velocity value is greater than approximately 72% of said calculated maximum fluid velocity value, and reports substantially said calculated maximum velocity value if said computed average fluid velocity value is less than approximately 72% of said calculated maximum velocity value.

9. A device as recited in claim 8, wherein:

said reporting means reports approximately 90% of said calculated maximum velocity value if said computed average fluid velocity value is less than approximately 72% of said calculated maximum velocity value.

10. A device as recited in claim 3, wherein:

said time duration measuring means comprises a timer circuit and means for programmably controlling said timer circuit.

11. A device as recited in claim 1, wherein:

said energy level extracting means comprises a microprocessor and a swept tuned local oscillator controlled by said microprocessor.

12. A device as recited in claim 5, wherein:

said fluid flow direction means comprises a third mixing means for mixing said reflected electrical signal with a signal having a frequency which is proportional to a frequency of said transmitted signal and being shifted in phase therefrom, third filtering means for filtering an output of said third mixing means so as to pass a signal at a second intermediate frequency, and a means for detecting a phase difference between said first filtering means output and said third filtering means output.

13. An apparatus for monitoring at least one variable related to fluid in a channel, comprising:

an integral operating unit provided in a unitary case, said integral operating unit including computer means for controlling said apparatus and input means for receiving detected signals related to said fluid variable in said channel;

said input means being selectively connectable to any selected one or more of a plurality of different types of fluid-sensing means for producing signals related to said fluid variable in said channel;

said integral operating unit further including means for processing said signals from each of said plurality of different types of fluid sensing means, for input to said computer means;

said computer means comprising a microprocessor, program memory, and data memory, wherein:

said data memory stores user-selected input parameters including at least one fluid-related parameter; and

said microprocessor receives said signals related to said fluid from said processing means and calculates values of said fluid-related variable based on

said signals and said user-input fluid-related parameter;

means for automatically sampling fluid from said channel and for storing said collected samples;

said user-selected input parameters include a predetermined value of said fluid-related variable;

said microprocessor generates control signals to initiate sampling operations by said automatic sampling means on the basis of said user-input predetermined value of said fluid-related variable or on the basis of a preselected time interval; and

means for storing a fluid sample which is substantially isolated from other collected fluid samples.

14. An apparatus as recited in claim 13, further including:

means for maintaining collected fluid samples in said storing means at preselected temperatures.

15. An apparatus as recited in claim 14, wherein:

a portion of said unitary case is substantially insulated for storing collected fluid samples; and

said temperature maintaining means includes a means for refrigerating said insulated portion of said unitary case.

16. An apparatus as recited in claim 13, wherein:

said collected sample storing means comprises a plurality of reservoirs; and

said sample isolating means includes means for designating a number of said reservoirs for storing collected samples based upon a user-input predetermined value of said fluid-related variable, and for preventing collected samples pertaining to other fluid variables from being stored in said designated reservoirs.

17. An apparatus as recited in claim 13, wherein:

said computer means includes means for determining average fluid velocity within said channel, comprising:

a transducer for transmitting an ultrasonic signal and receiving a reflection thereof, said reflected signal having a frequency shifted component related to velocity of fluid flow;

first means for mixing said reflected signal;

means for filtering an output of said first means so as to extract said frequency shifted component therefrom;

means, responsive to said filtering means, for sequentially extracting energy levels of said frequency shifted component at preselected frequencies;

means for storing said energy levels; and

means for calculating average fluid velocity based upon said extracted energy levels of said frequency shifted component of said reflected signal.

18. An apparatus as recited in claim 17, wherein:

said average fluid velocity determining means includes means, responsive to an output of said filtering means, for calculating maximum fluid velocity in said channel, means for comparing said calculated average fluid velocity with said calculated maximum fluid velocity, and means for reporting a value representing average fluid velocity based upon said comparison.

19. An apparatus as recited in claim 18, wherein:

said maximum fluid velocity calculating means comprises a means for measuring and storing consecutive time periods of said frequency shifted component, means for selecting the smallest of said measured time periods, and means for averaging said smallest time periods.

20. An apparatus as recited in claim 17, wherein:

said sequential energy level extracting means comprises a swept tuned local oscillator, controlled by said microprocessor.

21. A device as recited in claim 1, further including:

means for sampling fluid flowing in said channel based upon said reported average fluid velocity value; and

means for storing fluid samples.

22. A device as recited in claim 21, wherein:

said fluid sampling means comprises a means for selecting one or more parameters related to fluid in said channel, means for comparing said fluid parameter to said reported average fluid velocity value, and means for initiating a fluid sample operation based upon said comparison.

23. A device as recited in claim 21, wherein:

said storing means selectively maintains collected fluid samples at any one of a plurality of temperatures.

24. A device as recited in claim 23, wherein:

a portion of said storing means is substantially insulated; and

said storing means includes a means for refrigerating said insulated portion of said storing means.

25. A device as recited in claim 22, wherein:

said storing means includes a means for storing a fluid sample which is substantially isolated from other collected fluid samples.

26. A device as recited in claim 25, wherein:

said fluid sample isolation means comprises a plurality of fluid containers, a means for designating a number of said fluid containers for storing collected samples based upon one of said selected fluid parameters of said fluid in said channel, and a means for substantially preventing collected samples pertaining to other said selected fluid parameters from being stored in said designated fluid containers.

27. A fluid velocity measurement device, comprising:

means for transmitting a signal throughout a channel in which fluid flows;

means for receiving a reflection of said signal, said reflected signal including signals which are shifted in frequency from said transmitted signal;

means for generating an electrical signal from said reflected signal;

first mixing means for mixing said electrical signal;

first filtering means for filtering an output of said first mixing means;

means responsive to an output signal of said first filtering means, for calculating energy levels thereof at selected frequencies;

means for computing an average fluid velocity value from said calculated energy levels; and

means for calculating a maximum velocity of fluid flow from said output signal of said first filtering means.

* * * * *

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United States Patent [19]

Hungerford et al.

[11] Patent Number: 5,506,791

[45] Date of Patent: Apr. 9, 1996

[54] MULTI-FUNCTION FLOW MONITORING APPARATUS WITH MULTIPLE FLOW SENSOR CAPABILITY

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[73] Assignee: **American Sigma, Inc.**, Medina, N.Y.

[21] Appl. No.: **219,097**

[22] Filed: **Mar. 29, 1994**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 954,288, Sep. 30, 1992, Pat. No. 5,299,141, which is a continuation-in-part of Ser. No. 612,832, Nov. 13, 1990, Pat. No. 5,172,332, which is a continuation-in-part of Ser. No. 455,981, Dec. 22, 1989, Pat. No. 5,091,863.

[51] **Int. Cl.**[6] **G01F 11/00**; G01F 11/28

[52] **U.S. Cl.** **364/510**

[58] **Field of Search** 364/509, 510; 73/863.01, 863, 863.02, 863.03, 863.34; 141/1, 89, 91, 94, 130; 422/82.11, 98; 385/12

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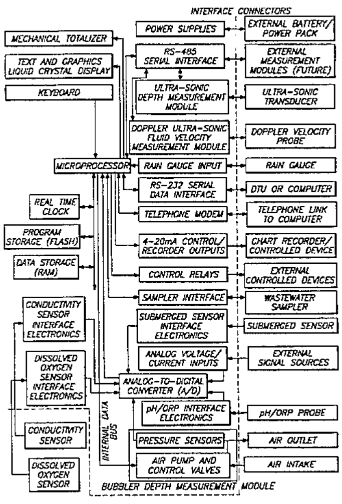
Primary Examiner—Ellis B. Ramirez
Attorney, Agent, or Firm—Weiner, Carrier & Burt; Irving M. Weiner; Pamela S. Burt

[57] **ABSTRACT**

A multi-function fluid flow monitoring apparatus capable of measuring fluid flow-related variables of fluid in a channel on the basis of signals from any one or more of a plurality of different types of flow sensors. Such different types of flow sensors may include, for example, a bubbler-type pressure sensor, a submerged pressure transducer, an ultrasonic transducer, and/or a velocity sensor forming part of an area-velocity sensor system, each of which sensors may be selectively connected to the apparatus as needed to accommodate various monitoring conditions. The apparatus is further capable of monitoring various conditions of fluid in the channel, such as pH level, ORP, temperature, solution conductivity, dissolved oxygen, and the like. In addition, the apparatus may be selectively linked with one of a variety of external devices, such as an automatic sampling apparatus, a rain gauge, or a pump, so as to selectively initiate desired actions by such external device(s) or to otherwise operably cooperate with such external device(s). The multi-function apparatus comprises an integral operating unit provided in a unitary case. The integral operating unit includes a computer control system including a microprocessor, program memory, and data memory. External connectors are provided for selective connection to one or more different flow sensors, fluid condition sensors, and/or external devices. Signals from the flow sensor(s) and/or fluid condition sensor(s) are received and processed by the computer control system, as are signals from, and/or operations by, external devices linked to the apparatus. The apparatus further includes a display screen, controlled by the computer control system, which selectively displays data in either text or graphics formats. Data including flow-related data, fluid condition data, as well as data from external devices, may be transferred from the data memory of the apparatus to an external computer, printer, or the like by use of a hand-held data transfer unit or a modem integrally provided in the apparatus.

60 Claims, 15 Drawing Sheets



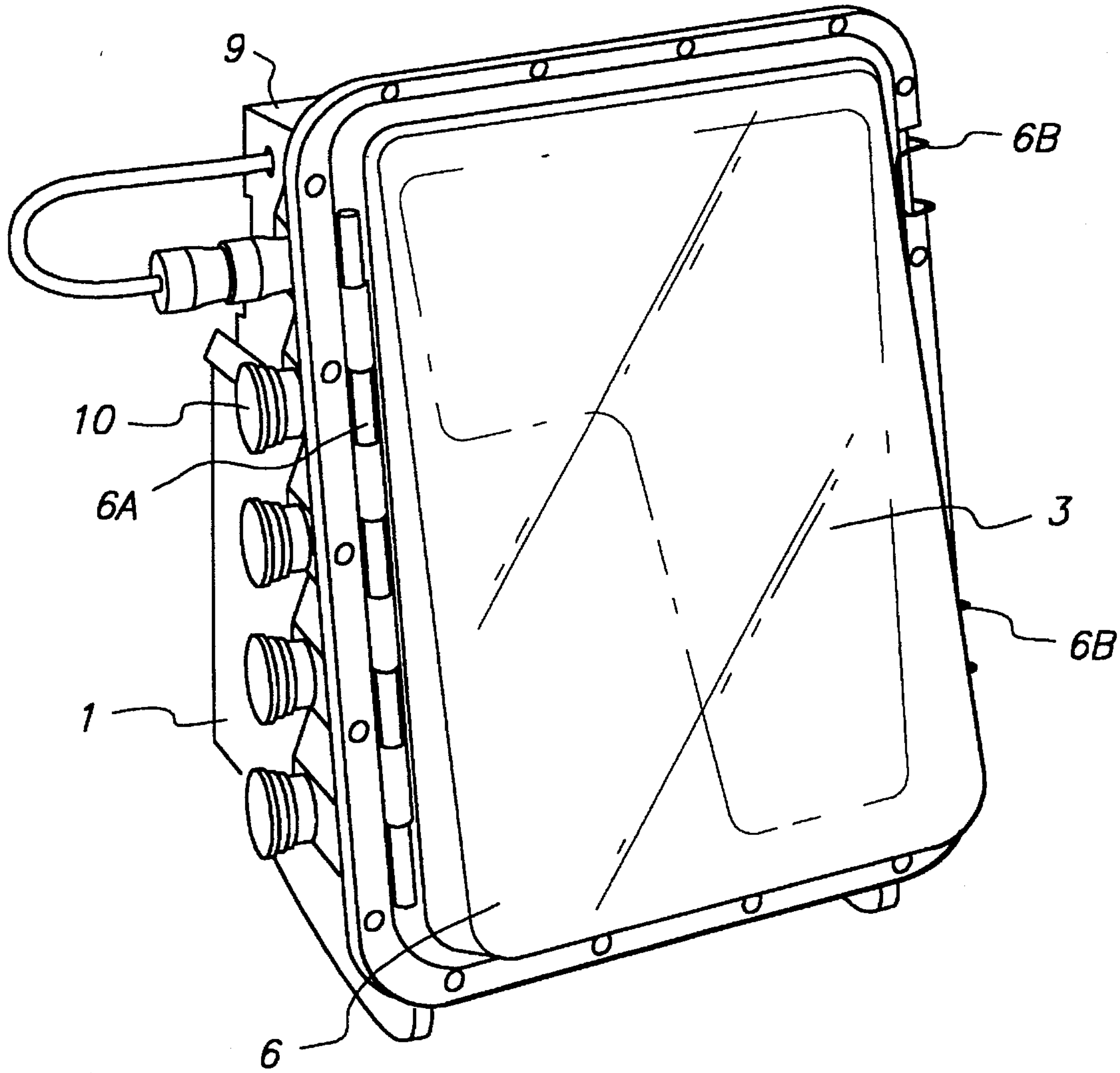


FIG. 1

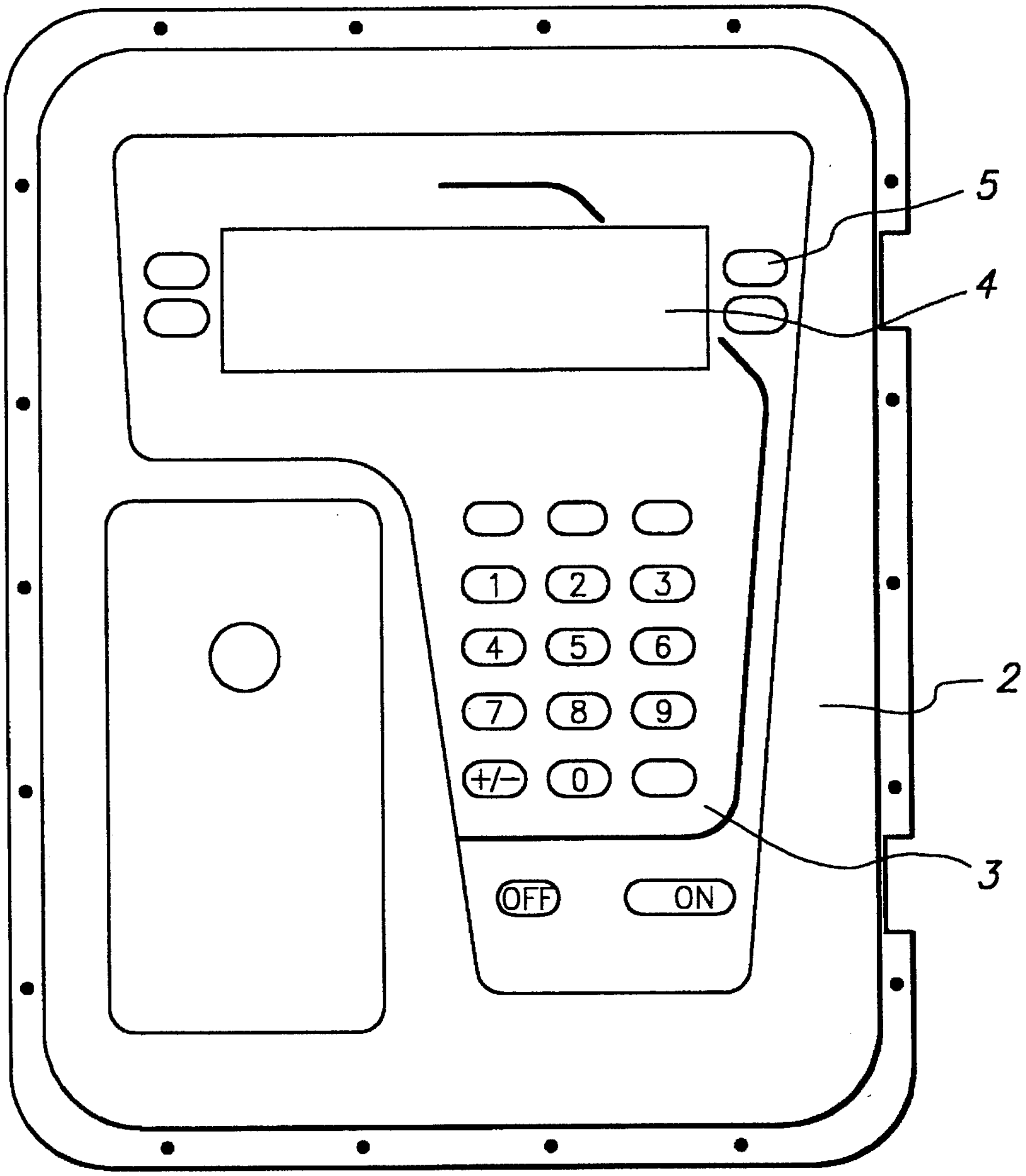


FIG. 2

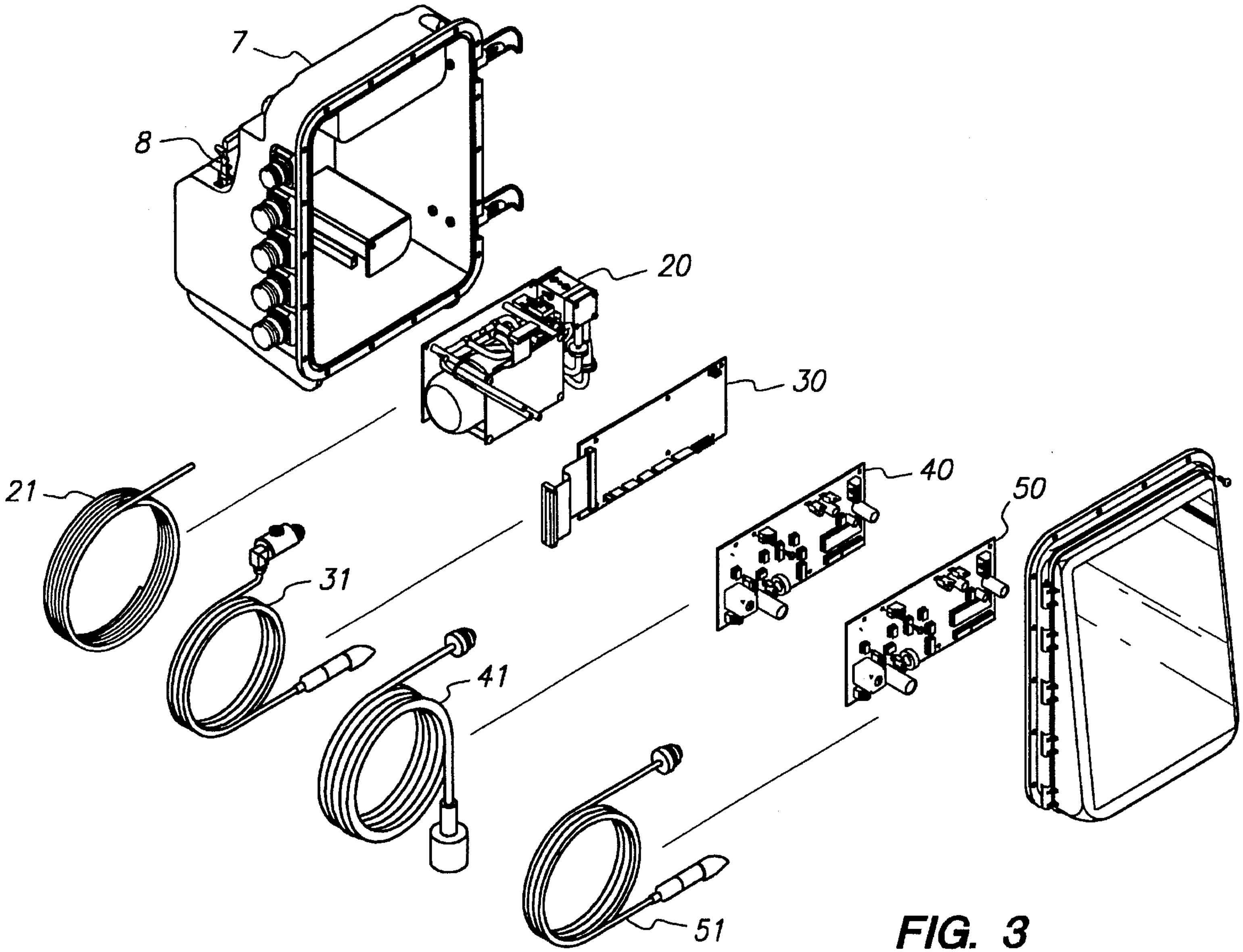


FIG. 3

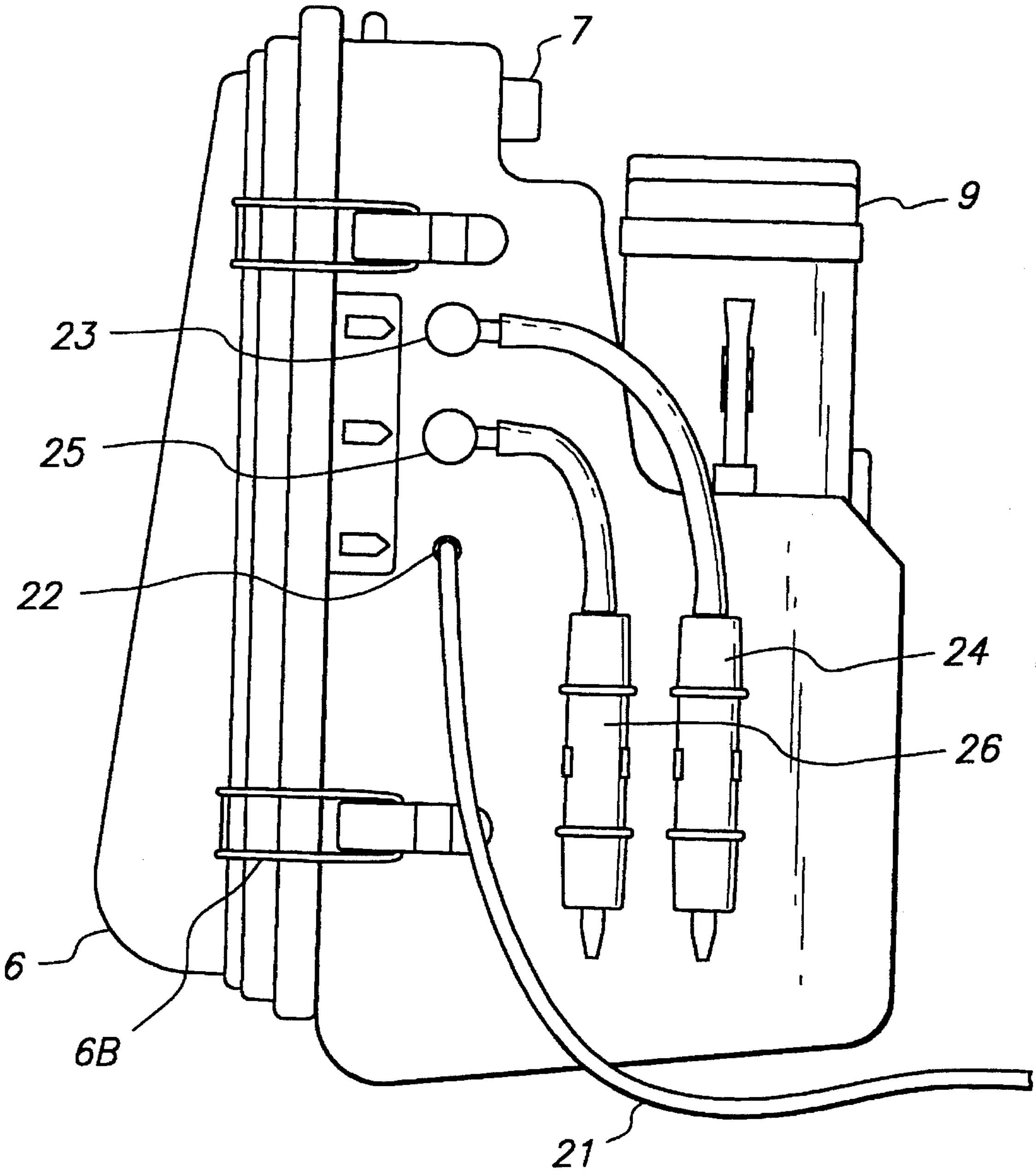
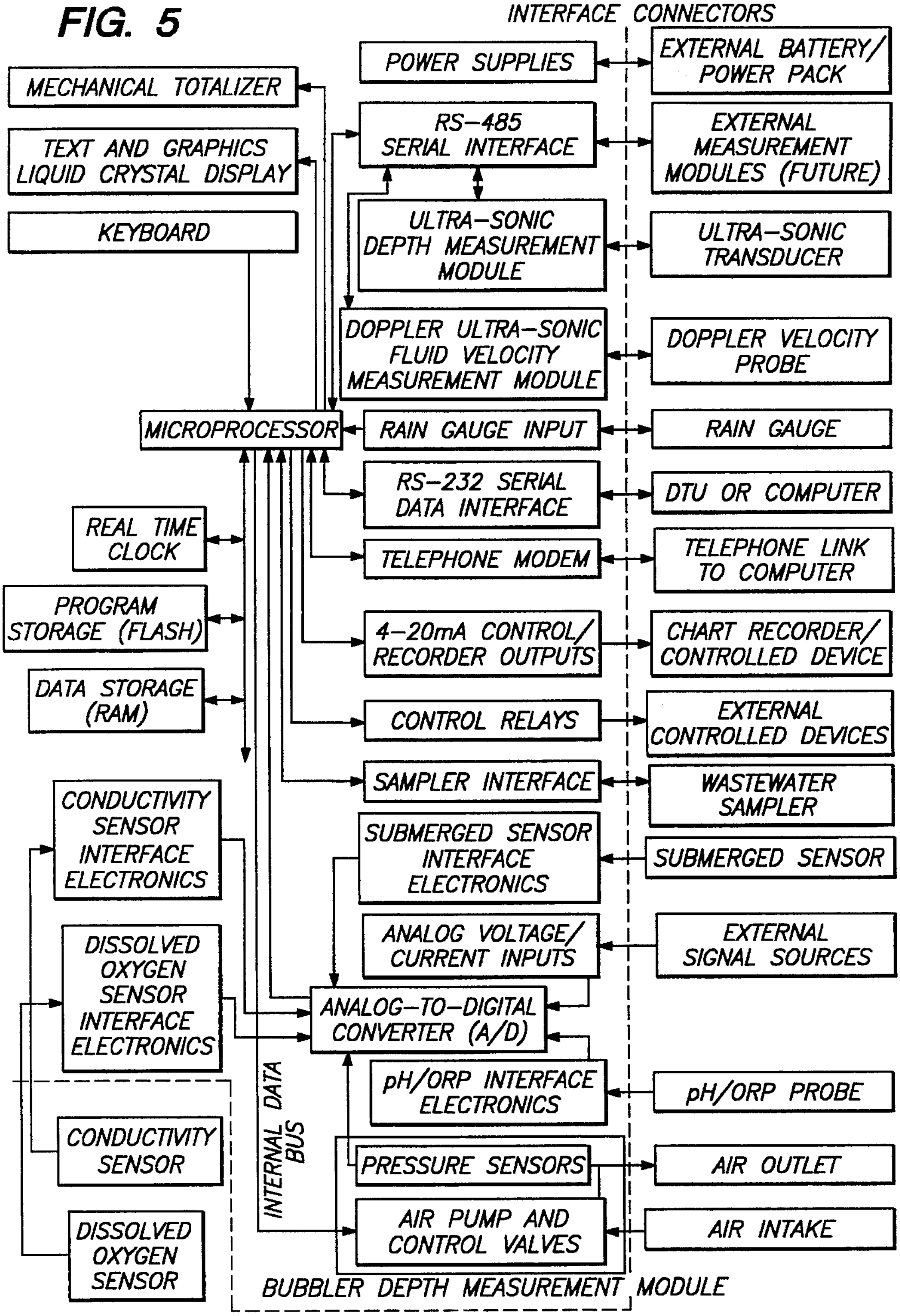


FIG. 4

FIG. 5


INTERFACE CONNECTORS
POWER SUPPLIES
EXTERNAL BATTERY/ POWER PACK
MECHANICAL TOTALIZER
RS-485 SERIAL INTERFACE
EXTERNAL MEASUREMENT MODULES (FUTURE)
TEXT AND GRAPHICS LIQUID CRYSTAL DISPLAY
KEYBOARD
ULTRA-SONIC DEPTH MEASUREMENT MODULE
ULTRA-SONIC TRANSDUCER
DOPPLER ULTRA-SONIC FLUID VELOCITY MEASUREMENT MODULE
DOPPLER VELOCITY PROBE
MICROPROCESSOR
RAIN GAUGE INPUT
RAIN GAUGE
RS-232 SERIAL DATA INTERFACE
DTU OR COMPUTER
REAL TIME CLOCK
TELEPHONE MODEM
TELEPHONE LINK TO COMPUTER
PROGRAM STORAGE (FLASH)
4-20mA CONTROL/ RECORDER OUTPUTS
CHART RECORDER/ CONTROLLED DEVICE
DATA STORAGE (RAM)
CONTROL RELAYS
EXTERNAL CONTROLLED DEVICES
SAMPLER INTERFACE
WASTEWATER SAMPLER
CONDUCTIVITY SENSOR INTERFACE ELECTRONICS
SUBMERGED SENSOR INTERFACE ELECTRONICS
SUBMERGED SENSOR
ANALOG VOLTAGE/ CURRENT INPUTS
EXTERNAL SIGNAL SOURCES
DISSOLVED OXYGEN SENSOR INTERFACE ELECTRONICS
ANALOG-TO-DIGITAL CONVERTER (A/D)
INTERNAL DATA BUS
pH/ORP INTERFACE ELECTRONICS
pH/ORP PROBE
CONDUCTIVITY SENSOR
PRESSURE SENSORS
AIR OUTLET
AIR PUMP AND CONTROL VALVES
AIR INTAKE
DISSOLVED OXYGEN SENSOR
BUBBLER DEPTH MEASUREMENT MODULE

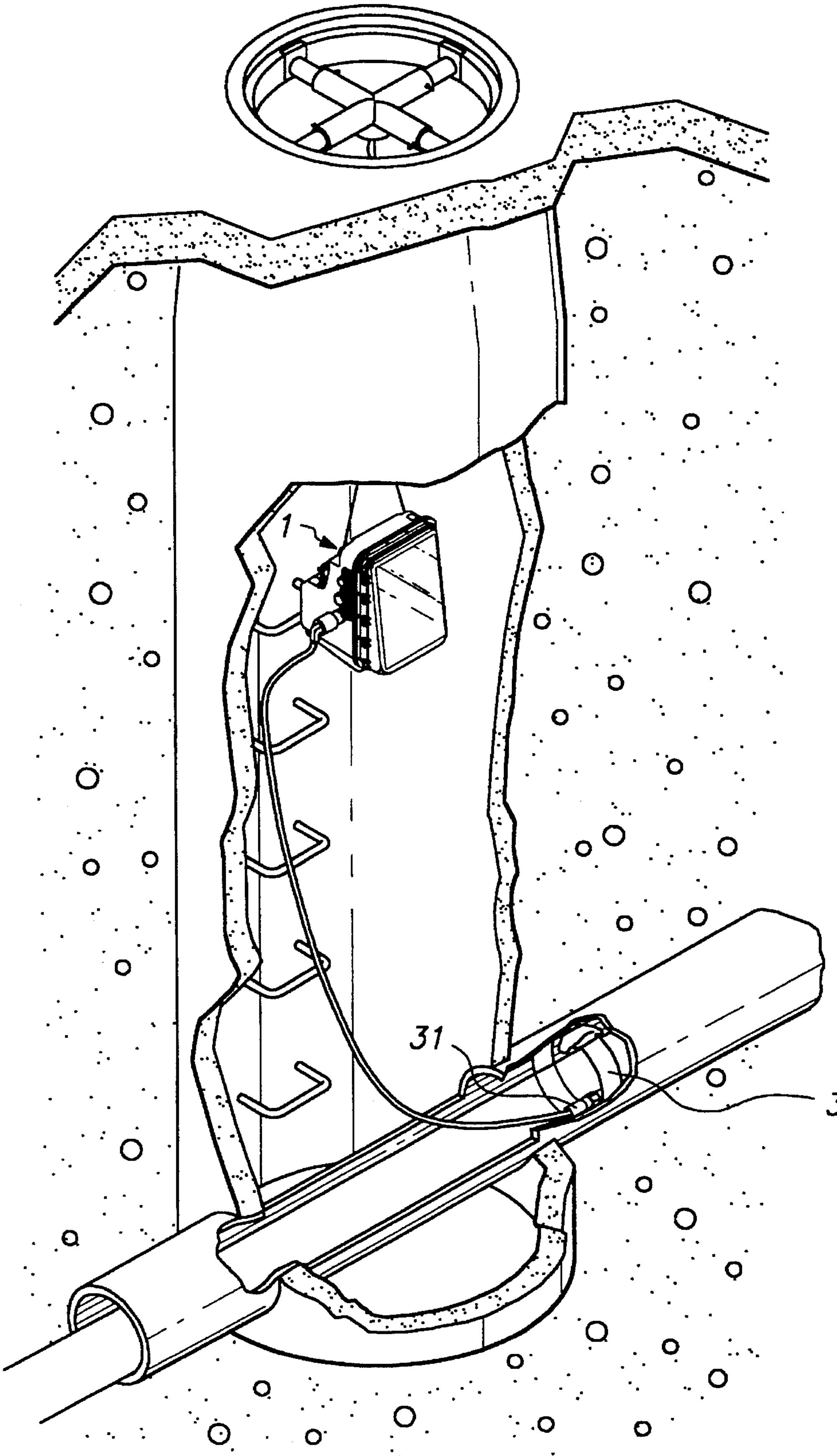


FIG. 6

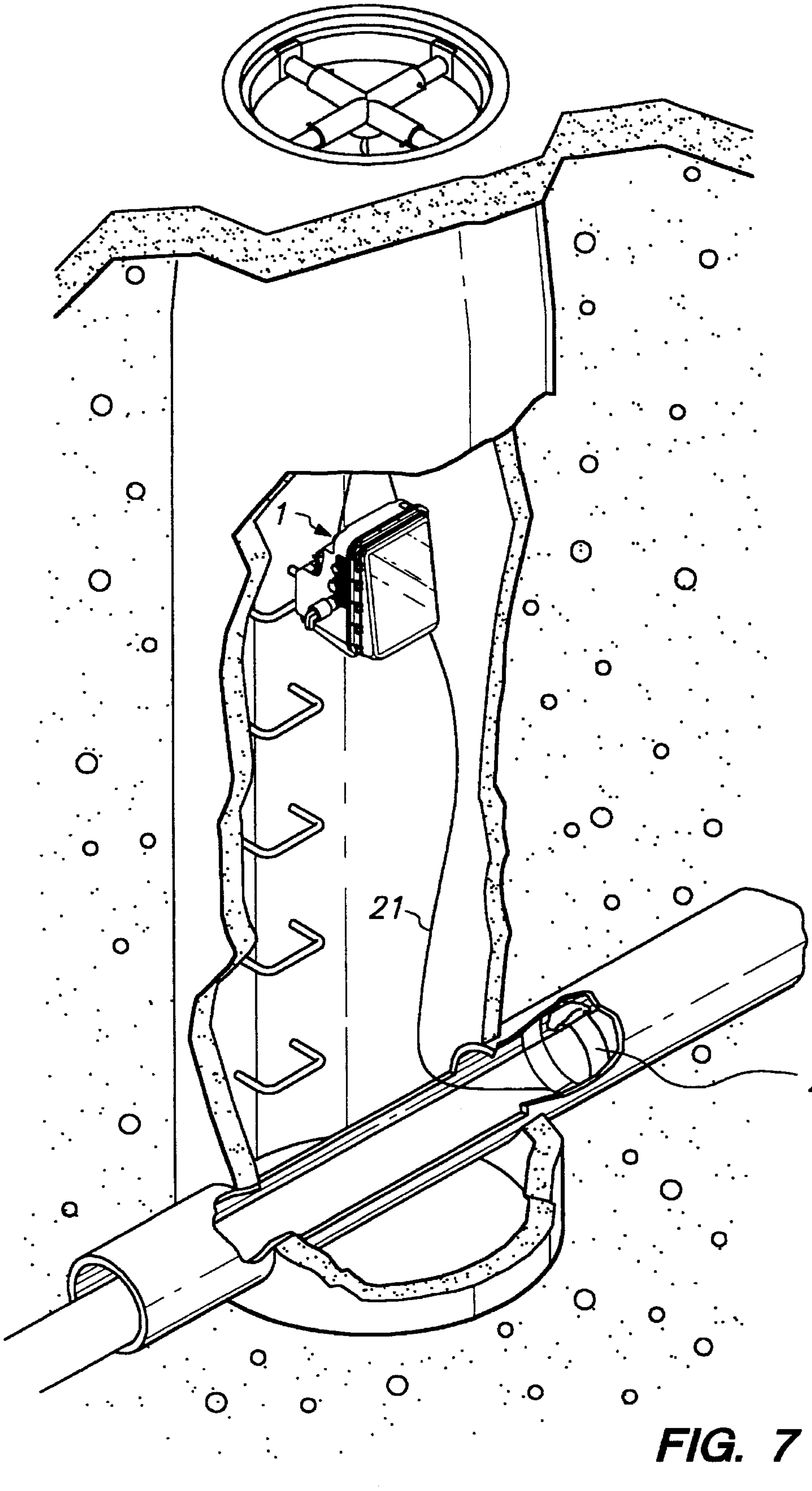


FIG. 7

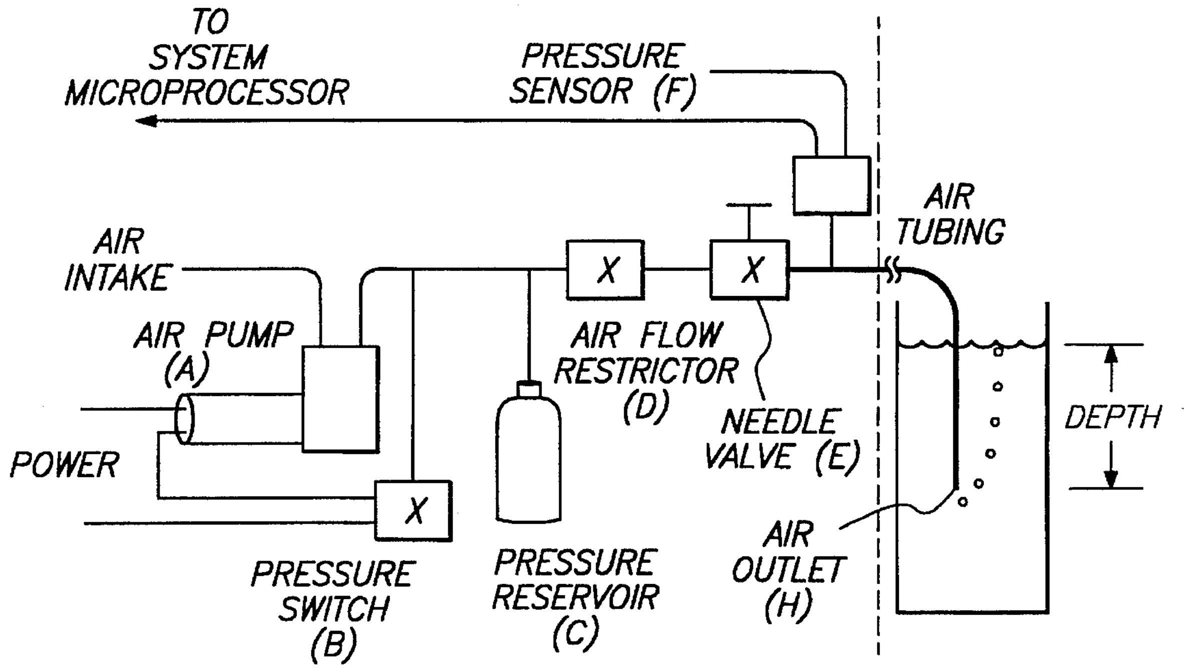


FIG. 8
PRIOR ART

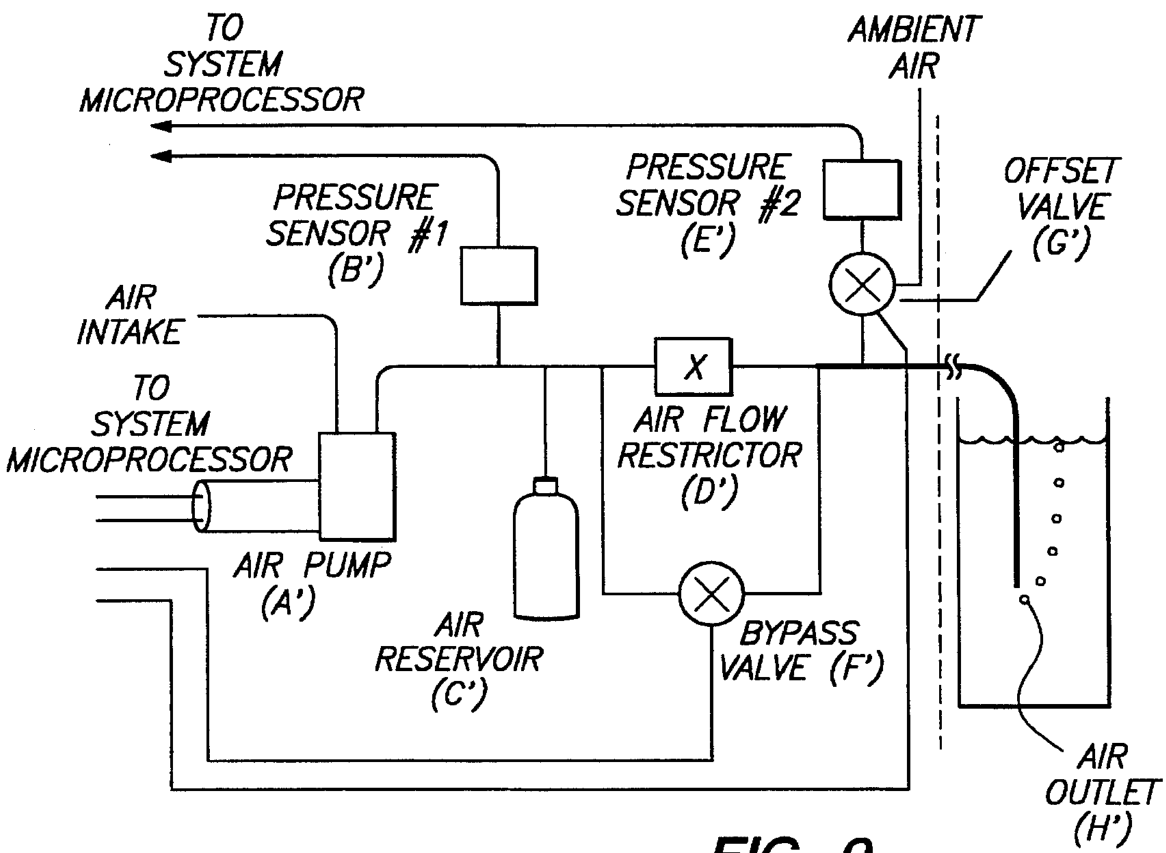


FIG. 9

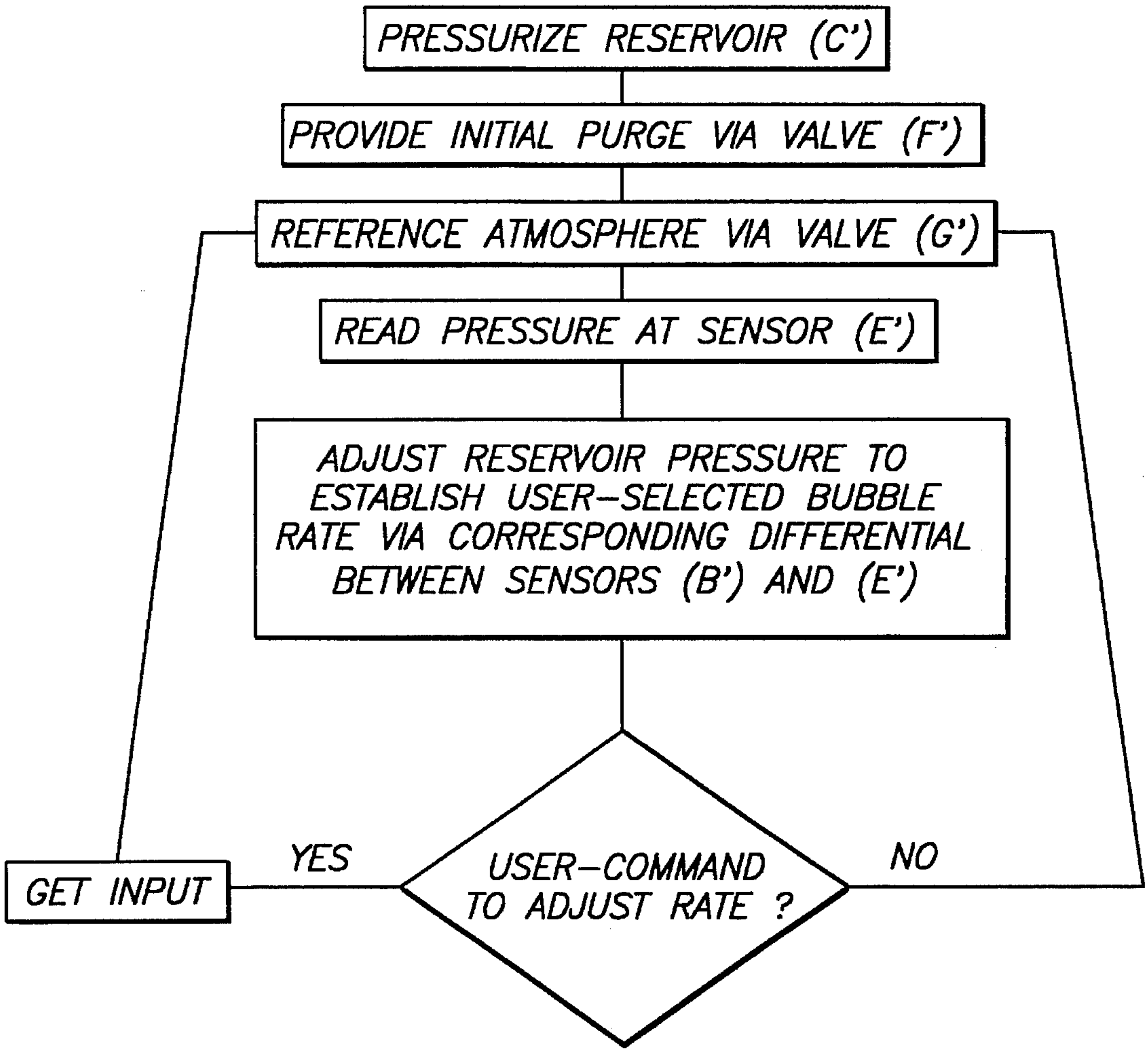

PRESSURIZE RESERVOIR (C')
PROVIDE INITIAL PURGE VIA VALVE (F')
REFERENCE ATMOSPHERE VIA VALVE (G')
READ PRESSURE AT SENSOR (E')
ADJUST RESERVOIR PRESSURE TO ESTABLISH USER–SELECTED BUBBLE RATE VIA CORRESPONDING DIFFERENTIAL BETWEEN SENSORS (B') AND (E')
USER–COMMAND TO ADJUST RATE ?
YES
NO
GET INPUT

FIG. 10

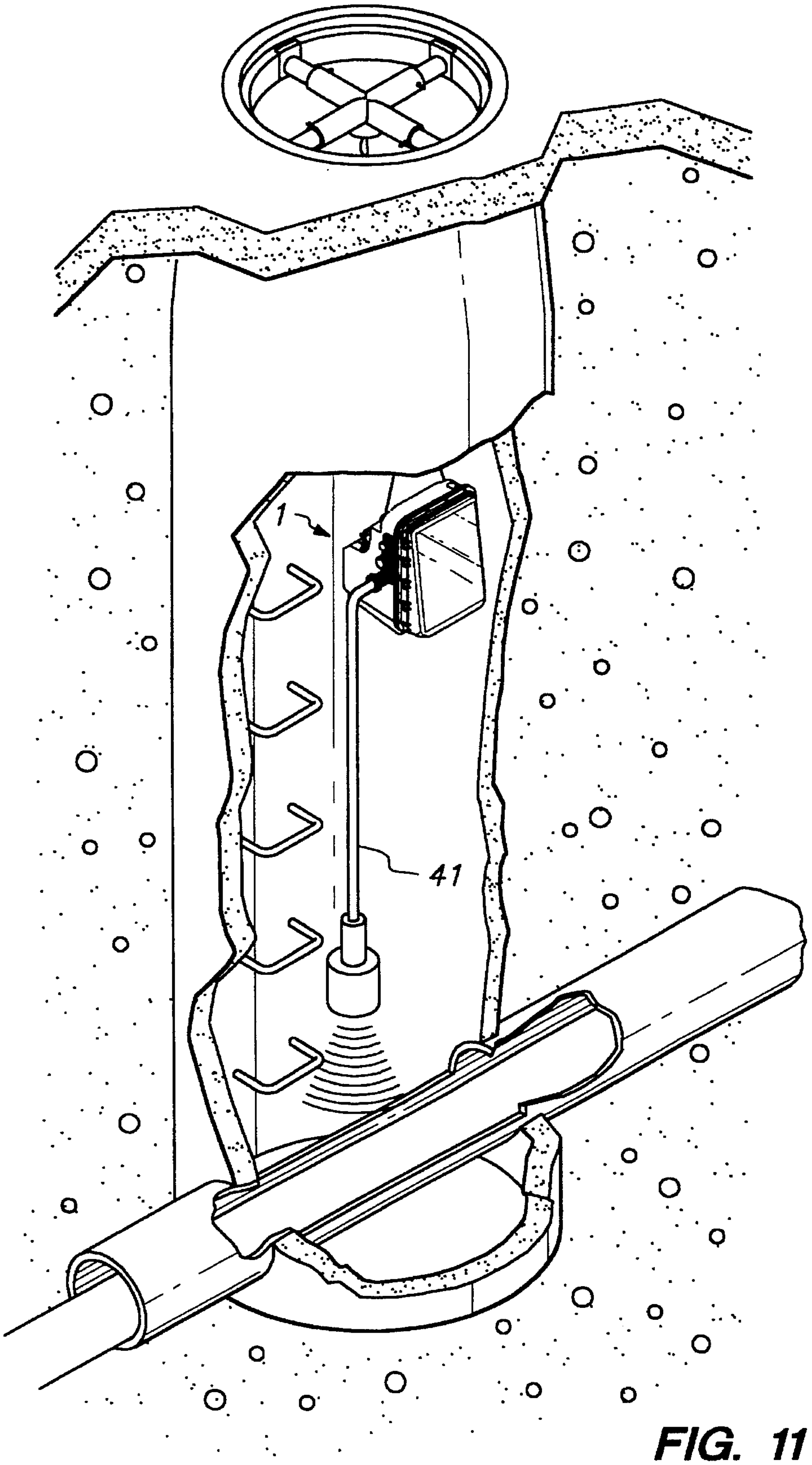


FIG. 11

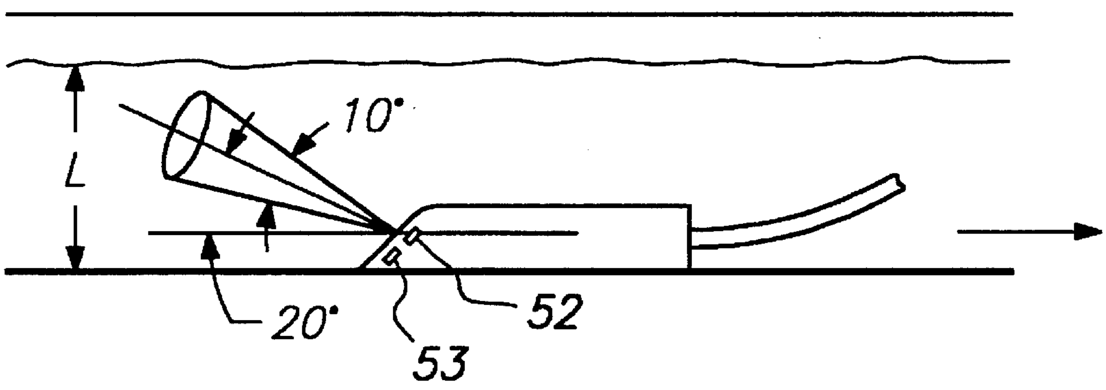


FIG. 12

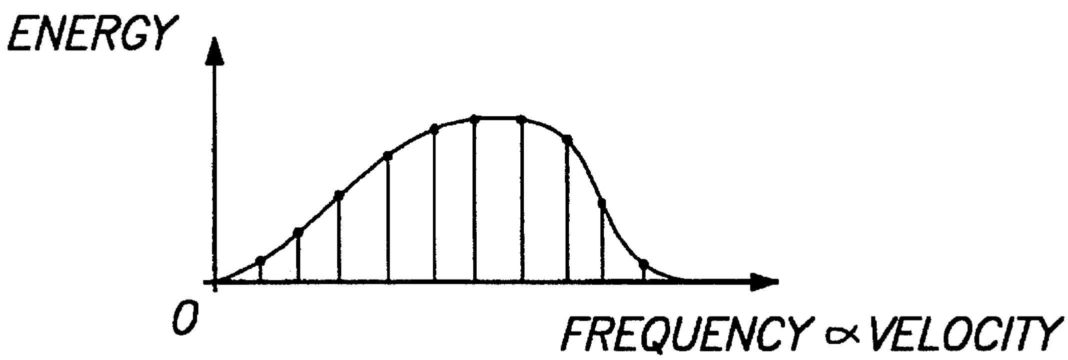


FIG. 13

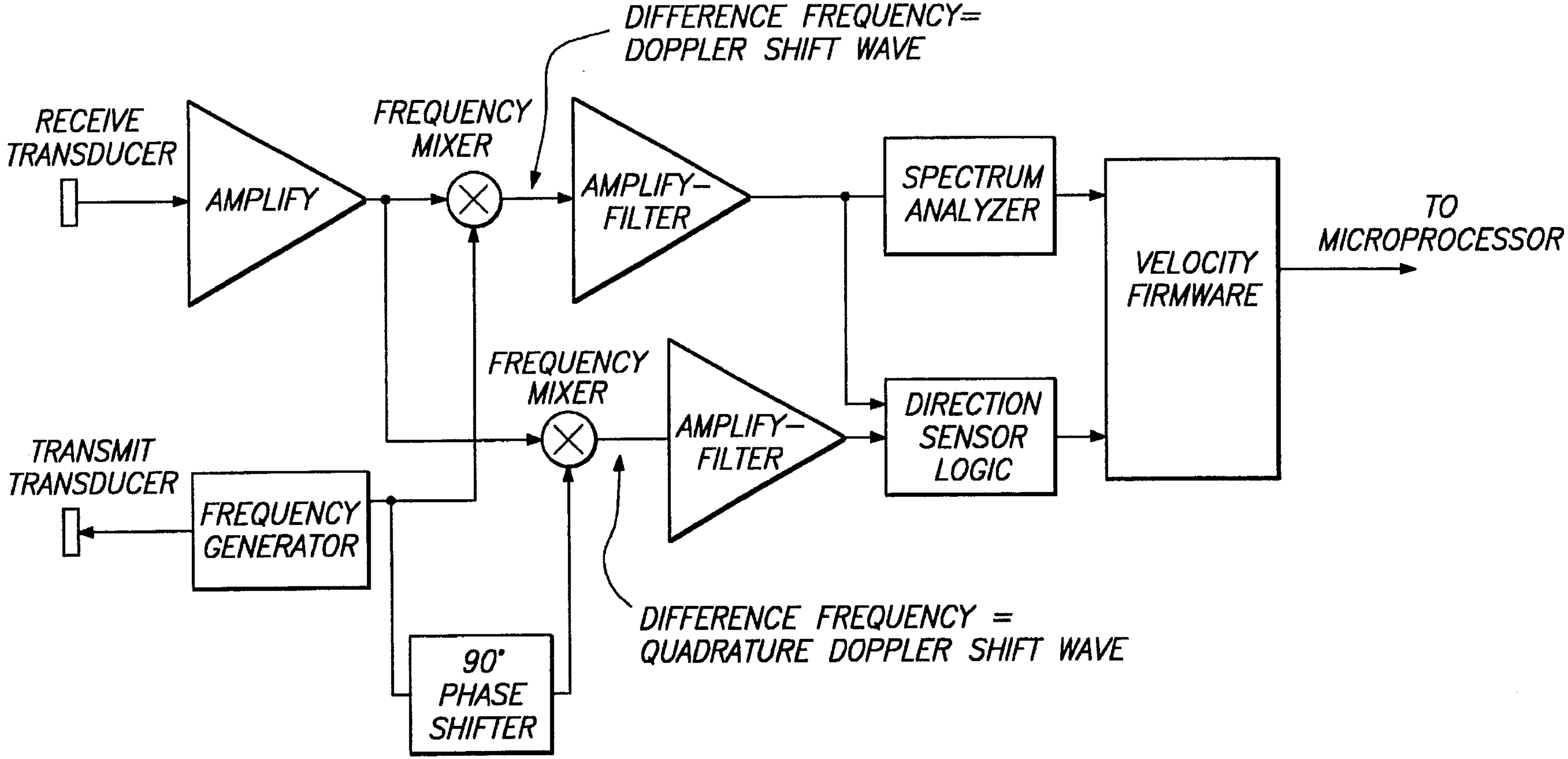

DIFFERENCE FREQUENCY= DOPPLER SHIFT WAVE
RECEIVE TRANSDUCER
AMPLIFY
FREQUENCY MIXER
AMPLIFY–FILTER
SPECTRUM ANALYZER
VELOCITY FIRMWARE
TO MICROPROCESSOR
FREQUENCY MIXER
AMPLIFY–FILTER
DIRECTION SENSOR LOGIC
TRANSMIT TRANSDUCER
FREQUENCY GENERATOR
90° PHASE SHIFTER
DIFFERENCE FREQUENCY = QUADRATURE DOPPLER SHIFT WAVE

FIG. 14

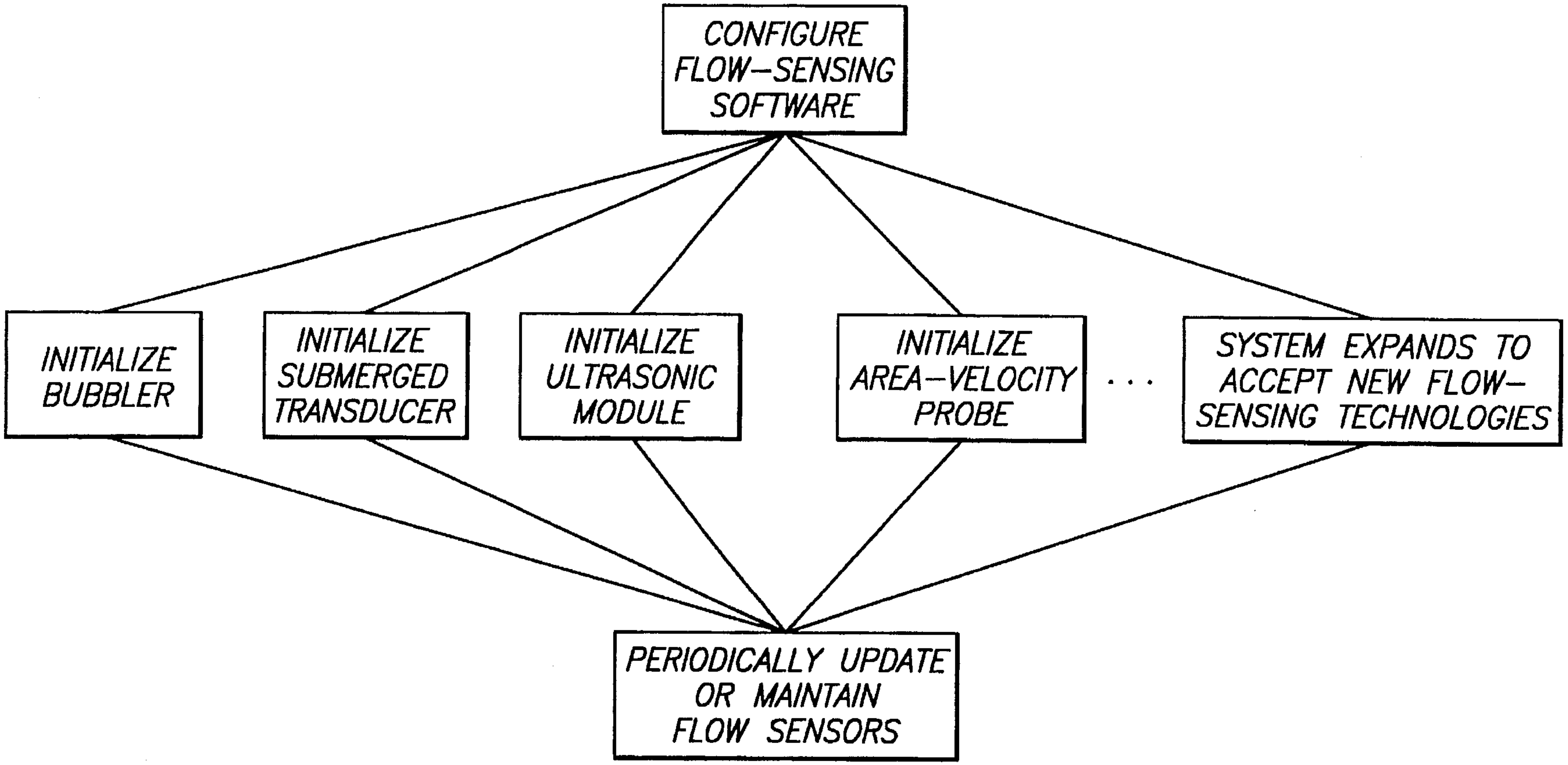

CONFIGURE FLOW–SENSING SOFTWARE
INITIALIZE BUBBLER
INITIALIZE SUBMERGED TRANSDUCER
INITIALIZE ULTRASONIC MODULE
INITIALIZE AREA–VELOCITY PROBE
. . .
SYSTEM EXPANDS TO ACCEPT NEW FLOW–SENSING TECHNOLOGIES
PERIODICALLY UPDATE OR MAINTAIN FLOW SENSORS

FIG. 15

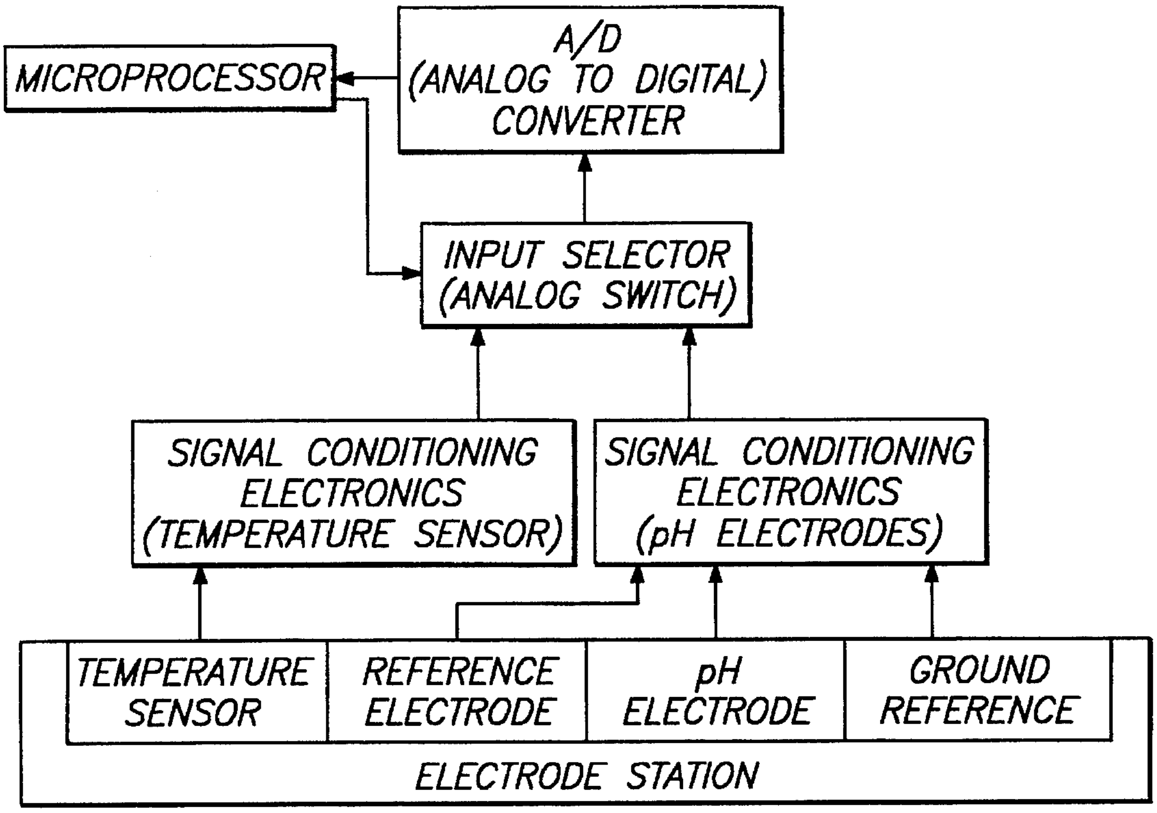

A/D
(ANALOG TO DIGITAL)
CONVERTER
MICROPROCESSOR
INPUT SELECTOR
(ANALOG SWITCH)
SIGNAL CONDITIONING
ELECTRONICS
(TEMPERATURE SENSOR)
SIGNAL CONDITIONING
ELECTRONICS
(pH ELECTRODES)
TEMPERATURE
SENSOR
REFERENCE
ELECTRODE
pH
ELECTRODE
GROUND
REFERENCE
ELECTRODE STATION

FIG. 16

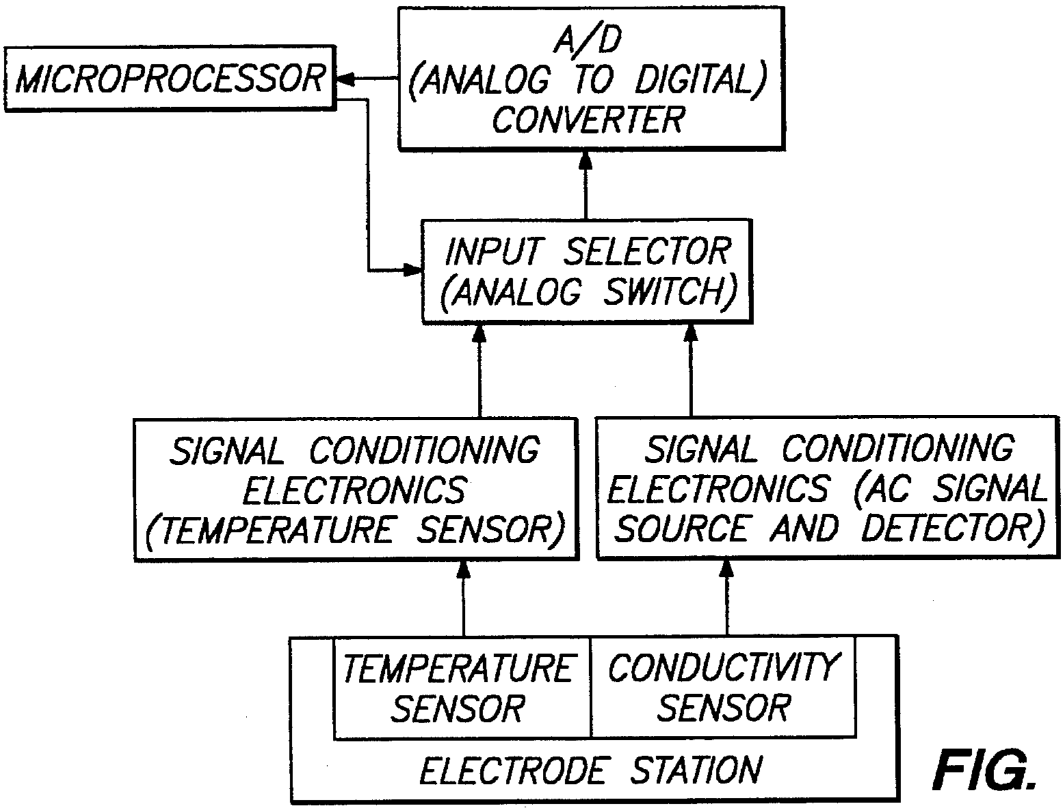

A/D
(ANALOG TO DIGITAL)
CONVERTER
MICROPROCESSOR
INPUT SELECTOR
(ANALOG SWITCH)
SIGNAL CONDITIONING
ELECTRONICS
(TEMPERATURE SENSOR)
SIGNAL CONDITIONING
ELECTRONICS (AC SIGNAL
SOURCE AND DETECTOR)
TEMPERATURE
SENSOR
CONDUCTIVITY
SENSOR
ELECTRODE STATION

FIG. 17

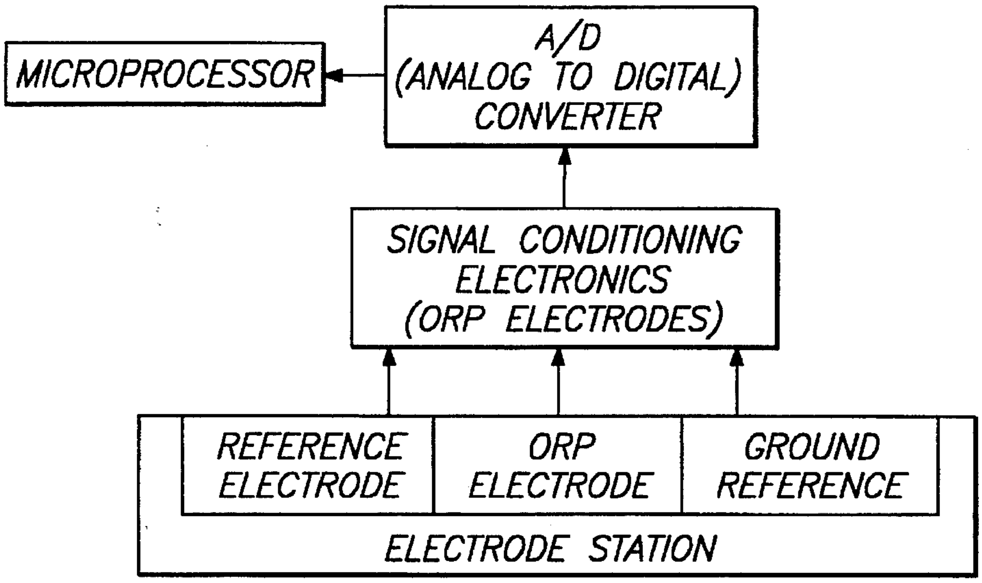

MICROPROCESSOR
A/D (ANALOG TO DIGITAL) CONVERTER
SIGNAL CONDITIONING ELECTRONICS (ORP ELECTRODES)
REFERENCE ELECTRODE
ORP ELECTRODE
GROUND REFERENCE
ELECTRODE STATION

FIG. 18

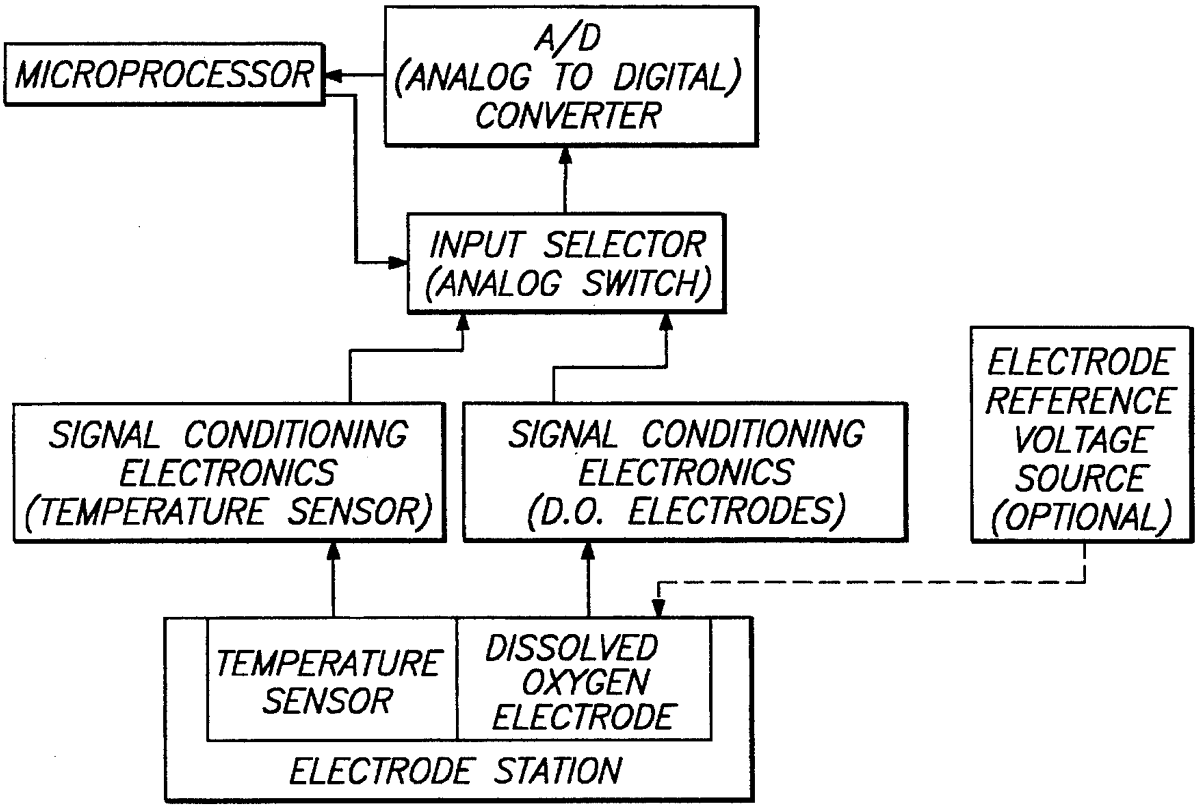

MICROPROCESSOR
A/D (ANALOG TO DIGITAL) CONVERTER
INPUT SELECTOR (ANALOG SWITCH)
SIGNAL CONDITIONING ELECTRONICS (TEMPERATURE SENSOR)
SIGNAL CONDITIONING ELECTRONICS (D.O. ELECTRODES)
ELECTRODE REFERENCE VOLTAGE SOURCE (OPTIONAL)
TEMPERATURE SENSOR
DISSOLVED OXYGEN ELECTRODE
ELECTRODE STATION

FIG. 19

MULTI-FUNCTION FLOW MONITORING APPARATUS WITH MULTIPLE FLOW SENSOR CAPABILITY

This is a continuation-in-part of application Ser. No. 954,288 filed Sep. 30, 1992 which issued as U.S. Pat. No. 5,299,141; which is in turn a continuation-in-part of application Ser. No. 612,832 filed Nov. 13, 1990 which issued as U.S. Pat. No. 5,172,332; which is in turn a continuation-in-part of application Ser. No. 455,981 filed Dec. 22, 1989 which issued as U.S. Pat. No. 5,091,863. The disclosure of each of such applications and patents is incorporated herein by reference thereto.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a multi-function fluid flow monitoring apparatus having the unique capability of measuring fluid flow-related variables on the basis of outputs from any one or more of a plurality of different types of flow sensors. In accordance with the multi-functional features of the invention, the apparatus can also perform fluid monitoring operations and can be linked to a variety of external devices, such as an automatic sampling apparatus, a rain gauge, and the like, so as to operably cooperate with same. The apparatus also provides for the displaying, storing, and transferring of data relating to fluid flow measuring and monitoring operations.

More particularly, the invention relates to a compact unitary apparatus having a computer control system which calculates fluid flow-related variables on the basis of outputs from any desired one or more of a plurality of different types of flow sensors which may be selectively and interchangeably connected to the apparatus. By virtue of this multiple flow sensor capability, the user is provided with substantial flexibility in selecting a flow sensor system suitable for a given application, and then selectively switching to any desired one of a plurality of other types of sensor systems as the need arises. The user is also afforded the flexibility of investing in a basic apparatus including, for example, a single type of flow sensor, and then later expanding the range of use of the apparatus by investing in additional types of flow sensors which are all fully compatible with, and supported by, the basic apparatus.

The apparatus of the invention also comprises a text and graphics display which permits a user to selectively view stored data in either text or graphic formats. Stored data can also be transferred to a computer for manipulating data or producing hard copy reports.

The invention also provides a novel bubbler sensor type fluid flow monitoring system comprising a novel bubbler control module which overcomes power consumption and inaccuracy problems associated with conventional bubbler sensor systems. The bubbler sensor flow monitoring system according to the invention is incorporated in the multifunction flow monitoring apparatus with multiple flow sensor capability. In an alternative embodiment, the bubbler sensor flow monitoring system of the invention may be provided independently in a flow measuring device having only a single sensor capability.

The terminology "flow sensors" as used herein refers to various available types of sensors for detecting a variable related to fluid flow and producing an electrical output signal corresponding thereto. Such sensors include, but are not limited to, bubbler-type pressure sensors, submerged pressure transducers, ultrasonic sensors, area-velocity sensor systems, and the like.

The terminology "fluid flow-related variables" as used herein embraces a multitude of fluid flow parameters, including fluid level or depth, flow rate, velocity, total flow, i.e., the actual quantity of fluid discharged over a given time period, and the like.

In addition to the versatility afforded by the interchangeability of different flow sensors, the apparatus of the invention may also provide fluid monitoring capabilities similar to those described in the aforesaid U.S. Pat. No. 5,172,332, by attaching an appropriate fluid condition sensor to the fluid flow monitoring apparatus of the invention. These monitoring capabilities enable the apparatus to calculate the value of a given fluid condition on the basis of inputs from a fluid condition sensor. By way of example, such fluid conditions may include pH level, oxidation reduction potential ("ORP"), temperature, solution conductivity or resistivity, dissolved oxygen, etc.

The apparatus according to the invention is further adapted to be selectively linked with external devices so as to operate in cooperation with same. By way of example, the apparatus of the invention may be connected with an automatic sampler similar to that disclosed in the aforesaid U.S. Pat. Nos. 5,091,863 or 5,172,332. The user may then instruct the apparatus to initiate sampling operations by the automatic sampler on the basis of fluid flow related variables, or on the basis of high, low, or a range of critical levels of fluid condition(s) as calculated by the apparatus. The apparatus of the invention also automatically calculates and stores fluid flow-related variables and levels of fluid conditions to permit tracking of the history of the fluid conditions in a process stream.

The apparatus according to the invention may also be selectively connected to other external devices to initiate desired actions based on fluid flow-related variables or fluid condition(s) values calculated by the apparatus. For example, the apparatus may be connected with a pump so as to initiate pump operation when water level rises above a predetermined level. It is further contemplated that the apparatus according to the invention may be selectively connected with other external devices, such as a rain gauge, so as to log data therefrom.

2. Description of the Relevant Art

Under current governmental statutes and regulations, municipal agencies and private organizations are required to carefully monitor fluid waste. Monitoring is also conducted for pollution research purposes and the like. By way of example, monitoring is typically conducted in the following applications: monitoring for compliance with NPDES permits; POTW compliance monitoring; storm water run-off monitoring; combined sewer overflow ("CSO") monitoring; pretreatment compliance; WWTP process control; and infiltration and inflow studies.

In these and similar monitoring applications, one of the principal devices used on-site is a flow meter. In addition to monitoring various fluid flow-related variables, the flow meter may also be used for pacing sampling operations in proportion to flow rate, i.e., in conjunction with a sampling apparatus which repeatedly collects samples for subsequent laboratory analysis. A separate analytical meter is also often used for on-site monitoring of critical fluid conditions, such as pH level or ORP, to alert the user in a relatively immediate fashion to an upset in the process stream. Because flow meters, analytical devices and samplers are regularly transported to and mounted at remote field sites, it is desirable for each piece of equipment to be as compact, versatile, and easy to use as possible.

The present inventors, in the apparatus disclosed in their aforesaid U.S. Pat. No. 5,091,863, have overcome many of the problems associated with using separate samplers and flow meters by providing an integrated, compact automatic sampling and flow measuring apparatus capable of pacing sampling in proportion to flow rate, and of storing sample collection and flow data for retrieval in hard copy form.

In the apparatus disclosed in their aforesaid U.S. Pat. No. 5,172,332, the present inventors have also overcome the problems associated with separate automatic sampler and analytical meter devices. The apparatus combines a sampler and analytical meter in a single unitary structure, with the sampler and analytical meter sharing the same computer control means, digital display, keyboard, circuitry, etc. The computer control means of the apparatus automatically calculates the values of fluid condition(s) such as pH level, and controls sampling operations on the basis of time and/or fluid condition(s). The apparatus also stores sample collection and fluid condition(s) data for later retrieval by the user.

The multi-function apparatus of the present invention is particularly directed to solving problems associated with transporting and using flow meters at remote monitoring sites. Technicians in the field encounter a variety of different conditions at different sampling sites, sewer manholes, and other monitoring environments, so that different types of flow sensors are required to accommodate varying open channel flow applications. Heretofore, it has been necessary to use different flow meter devices, each adapted to operate with only a single sensor type, to accommodate varying field conditions. For example, where an ultrasonic flow sensor would be best suited for a particular application, the user would have to acquire and transport a separate flow meter having an ultrasonic flow sensor. Subsequently, if the user were to encounter field conditions for which a bubbler-type flow sensor would be most suitable, the user would have to acquire and transport a different flow meter having a bubbler-type sensor.

The expense and inconvenience entailed by the use of different flow meters is eliminated by the present invention, in which the same compact apparatus accommodates a variety of interchangeable flow sensors. The multi-function fluid monitoring apparatus of the present invention has a compact, unitary structure incorporating a microprocessor which is programmed to automatically calculate and store data, as well as to perform other functions. A principal advantage afforded by the present invention is that the same compact fluid monitoring apparatus accommodates a plurality of different types of interchangeable flow sensors. Other advantages afforded by the invention include the selective graphic or tabular display of stored data in a convenient form for the user, the capability of monitoring various fluid conditions in addition to fluid flow-related variables, and the ability to initiate actions by external devices linked to the fluid monitoring apparatus, such as sampling by an automatic sampler. These and other features of the apparatus according to the invention render it multi-functional and highly versatile in use, while providing a structure which is very compact, conveniently transportable, and minimizes expense.

SUMMARY OF THE INVENTION

The invention provides an apparatus for monitoring at least one flow-related variable of fluid flow in a channel, comprising an integral operating unit provided in a unitary case, the integral operating unit including computer means for controlling the apparatus and input means for receiving detected signals related to fluid flow in the channel. The input means is selectively connectable to any selected one or more of a plurality of different types of flow-sensing means for producing signals related to the fluid flow in the channel. The integral operating unit further includes means for processing the signals from each of the plurality of different types of flow-sensing means, for input to the computer control means. The apparatus is also provided with power means for supplying power to each element of the apparatus. The computer control means comprises a microprocessor, program memory, and data memory. The data memory stores user-selected input parameters including at least one fluid flow-related parameter, and may further store fluid flow-related data. The microprocessor receives the signals related to fluid flow from the processing means and calculates values of at least one flow-related variable based on the signals, the user-input fluid flow-related parameter, and a selected one of a plurality of equations for computing values of the flow-related variable. Preferably, the plurality of equations are stored in the program memory of the computer control means.

In a preferred embodiment, a plurality of flow sensor control modules incorporate the signal processing means and other interface means, with each control module being associated with a particular type of flow sensor. The plurality of flow sensors may preferably include at least a bubbler sensor, a submerged sensor, an ultrasonic sensor, and a velocity sensor.

The bubbler sensor control module of the invention comprises, in addition to the signal processing means, an air pump operatively connected with an air reservoir so as to pressurize same, air flow restriction means connected to the reservoir, first pressure sensing means connected between the air flow restriction means and the reservoir, and second pressure sensing means connected downstream of the reservoir. The external connector associated with the bubbler sensor is connected to the air pump downstream of the second pressure sensing means. The microprocessor receives signals from the first and second pressure sensing means, and calculates the difference in pressure between the first and second pressure sensing means. The microprocessor is connected to the air pump so as to operate the pump to maintain a predetermined pressure difference between the first and second pressure sensing means. By virtue of this arrangement, the pressure across the air flow restrictor is kept constant, so that a nearly constant air flow or bubble rate is maintained in the fluid channel. The arrangement results in decreased power consumption and increased accuracy relative to known arrangements. In an alternative embodiment, the novel bubbler flow sensing system of the invention may be incorporated in a single-sensor type flow meter.

It is an object of the invention to provide a fluid flow monitoring apparatus which is completely contained in a compact, unitary case and which has the capability of measuring fluid flow-related variables on the basis of outputs from any one or more of a plurality of different types of flow sensors. The invention thus eliminates the expense and inconvenience associated with having to employ a number of different flow meters which each support only a single type of flow sensor.

In accordance with another important object of the invention, the flow monitoring apparatus is integrally provided with one or more fluid condition monitoring assemblies or modules which are connected with the microprocessor of the apparatus so as to input signals thereto from one or more fluid condition sensors, such as a pH sensor, ORP sensor, dissolved oxygen sensor, solution conductivity sensor, and/or other fluid condition sensors. The apparatus is thus provided with multi-functional capabilities to monitor fluid flow and fluid condition variables either independently or simultaneously, as desired.

According to yet another object of the invention, the multi-functional apparatus may be selectively linked with a variety of external devices, including an automatic sampling apparatus, a rain gauge, a pump, and the like, via suitable interface electronics integrally connected with the microprocessor of the apparatus. The apparatus is thus able to transmit control signals to the external device(s), and to receive and record data from same. The additional capabilities afforded by such links to external devices, include, for example, control by the apparatus of an external sampler on the basis of either fluid flow related variables or critical level(s) of fluid condition(s).

The above and further objects, details, and advantages of the invention will become apparent from the following detailed description, when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a multi-function flow monitoring apparatus according to a preferred embodiment of the invention.

FIG. **2** is a front view of the operating panel of the apparatus of FIG. **1**.

FIG. **3** is a partially disassembled view of the multi-function flow monitoring apparatus of FIG. **1**, showing four interchangeable flow sensors accommodated by the apparatus together with their respective control modules.

FIG. **4** is a side view of the apparatus of FIG. **1**, showing externally mounted components forming part of the bubbler sensor system of the apparatus.

FIG. **5** is a block diagram of the various components of a preferred embodiment of the invention, as controlled by the computer control means of the apparatus.

FIG. **6** is a perspective view of the apparatus according to the invention having a submerged sensor connected thereto, shown in a mounted position within a sewer manhole.

FIG. **7** is a perspective view of the apparatus according to the invention having a bubbler sensor connected thereto, shown in a mounted position within a sewer manhole.

FIG. **8** is a diagrammatic view of a prior art bubbler flow sensor system.

FIG. **9** is a diagrammatic view of a bubbler flow sensor system according to the invention, as incorporated within the multi-function flow monitoring apparatus.

FIG. **10** is a flow chart showing operational sequences of the bubbler flow sensor system of the invention.

FIG. **11** is a perspective view of the apparatus according to the invention having an ultrasonic flow sensor connected thereto, shown in a mounted position within a sewer manhole.

FIG. **12** is a side elevational view of a velocity sensor forming part of an area-velocity sensor system according to the invention, as mounted in an open fluid channel.

FIG. **13** shows a typical frequency distribution of signals from the velocity sensor of FIG. **12**.

FIG. **14** is a block diagram showing the processing circuit for signals received from the velocity sensor of FIG. **12**.

FIG. **15** is a flow chart showing operational sequences of the apparatus according to the invention.

FIG. **16** is a partial block diagram showing a fluid condition monitoring assembly with an associated pH electrode station, with other system components omitted for ease of illustration.

FIG. **17** is a partial block diagram showing a fluid condition monitoring assembly with an associated conductivity electrode station, with other system components omitted.

FIG. **18** is a partial block diagram showing a fluid condition monitoring assembly with an associated oxygen reduction potential ("ORP") electrode station, with other system components omitted.

FIG. **19** is a partial block diagram showing a fluid condition monitoring assembly with an association dissolved oxygen electrode station, with other system components omitted.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With reference to FIGS. **1–4**, there is shown a preferred embodiment of the multifunction flow monitoring apparatus according to the invention. The apparatus includes a compact case **1** which houses the various electronic, microprocessing, and mechanical components of the invention. Case **1** is preferably fabricated of a rugged thermoplastic material, such as ABS plastic, which is impact resistant and capable of withstanding the stresses of mounting and use under harsh conditions. The front portion of case **1** includes an operating panel **2** provided with a sealed membrane switch numeric keypad **3** for user input, a liquid crystal graphics/alphanumeric display **4**, push buttons **5** for selectively operating display **4**, and ON/OFF switches. A door **6**, fabricated of a rugged thermoplastic material which is transparent, protectively covers the operating panel **2** when it is not being used. Door **6** is hingedly secured at **6A** to one side of the front case portion, and is retained in a closed position by a pair of stainless steel lockable latches **6B** at the opposite side. The case **1** including operating panel **2** is completely sealed so as to be watertight, with added protection of operating panel **2** being afforded by fastening door **6** in a closed position. However, even when door **6** is open, the case **1** with the components mounted therein is submersible, watertight, dust-tight, and corrosion resistant, conforming to NEMA 4X, 6 standards.

As shown in FIG. **3**, the rear top portion of case **1** may be provided with an integrally molded handle portion **7**. Below the handle portion is an integrally molded recessed pocket portion **8** adapted to securely hold a power source for the apparatus, such as a battery **9**, an A/C power converter, or the like.

Mounted on a side portion of case **1** is a plurality of external connectors **10** which preferably are each provided with a removable cap to protect same when not in use, although the connectors **10** are sealed in a watertight manner even without the caps. As described in greater detail below, connectors **10** are adapted to have various devices connected thereto, including any one of a plurality of interchangeable flow sensors, fluid condition monitoring sensor(s), an automatic sampler, a rain gauge, a power source such as a battery, a data transfer unit, etc. It will be understood in this respect that the number of connectors **10** may be varied as desired to accommodate a desired number and/or types of sensors and external devices. In the embodiment shown in

FIGS. **1–3**, the uppermost connector **10** is adapted to receive one end of an electrical connector for connection to rear-mounted battery **9**, which in a preferred embodiment provides a power source for the apparatus.

A principal feature of the multi-function fluid flow monitoring apparatus of the invention is its ability to calculate fluid flow-related variables on the basis of outputs from any one of a plurality of interchangeable flow sensors. In effect, the multiple flow sensor capability of the invention renders the apparatus equivalent to a plurality of different types of flow meters all integrated in a single unit. The user is thus able to adapt the apparatus for use in a wide variety of different site conditions simply by selecting a type of flow sensor which is suitable for the conditions at a given monitoring site, instead of having to switch to an entirely different flow meter. In the preferred embodiment described below, the apparatus is adapted to measure fluid flow-related variables on the basis of outputs from at least four different types of sensors, i.e., a bubbler-type pressure sensor, an ultrasonic type sensor, a submerged type sensor, and a velocity sensor forming part of an area-velocity sensor system. It will be understood, however, that the apparatus is capable of accommodating additional and alternative types of sensors by means of suitable control modules which may be integrally connected with the computer control means of the apparatus as desired.

As shown in FIG. **5**, the apparatus according to the invention includes computer control means in the form of a microprocessor which performs all mathematical and control functions required to operate the apparatus, a keyboard (keypad **3** in FIG. **1**) defining the interface to the user which allows the user to program the apparatus and monitor its operation, and a real-time clock. The real-time clock provides the computer control means with access to current time and date information, so that events occurring during program execution may be recorded with corresponding time and date of occurrence.

As shown in FIG. **3**, four control modules **20**, **30**, **40**, **50** are provided for the four interchangeable flow sensors **21**, **31**, **41**, **51**, respectively, with each module being integrally connected with the microprocessor within case **1** in the assembled state. Control module **20**, which operatively cooperates with a bubbler type sensor in the form of bubbler tubing **21**, includes an air pump and various mechanical and electronic circuitry components, including signal processing means, of a bubbler depth measurement system described in detail below. Control module **30**, in the form of an electronic circuitry board, includes signal processing means and interface means for submerged sensor **31** as described in detail below. Likewise, control modules **40** and **50**, each in the form of an electronic circuitry board, define signal processing and interface means for ultrasonic sensor **41** and a velocity sensor **51**, respectively, as also described in detail below.

Submerged Sensor

With reference to FIGS. **1–3**, **5** and **6**, the operating characteristics of the invention will first be described with respect to sensor **31**, which comprises a submerged pressure transducer.

By way of example, submerged pressure transducer or submerged sensor **31** is suitable for use in monitoring conditions where floating oil, grease, foam, steam, silt, solids, or turbulence are present. The sensor **31** is selectively connected with one of the connectors **10** on case **1**, which is in turn connected with the microprocessor of the apparatus via control module **30**. The interface means incorporated in module **30** are defined by signal conditioning electronics and an analog to digital ("A/D") converter, as represented in the lower portion of FIG. **5** by labelled blocks. The circuitry provided in control module **30** operates to transmit a precision voltage level to the sensor **31**, as well as to condition and convert signals detected from sensor **31** for input to the computer control means. The detected signals are amplified and smoothed (filtered for noise), and then converted to digital form by an A/D converter (FIG. **5**) for input to the microprocessor.

With reference to FIG. **6**, the apparatus with submerged sensor **31** connected thereto is shown in a mounted position in a sewer manhole. As shown, the apparatus may be suspended by a plurality of lines attached to case **1** and extending from a cross-bar support provided at the upper end of the manhole. Sensor **31** is shown as installed in an open flowing sewer passage, secured in position by a stainless steel mounting band **32** such that the sensor is positioned directly in the flow stream. The pressure over the sensor **31** changes with changes in fluid level. The microprocessor of the apparatus, on the basis of inputs from sensor **31** processed by control module **30**, converts the level reading to a flow rate based on the level-to-flow relationship of the channel configuration. The flow rate relationship is determined on the basis of the dimension, declination, and inside roughness of the pipe.

Submerged sensor **31**, like the other interchangeable sensors described in detail below, may alternatively be installed in a fluid flow restricting or primary device which is in turn installed in an open flowing sewer passage to define a fluid channel for measuring fluid flow rate. Such a primary device may take the form of a weir, such as a V-notch weir, a contracted or non-contracted rectangular weir, a Cipolletti weir, a Thelmar weir, or a compound V-notch and rectangular weir. Alternatively, the primary device may comprise a flume, such as an H, HL or HS flume; a Parshall flume; a trapezoidal flume; a Palmer-Bowlus flume, or a Leopold-Lagco flume. The primary device may also take the form of a nozzle, such as a Kennison or parabolic nozzle.

Each of the foregoing primary devices is adapted to restrict fluid flow in an open passage so as to increase the fluid depth upstream of the device. The upstream fluid depth or "head" of each such device has a known mathematical relationship with the rate of flow through the channel of the device. This head vs. flow rate relationship is available in published form for various different sizes of each type of device.

When the sensor **31** is submerged upstream of one of the above-described flow restriction or primary devices, the voltage output from sensor **31** will be directly related to the "head" value used to calculate the flow rate. Typically, the sensor **31** will be mounted at a low point in a primary device so that it will remain submerged. Processing of the signals from sensor **31** and calculation of the flow rate is performed by the apparatus including the computer control means as described below.

The computer control means according to the invention comprises a microprocessor, and preferably has program storage firmware in the form of FLASH memory which permits software enhancements without replacing E-PROM chips. In addition to program storage memory, the computer control means is also provided with data storage memory in the form of random access memory (RAM) which stores specific details of operation set by the user and records flow and other data as described below. The RAM is backed-up by its own battery, e.g., a lithium battery, so that data will remain stored therein even when the overall power source of the apparatus is turned off.

Program Storage Memory

The program storage memory of the computer control means according to the invention implements all of the functions required to read and process data from submerged sensor **31**, as well as any other interchangeable sensor being used, and to operate the text and graphics display **4** and keypad **3**. The program storage memory may include the following programming:

Interface Programming;

Flow Measuring Programming; and

Fluid Condition Monitoring Programming.

The Interface Programming allows the microprocessor to control the user input keypad **3**, the text/graphics display **4**, the real-time clock, and to access the active interface devices including the interchangeable sensors and any external devices connected with the apparatus. With respect to the bubbler module **20**, the computer control means is also programmed to control operation of the bubbler air pump based on inputs from pressure sensors received via an A/D converter (FIG. **5**), as described in greater detail below.

The Flow Measuring Programming allows the microprocessor to calculate the fluid depth, flow rate, velocity, and other fluid flow-related variables on the basis of processed signals received from the sensor **31** or one of the other interchangeable sensors described below. The programming includes depth vs. flow equations which characterize the relationship between the "head" and flow rate for various types and sizes of fluid flow restricting devices. Also included are equations (e.g., the Manning Equation) for calculating flow variables on the basis of sensor inputs directly from various shaped channels, such as round pipes, U channels, rectangular channels, and trapezoidal channels. While these various equations could alternatively be selectively input by the user via keypad **3**, in the preferred embodiment of the invention the equations are stored in the program memory of the computer control system of the apparatus. Boating point math algorithms are provided to enable the microprocessor to perform high precision mathematical operations required to accurately calculate the values of fluid flow-related variables. Such fluid flow-related variables include the fluid depth which is calculated from the output of a selected one of the sensors, and the fluid flow rate which is calculated from the measured fluid depth. Algorithms are included for performing addition, subtraction, multiplication, division, exponentiations, logarithms and trigonometry functions to a precision equivalent to over four significant figures.

It will be understood that the Interface Programming and Flow Measuring Programming also allow the microprocessor to perform a variety of other operations which will become apparent from the following detailed description. For example, one such operation comprises a totalizer feature in which the microprocessor calculates and keeps a running total of the fluid quantity discharged over a given time period, on the basis of inputs from a flow sensor being used with the apparatus, with the running total being displayed on display **4**. A second running total may also be provided which is re-settable by the user so as to track total flow over only a selected period of time. As shown in FIG. **5**, a mechanical totalizer operated by the microprocessor is also provided so as to ensure that a totalized value will not be erased.

The Fluid Condition Monitoring Programming comprises firmware which allows the microprocessor to calculate the values of a given fluid condition(s) on the basis of processed signals received from a fluid condition sensor via suitable interface means, as described in greater detail below.

Data Storage Memory

The data storage memory of the computer control means is preferably provided in the form of random access memory (RAM) which stores specific operational parameters set by the user, and stores data during operation. Parameters which may be set by the user include fluid flow and fluid level logging intervals, such as on the basis of time, a given depth in the fluid channel, and/or rainfall (where a rain gauge is connected with the apparatus), as well as selection of a primary device or channel configuration. The user may also select parameters for monitoring fluid conditions such as pH, temperature, ORP, rainfall, conductivity, dissolved oxygen, turbidity, etc., on the basis of inputs from external signal sources as described below. Other parameters which may be set include control parameters for external equipment linked with the apparatus via connector(s) **10**, such as trip points based on high and/or low fluid condition levels (e.g., pH levels or water level) which trigger the operation of an automatic sampling apparatus, a pump, or the like. A variety of other parameters which may be input by the user will become apparent from the description below.

The invention contemplates that the computer control means be programmed to selectively prompt the user, via a series of menu screens displayed on display **4**, to enter various desired parameters via keypad **3**. Various user-keyed parameters associated with particular sensors and external devices are described in detail below. In addition to user-programmed entries, all data collected during operation is stored in RAM.

Bubbler Sensor

In accordance with the interchangeable flow sensor capability of the invention, the use of the apparatus as a bubbler-type pressure sensor system including the bubbler sensor **21** (FIG. **3**) will now be described with reference to FIGS. **3–5** and **7–10**.

The bubbler sensor **21**, which comprises a length of plastic tubing, is particularly suitable for use in low or intermittent flow conditions, or where interfering conditions are present, such as floating oil, grease, foam, steam, surface turbulence, and/or excessive wind. Because only inexpensive tubing is exposed once the bubbler type sensor is mounted for operation, it is also well suited for applications in which vandalism may be a problem. The ease of installation of the bubbler sensor, described below, also makes it well suited for temporary flow applications, such as POTW monitoring or infiltration and inflow studies.

As shown in FIG. **3**, the control module **20** for bubbler sensor **21** includes an air pump and various mechanical and electronic circuitry components of a bubbler depth measurement system according to the invention, including signal processing and interface means connected with the microprocessor. The bubbler system of the invention represents a substantial improvement over a conventional bubbler depth measurement system, such as shown in FIG. **8**, as described in detail below.

With reference to FIG. **8**, the conventional bubbler system includes an air pump A which is controlled by a pressure switch B so as to maintain an approximately constant air pressure in a pressure reservoir C. Such pressure must be sufficient to force air bubbles into the maximum fluid depth which is expected to be encountered by the system, as follows:

$$P \geqq 0.03612 \times D$$

where

P=Reservoir Pressure (PSI)

D=Maximum expected water depth (inches)

In the conventional system, an air flow restrictor D and needle valve E cooperate to limit the air flow from the reservoir to some desired rate. In practice, the user adjusts the needle valve to obtain an air flow rate which yields approximately one to three bubbles per second from the air outlet H. Air outlet H is mechanically fixed in place inside a fluid channel. The fluid depth in the channel may then be determined by measuring the back pressure on the output air line by means of a pressure sensor F. Ideally, the fluid depth may be calculated as:

$$D=27.681 \times P$$

where

D=Channel fluid depth (inches)

P=Measured Pressure (PSI).

In reality, however, the movement of air through the output tubing adds a friction term to the measured pressure. This friction or error term must be subtracted from the measured pressure in order to make an accurate depth calculation, as follows:

$$D=27.681 \times [P-f(1,d,v)]$$

where

D=Channel fluid depth (inches)

P=Measured Pressure

f(l,d,v)=Measured Pressure Error due to air moving in output tube; a function of air tubing length (l), diameter (d), and air flow velocity (v).

The magnitude of the error term is determined by the length and diameter of the output tube, and the velocity of the air flowing through it. Two of the factors in the error term, the tubing length (I) and diameter (d), remain constant for a given installation. However, the air flow velocity is primarily a function of the position of the needle valve, and the pressure difference between the pressure reservoir and the air output. Because the air outlet is mechanically fixed inside the fluid channel, this pressure difference will be determined primarily by the fluid depth in the channel. The net result is that the fluid depth calculated by the conventional system will include an error term which is a function of the current needle valve setting, the length and diameter of the output tubing, and the current depth in the fluid channel.

When the conventional system shown in FIG. **8** is used in applications where the measured fluid depth changes only slightly, the error term [f(l,d,v)] is more or less constant, and may be compensated for when installing and calibrating the system at the site. When the conventional system is used in applications where the fluid level varies over a wide range, the error term will add significantly to worst case measurement error. In either case, any movement of the needle valve after calibration will alter the error term and thus detrimentally affect the accuracy of depth measurement.

Another problem which the conventional bubbler system of FIG. **8** suffers is excessive power consumption. When the system is adjusted to provide a suitable bubble rate at maximum fluid depth, the air flow will be substantially greater near zero fluid depth. This causes the air pump to run more frequently, thus consuming additional power. Such power consumption is particularly undesirable in battery operated systems where battery life is an important factor.

The bubbler system according to the present invention, shown in the block diagram of FIG. **9**, overcomes the various problems associated with the conventional bubbler system of FIG. **8** while maximizing accuracy and minimizing power consumption. The bubbler system according to the invention includes an air pump A' which pressurizes an air reservoir C', both of which are housed, together with other components of the bubbler system, within case **1** of the apparatus as part of the bubbler control module **20** (FIG. **3**). Unlike the conventional system, in the bubbler system according to the invention the air pump A' is controlled by the microprocessor of the apparatus. The microprocessor is programmed to determine when and for how long the air pump A' must be run by reading the two pressure sensors B' and E' shown in FIG. **9**. As shown in FIG. **5**, inputs from pressure sensors B' and E' are transmitted to the microprocessor via an A/D converter. The pressure difference between sensors B' and E' is equivalent to the pressure drop across the air flow restrictor D'. The microprocessor controls operation of pump A' so as to maintain a predetermined pressure across the air flow restrictor D'. As the fluid level in the channel changes, the pressure maintained in the reservoir C' is thus changed by a like amount.

An important advantage afforded by the bubbler system according to the invention is that the constant pressure across the air flow restrictor D' results in a nearly constant air flow or bubble rate into the fluid channel, thus virtually eliminating the depth dependency from the error term in the depth-pressure equations set out above for the conventional system. The depth-pressure relationship for the bubbler system according to the invention is as follows:

$$D=27.681 \times [P-f(1,d)]$$

where

D=Channel depth (inches)

P=Pressure measured at pressure sensor E' (PSI)

f(l,d)=Measured Pressure Error due to air moving in output tube; a function of air tubing length (l) and diameter (d).

Because the bubbler system according to the invention effectively controls the air flow velocity, it is unaffected by the fluid depth in the channel. The tubing-based error term (f(l,d)) from which the conventional system suffers, while still present, is in the present system a function of only the output air tubing length and diameter. The error term is thus constant for a given installation and may be effectively canceled at the time the apparatus of the invention is installed and calibrated at the site.

Another important advantage afforded by the bubbler system according to the invention is that a lower pressure is maintained in the air reservoir C' when the channel fluid depth is less than the maximum. The lower reservoir pressure reduces pump run time, thus conserving power and increasing battery life. A further advantage of the present system is that the air flow or bubble rate is set by a command to the microprocessor of the apparatus which is effected via keypad **3**, rather than mechanical adjustment of a needle valve as in the conventional system. Once the bubble rate has been initially set by the user, it will remain constant even when the apparatus is moved from one installation site to another. In most cases, the bubble rate need never be changed from the original factory setting for the life of the unit.

As shown in FIG. 4, the bubbler sensor tubing **21** is selectively connected to the apparatus via a bubbler line port connection **22** which is preferably provided on the side of case **1** opposite the side provided with connectors **10**. Also provided is an air intake port **23** with an associated dryer tube **24** for air supply to the bubbler air pump A', as well as a reference port **25** with an associated dryer tube **26**. The reference port **25** communicates with the atmosphere via an offset valve G' as shown in FIG. **9**. The microprocessor is programmed to open the bubbler port and reference port to atmosphere at regular intervals, and to electronically zero same so as to eliminate any drift due to changing barometric pressure. Further, a bypass valve F' is opened periodically by the microprocessor for a short time. The resulting burst of high velocity air through the air tube helps to dislodge any debris which otherwise might accumulate on the air outlet H' and restrict air flow.

The sequential steps of initializing and operating the bubbler system, as described above, are summarized in the flow chart of FIG. **10**.

With reference to FIGS. **4** and **7**, installation and operation of the bubbler type sensor is as follows. The bubbler sensor **21** is connected at one end to bubbler line port connection **22** and is mounted at its other end within the fluid in a channel. As shown in FIG. **7**, a stainless steel mounting band **28** may be used for securing the outlet end of sensor **21** in a channel, although it is contemplated that any suitable mounting means may be employed. The bubbler air supply arrangement described above, in cooperation with the microprocessor of the apparatus following the sequence of steps shown in FIG. **10**, communicates through the bubbler line port **22** with bubbler sensor **21** so as to direct a constant, small volume of air through the tubing of sensor **21** to the measurement point in the fluid channel. As the pressure in the sensor tubing **21** changes in proportion to fluid level, the flow measuring programming converts the level reading to flow based on the level-to-flow relationship of the channel configuration, or that of a primary device.

In accordance with another embodiment of the invention, the bubbler sensor system as described above may alternatively be provided in a single-sensor capacity fluid flow monitoring apparatus or flow meter. Such embodiment would include the bubbler control module **20**, but not the other control modules **30**, **40** and **50** shown in FIG. **3**. The bubbler type fluid flow monitoring apparatus as thus constructed may also include any one or more of the other multi-functional features of the invention, such as the ability to link the apparatus with external devices such as a rain gauge, automatic fluid sampling apparatus, and the like, as well as accommodating one or more fluid condition monitoring sensors.

Ultrasonic Sensor

In accordance with the interchangeable flow sensor capability of the invention, the use of the apparatus with the ultrasonic type sensor **41** (FIG. **3**) will now be described with reference to FIGS. **3**, **5** and **11**.

The ultrasonic transducer or sensor **41**, which functions without contacting the fluid being monitored as discussed below, is particularly suitable for use where chemicals would adversely affect a sensor located in the fluid. The ultrasonic sensor **41** is also suitable for permanent applications, particularly where silt or solids are present. Further, because ultrasonic sensor **41** is mounted above the fluid channel instead of within the channel, it is capable of accurately measuring channel depth as low as zero and is not affected by high fluid velocities in the channel.

The signal processing and interface electronics for sensor **41** are provided on control module or board **40** as shown in FIG. **3**. Ultrasonic sensor **41** uses an echo range measurement through air technique to measure the distance from a fixed point above the channel to the fluid surface. The output from sensor **41** based on such measurement, processed by control module **40** for input to the microprocessor, is then processed to calculate the depth of the fluid in the channel, and the rate of flow. Control module **40** cooperates with sensor **41** to supply a series of acoustic pulses from a high-energy, high-frequency source which are directed toward the fluid surface by sensor **41**, and echo signals are reflected back and amplified. Timing circuitry provided in module **40** clocks the amount of time for the echo signals to return to a detector, which time is directly proportional to the distance to the fluid surface. This value is then input to the microprocessor for calculating the flow rate therefrom based on the level-to-flow relationship of the channel configuration or primary device.

The operating parameters of the ultrasonic sensor system as described above are all controlled by the microprocessor of the apparatus, with which control module **40** is connected. The microprocessor performs routine optimizing operations to determine and adjust the optimal settings for pulse strength, pulse width, detector sensitivity, and frequency. For example, if the echo signal quality deteriorates below an acceptable level, the condition will be detected and automatically corrected. Because the frequency at which the ultrasonic sensor **41** is driven can be varied, while the strength of the resulting echo is monitored, the ultrasonic sensor system according to the invention effectively tunes itself to match the particular ultrasonic sensor being used. The user is thus able to replace one ultrasonic sensor with another in the field, without having to return the unit to the factory for re-tuning.

In use, ultrasonic sensor **41** is selectively connected to one of the connectors **10** on case i which is in turn connected with ultrasonic control module **40**. As shown in FIG. **11**, the apparatus with the sensor **41** connected thereto is installed in a sewer manhole in the manner described above with respect to the other types of sensors. As also shown in FIG. **11**, the sensor **41** is positioned above the fluid in the channel, which may be accomplished by simply allowing the sensor cable to hang from the connector **10**. It will be understood, however, that any suitable mounting means may be used for mounting sensor **41**, provided that the sensor is held in position above the fluid and out of contact therewith.

Area-Velocity Sensor System

In accordance with the interchangeable flow sensor capability of the invention, the use of the apparatus as an area-velocity sensor system (FIG. **3**) will now be described with reference to FIGS. **12–14**.

The area-velocity sensor system according to the invention includes a fluid level measuring subsystem and a fluid velocity measurement subsystem. The fluid level measuring subsystem may take the form of any of the above-described flow sensor systems capable of measuring fluid depth, including the bubbler sensor system, the ultrasonic sensor system, or the submerged sensor system described above. The fluid velocity measurement subsystem, used in conjunction with the fluid level measuring subsystem, includes the velocity sensor **51** and associated electronic circuitry provided on control module or board **50**, with module **50** being connected with the microprocessor of the apparatus. The circuitry details of module **50** are shown diagrammatically in FIG. **14**, and discussed in detail below. When it is desired to use the velocity sensor **51**, its coaxial cable is selectively connected with the apparatus via one of the connectors **10** which is in turn connected with module **50**. Simultaneously, one of the flow sensors **21**, **31**, or **41** is connected with its associated connector **10**, so as to measure fluid level.

The velocity sensor **51** is shown in FIG. **12** as mounted on the bottom of an open channel, with fluid flowing through the channel to the right as indicated by the arrow. Sensor **51** is mounted substantially horizontally, facing in the upstream direction so as to eliminate sensor induced turbulence on the velocity measurement. It will be understood with respect to the following description of velocity measurement that free surface, open channel flow is assumed. To simultaneously measure fluid level, designated as L in FIG. **12**, one of the sensors **21**, **31**, **41**, or an alternative flow sensor capable of measuring fluid depth, is also mounted in the channel.

Provided within the plastic housing of sensor **51** is a piezoelectric transmit transducer **52** and a piezoelectric receive transducer **53**. The signal processing circuitry on board **50** of the apparatus transmits average velocity results to the microprocessor while simultaneously the microprocessor receives fluid level information from the fluid level measuring subsystem. The microprocessor then calculates average flow rate by the following equation:

Average Flow Rate=Average Velocity×Channel Cross-Sectional Area

The channel cross-sectional area is calculated by the microprocessor on the basis of channel geometry information entered by the user via keypad **3**, and fluid level information.

The fluid velocity subsystem of the area-velocity sensor system operates on the principle of the Doppler frequency shift of a transmitted electromagnetic wave. A high frequency (e.g., 1-Megahertz) ultrasonic wave is emitted from transmit transducer **52** at an angle from the long axis of the sensor (typically an angle of 15° to 35° , e.g., 20° in FIG. **12**), with the wave being emitted in the form of a cone with a 10° cone angle as shown in FIG. **12**. Relative motion between the stationary probe and moving particles in the fluid are detected by receive transducer **53**, which is manifested as a change in frequency from the transmitted wave. This Doppler shifted frequency is proportional to the speed of the moving particles in the fluid.

The signal from receive transducer **53** actually comprises a time domain sum of sinusoidal signals corresponding to packets of scattering particles in the fluid. As shown in FIG. **14**, circuitry provided on control module **50** processes the signal from receive transducer **53** by amplifying, filtering, and mixing it with the transmitter frequency, yielding the sum and difference frequencies of the inputs to the mixer. The sum frequency is filtered out and the difference frequency is the actual Doppler shifted frequency. This Doppler signal is then input to a spectrum analyzer circuit on module **50**, and a frequency scan is performed on the time domain signal over the expected full-scale range of velocities for the instrument. The output comprises a weighted frequency distribution of the input signal over discrete, evenly-spaced frequency intervals, as shown in FIG. **13**. The weighting of each frequency component corresponds to the strength of the scattered energy at each velocity interval. To obtain average velocity, the centroid of this frequency distribution is calculated and the result is used by the microprocessor for calculating the average flow rate.

The flow direction, whether downstream or upstream, is obtained by detecting the relative phase difference between the actual transmitted wave and the quadrature shifted (90°) transmit wave. This quadrature transmit wave is processed internally on module or board **50** in parallel with the actual transmitted wave to yield the actual Doppler wave and a quadrature shifted Doppler wave. The quadrature shifted Doppler wave is used only for flow direction sensing, and not in the average velocity measurement. The actual Doppler wave and the quadrature shifted Doppler wave are then input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to the microprocessor.

With reference to FIG. **15**, there is shown a flow chart showing the overall sequence of operation of the apparatus with respect to the four sensor systems described above. From FIG. **15** and the above detailed description of the four sensors **21**, **31**, **41**, and **51**, and their respective control modules **20**, **30**, **40**, and **50**, it will be understood that the flow monitoring apparatus of the invention essentially incorporates tour different flow monitoring assemblies into a single compact unit. By employing a common microprocessor and command structure, and housing the computer control means with modules **20**, **30**, **40**, and **50** in a single case, the apparatus is able to accommodate a very wide range of monitoring needs which heretofore could be accommodated only by relying upon a number of separate flow meter devices. The case I which houses the microprocessor and control modules of the invention is at least as compact as commercially available flow meters which are limited to use with only a single type of flow sensor. In order to adapt the operation of the apparatus to the desired bubbler, submerged sensor, ultrasonic sensor, or area-velocity mode, the user has merely to connect the desired sensor or sensors to the appropriate connector(s) **10** and enter corresponding operating parameters via keypad **3**. The invention thus enables the user to select from a variety of flow sensor systems the particular type which will be best suited to a given monitoring application.

Multi-Functional Modes of Operation

In addition to the unique capability of the invention to selectively operate as essentially four (or more) different flow meters in accordance with the above-described embodiment of the invention, the apparatus of the invention may also be integrally provided with one or more means for monitoring various fluid conditions, such as pH, ORP, temperature, dissolved oxygen, conductivity, turbidity, and the like.

The means for monitoring a given fluid condition(s) preferably takes the form of one or more fluid condition monitoring assemblies or control modules such as those disclosed in the aforesaid U.S. Pat. No. 5,172,332, the disclosure of which is incorporated herein by reference thereto. Four such fluid condition monitoring assemblies or modules are depicted in the block diagrams of FIGS. **16–19**, i.e., for a pH sensor, a conductivity sensor, an ORP sensor, and a dissolved oxygen sensor, respectively. FIGS. **16–19** are all partial system views showing only the individual fluid condition monitoring modules and electrode stations as connected to the microprocessor of the apparatus, with the various other components of the invention shown in FIG. **5**, including the various control modules for the flow sensors, omitted for ease of illustration.

It is contemplated that each of the fluid condition monitoring assemblies or control modules of FIGS. **16–19** may desirably be provided in the form of a single board similar to the control modules **30**, **40**, and **50** shown in FIG. **3**. As shown in FIG. **16**, a control module for a pH electrode station or sensor includes signal conditioning electronics, an input selector (analog switch), and an A/D converter. These components may be provided on a single board which is integrally connected with the microprocessor within case **1**, and which is also connected to one of the external connectors **10**. Programming in the form of firmware is provided which allows the microprocessor to calculate the pH level on the basis of processed signals received from the fluid condition monitoring assembly or module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and to permit user selection, via keypad **3**, of the time interval for recording data. A sensor in the form of a pH electrode station may be selectively connected to the corresponding connector **10**, so that pH levels can be monitored along with fluid flow-related variables. A more detailed description of the structural and functional features of the pH sensor control module and the electrode station itself is set out in the aforesaid U.S. Pat. No. 5,172,332.

With reference to FIG. **17**, a control module for a solution conductivity sensor includes signal conditioning electronics, an input selector (analog switch), and an A/D converter, all preferably provided on a single board connected with the microprocessor within case **1**, and also connected to one of the external connectors **10**. Programming in the form of firmware allows the microprocessor to calculate the conductivity level on the basis of processed signals received from the fluid condition monitoring module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and user selection via keypad **3** of the time interval for recording data. A solution conductivity electrode station or sensor is selectively connected to the corresponding connector **10** to permit monitoring of conductivity levels. A more detailed description of the conductivity sensor control assembly or module and the electrode station itself is set out in the aforesaid U.S. Pat. No. 5,172,332.

FIG. **18** shows a control assembly or module for an oxygen reduction potential ("ORP") sensor, including signal conditioning electronics and an A/D converter preferably provided on a board connected with the microprocessor within case **1**, and also connected to one of the external connectors **10**. Programming in the form of firmware allows the microprocessor to calculate the ORP level on the basis of processed signals received from the fluid condition monitoring module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and user selection via keypad **3** of the time interval for recording data. An ORP electrode station or sensor is selectively connected to the corresponding connector **10** for monitoring of ORP levels. A more detailed description of the ORP control assembly or module and ORP electrode station is set out in the aforesaid U.S. Pat. No. 5,172,332.

With reference to FIG. **19**, there is shown a control assembly or module for a dissolved oxygen sensor of either a polarographic or galvanic type. The control module includes signal conditioning electronics, an optional electrode reference voltage source, an input selector (analog switch), and an A/D converter. The control module circuitry is preferably provided on a board, which is connected with the microprocessor within case **1** and also connected to one of the external connectors **10**. Programming in the form of firmware allows the microprocessor to calculate the dissolved oxygen level on the basis of processed signals received from the fluid condition monitoring assembly or module, and to record calculated data in RAM. Programming is also provided to permit calibration of the sensor, and user selection via keypad **3** of the time interval for recording data. A dissolved oxygen electrode station or sensor is selectively connected to the corresponding connector **10** for monitoring of dissolved oxygen levels. A more detailed description of the dissolved oxygen control assembly or module and dissolved oxygen electrode station is set out in the aforesaid U.S. Pat. No. 5,172,332.

By incorporating one or more of the fluid condition monitoring assemblies shown in FIGS. **16–19**, the apparatus according to the invention may be adapted to monitor a number of different fluid conditions. To this end, the program storage memory of the computer control means of the apparatus may be programmed to perform the calculations necessary for a variety of different fluid conditions, and to allow for necessary calibration. As such, the program storage memory can be programmed to have a relatively universal capacity capable of processing inputs from a variety of different fluid condition sensors. It will be understood that the invention is not limited to the particular fluid conditions and sensors described above, and other suitable known sensors and corresponding interface electronics and programming may be employed for monitoring other conditions. With the multi-functional fluid monitoring and flow sensing capabilities of the invention, the user can choose to monitor and record data relating to a given fluid condition either independently of flow, or in conjunction with flow.

It will be further understood that the fluid flow monitoring apparatus of the invention may be selectively employed for use for flow monitoring only, for fluid condition monitoring only, or for monitoring both flow and fluid condition(s) simultaneously. These independent or dual operation modes can be effected by user input via keypad **3** to the microprocessor of the apparatus.

As shown in the diagram of FIG. **5**, the multi-function fluid flow monitoring apparatus of the invention is also capable of being selectively linked with a variety of external devices, such as an automatic sampling apparatus, a rain gauge, a pump, and the like. To this end, suitable interface electronics are provided, as shown in FIG. **5**, which are connected with corresponding ones of the connectors **10**. The external device interface electronics are in turn connected with the microprocessor of the apparatus, and suitable programming is provided to permit the apparatus to send control signals to the external device(s), as well as to receive and record data from same.

By way of example, the apparatus of the invention may be connected with an automatic sampler similar to that disclosed in the aforesaid U.S. Pat. Nos. 5,091,863 or 5,172,332. The user may then instruct the apparatus, via keypad **3**, to initiate sampling operations by the automatic sampler on the basis of a fluid flow related variable, or on the basis of high, low, or a range of critical levels of fluid condition(s) as calculated by the microprocessor on the basis of inputs from one of the fluid condition monitoring modules.

The apparatus according to the invention may also be selectively connected with an external pump so as to initiate pump operation when the fluid rises above a predetermined level as input by the user via keypad **3**. It is further contemplated that the apparatus according to the invention may be selectively connected with a rain gauge. The computer control means of the apparatus may be provided with programming which permits the apparatus to initiate flow measurement based on rainfall as measured by signals received from the rain gauge, and or based on fluid depth and rainfall. Further, the apparatus is programmed to store rainfall data measured by the rain gauge in the RAM memory of the apparatus of the invention.

With further reference to FIG. 5, the fluid flow monitoring apparatus according to the invention is also desirably provided with at least one 4–20 mA output connection to enable the apparatus to form pan of a current loop for driving a chart recorder or other external device. Preferably, an RS-232 standard type serial data interface and connection is also provided, to permit the apparatus to be connected with means for transferring recorded data as described below.

User Access to Stored Data

The user can request, via keypad 3, that data stored in RAM, such as flow related data, fluid condition data, and/or other data gathered from external devices linked to the apparatus, be displayed on display 4 when desired. Further, the combined text and graphics display 4 permits the user to selectively view data either in graphics or tabular form.

The invention provides an alternative means for retrieving stored data in the form of a portable data transfer unit, indicated as a "DTU" in FIG. 5. The portable data transfer unit is preferably very compact, i.e., pocket-sized, so that the user can conveniently carry same for selective use. The data transfer unit is provided with its own microprocessor, the memory of which may take the form of CMOS RAM chips powered by a lithium battery (battery backed-up RAM), or FLASH memory not requiring battery back-up. The data transfer unit is also preferably provided with its own user-input keypad and an alphanumeric display, and resembles a conventional small pocket calculator in overall appearance.

The data transfer unit is connected via a conventional connector cable (not shown) with the RS-232 serial connector. The user may then send an electronic data request command from the data transfer unit to the microprocessor of the apparatus. Upon receipt of such command, the microprocessor of the apparatus retrieves the requested data from its RAM and sends it for storage in the memory of the data transfer unit.

When it is desired to retrieve the data thus stored in the data transfer unit, the unit is in turn connected, via a standard computer or printer jack for example, to an external output device in the form of a conventional printer or computer (e.g., a personal computer). The stored data can be read out directly on a printer to produce a hard copy thereof, with the microprocessor of the data transfer unit itself operating the printer in a known manner. The user is thus able to obtain a complete and accurate hard copy record of the data. Alternatively, the stored data can be transferred to a conventional computer for manipulation using an available software program for statistical analyses, spreadsheeting, etc.; for more permanent storage in a database stored in the computer's memory; and/or for printing by a printer connected to the computer.

As also shown in FIG. 5, an alternative data transfer means may be provided in the form of a modem which is built-in to the apparatus and provided with a standard external connector. The modem may comprise, for example, an FCC approved, 2400 baud modem with X modem feature. By virtue of the built-in modem, the apparatus can be linked by telephone line to a modem in a remote computer to permit immediate, long-distance transfer of stored data from a monitoring site.

Although it may not always be practical, the apparatus can alternatively be directly linked to a remote computer (e.g., a laptop computer) for direct transfer of the stored data from the apparatus to the computer.

It will be understood from the foregoing that the fluid monitoring apparatus according to the invention not only affords the unique capability of monitoring fluid flow on the basis of any desired one of a variety of different types of fluid flow sensor systems, but is also multi-functional in that it is capable of performing non-flow related operations such as fluid condition monitoring and operable interactions with various external devices. The apparatus thus offers the user a wide variety of monitoring features in a single compact unit which is conveniently transported and easy to use.

While there have been described hereinabove what are at present considered to be the preferred embodiments of the invention, it will be understood that various modifications may be made therein without departing from the spirit and scope of the invention. The present embodiments are therefore to be considered in all respects as illustrative, and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description.

We claim:

1. An apparatus for monitoring at least one variable related to fluid flow in a channel, comprising:

an integral operating unit provided in a unitary case, said integral operating unit including computer means for controlling said apparatus and input means for receiving detected signals related to said fluid flow in said channel;

said input means being selectively connectable to any selected one or more of a plurality of different types of flow-sensing means for producing signals related to said fluid flow in said channel;

said integral operating unit further including means for processing said signals from each of said plurality of different types of flow-sensing means, for input to said computer control means;

power means for supplying power to each element of said apparatus; and

said computer control means comprising a microprocessor, program memory, and data memory, wherein:

said data memory stores user-selected input parameters including at least one fluid flow-related parameter; and

said microprocessor receives said signals related to fluid flow from said processing means and calculates values of said flow-related variable based on said signals and said user-input fluid flow-related parameter.

2. An apparatus according to claim 1, wherein:

said at least one flow-related variable comprises fluid depth, fluid flow rate, total flow, and fluid velocity.

3. An apparatus according to claim 1, wherein:

said integral operating unit further comprises interface means for an external rain gauge, said interface means being connected with an external connector mounted on a portion of said unitary case;

said rain gauge interface means including means for processing signals for input to said computer control means;

said data memory stores rainfall data measured by said rain gauge;

said user-selected input parameters includes a predetermined rainfall value; and said microprocessor initiates flow monitoring operations on the basis of said predetermined rainfall value.

4. An apparatus according to claim **1**, wherein:

said integral operating unit further comprises at least one fluid condition monitoring module;

said fluid condition monitoring module being connected with an external connector mounted on an external portion of said unitary case;

said external connector being selectively connectable to a fluid condition sensor means for detecting at least one variable related to a condition of said fluid and outputting signals proportional thereto;

said fluid condition monitoring module including means for processing said signals for input to said computer control means;

said program memory being programmed for computing values of said fluid condition; and

said microprocessor receives said fluid condition signals via said fluid condition monitoring module and utilizes said program memory to calculate values of said fluid condition based on said signals.

5. An apparatus according to claim **4**, wherein:

said fluid condition comprises pH;

said fluid condition sensor means comprises a pH sensor; and

said data memory stores fluid condition data.

6. An apparatus according to claim **4**, wherein:

said fluid condition comprises solution conductivity;

said fluid condition sensor means comprises a conductivity sensor; and

said data memory stores fluid condition data.

7. An apparatus according to claim **4**, wherein:

said fluid condition comprises oxygen reduction potential (ORP);

said fluid condition sensor means comprises an ORP sensor; and

said data memory stores fluid condition data.

8. An apparatus according to claim **4**, wherein:

said fluid condition comprises dissolved oxygen;

said fluid condition sensor means comprises a dissolved oxygen sensor; and

said data memory stores fluid condition data.

9. An apparatus according to claim **4**, wherein:

said integral operating unit further comprises interface means for an external automatic sampling apparatus, said interface means being connected with an external connector mounted on an external portion of said unitary case;

said automatic sampling apparatus interface means including means for processing signals for input to, and output from, said computer control means;

said user-selected input parameters includes at least one predetermined value of said fluid condition; and

said microprocessor sends control signals to said automatic sampling device, via said interface means, to initiate sampling operations by said automatic sampling apparatus on the basis of said user-input at least one predetermined value of said fluid condition.

10. An apparatus according to claim **1**, wherein:

said flow-sensing means includes a fluid level measuring system for measuring fluid depth in said channel and for sending to said microprocessor signals representing depth of fluid in said channel;

said flow-sensing means includes a fluid velocity measuring system operably connected to said microprocessor;

said fluid velocity measuring system operates on the principle of Doppler frequency shift of a transmitted electromagnetic wave;

said fluid velocity measuring system sends to said microprocessor signals representing average velocity of said fluid flow in said channel;

there is provided a keypad operably connected to said microprocessor for entering information into said microprocessor;

said microprocessor calculates cross-sectional area of said fluid in said channel based on channel geometry information entered by a user via said keypad and said signals representing depth of fluid in said channel; and

said microprocessor calculates average flow rate by the equation average flow rate equals average velocity multiplied by said calculated channel cross-sectional area.

11. An apparatus according to claim **10**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

12. An apparatus according to claim **10**, wherein:

said fluid velocity measuring system includes means for obtaining a Doppler shifted frequency signal which is proportional to the speed of moving particles in said fluid;

said fluid velocity measuring system also includes a spectrum analyzer circuit to which said Doppler shifted frequency signal is fed as an input; and wherein the output of said spectrum analyzer circuit is a weighted frequency distribution of its input signal over discrete frequency intervals, and wherein the weighting of each frequency component corresponds to the strength of scattered energy at each velocity interval; and

to obtain average velocity, the centroid of said frequency distribution is calculated and the result is used by said microprocessor for calculating said average flow rate.

13. An apparatus according to claim **12**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

14. An apparatus according to claim 1, wherein:

said program memory stores a plurality of equations for computing values of said at least one flow-related variable;

said microprocessor calculates values of said flow-related variable based on said signals, said user-input fluid flow-related parameter, and a selected one of said stored equations;

said data memory further stores fluid flow-related data;

said processing means comprises a plurality of control modules, each of said control modules being respectively operatively associated with one of said plurality of different types of flow sensing means;

said input means comprises a plurality of connectors mounted on an external portion of said unitary case, each of said connectors being selectively connectable with an associated one of said plurality of flow sensing means; and

each of said control modules is operably connected between an associated one of said plurality of connectors and said computer control means.

15. An apparatus according to claim 14, wherein:

said plurality of control modules comprises a submerged sensor control module, and said plurality of different types of flow sensing means comprises a submerged sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said submerged sensor control module.

16. An apparatus according to claim 14, wherein:

said plurality of control modules comprises a velocity sensor control module, and said plurality of different types of flow sensing means comprises a velocity sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said velocity sensor control module.

17. An apparatus according to claim 14, wherein:

said plurality of equations stored in said program memory include equations for computing values of said at least one flow-related variable with respect to a plurality of different fluid flow restricting devices;

said plurality of equations stored in said program memory further include equations for computing values of said at least one flow-related variable with respect to a plurality of different fluid channel configurations; and

said at least one user-input fluid flow-related parameter comprises a selected fluid flow restricting device or channel configuration.

18. An apparatus according to claim 14, wherein:

said integral operating unit further comprises interface means for an external automatic sampling apparatus, said interface means being connected with an external connector mounted on an external portion of said unitary case;

said automatic sampling apparatus interface means including means for processing signals for input to, and output from, said computer control means;

said user-selected input parameters includes a predetermined value of said flow-related variable; and

said microprocessor sends control signals to said automatic sampling device, via said interface means, to initiate sampling operations by said automatic sampling apparatus on the basis of said user-input predetermined value of said flow-related variable.

19. An apparatus according to claim 14, wherein:

said integral operating unit further comprises interface means for an external pump, said interface means being connected with an external connector mounted on a portion of said unitary case;

said pump interface means including means for processing signals for input to, and output from, said computer control means;

said user-selected input parameters includes a predetermined flow-related variable value; and

said microprocessor initiates operation of said pump on the basis of said predetermined flow-related variable value.

20. An apparatus according to claim 14, wherein:

said plurality of control modules comprises an ultrasonic sensor control module, and said plurality of different types of flow sensing means comprises an ultrasonic sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said ultrasonic sensor control module.

21. An apparatus according to claim 20, wherein:

said ultrasonic sensor control module includes means for supplying acoustic pulses to said ultrasonic sensor, and detector means for receiving echo signals from said ultrasonic sensor; and

said microprocessor controls operations of said ultrasonic sensor control module to optimize settings for said acoustic pulse means and said detector means.

22. An apparatus according to claim 14, further comprising:

display screen means for selectively displaying said data stored in said data memory in either text or graphics form, said display screen means being mounted on an exterior portion of said unitary case;

means for selectively transferring said stored data to an external output device; and

said display means and said transfer means being controlled by said computer control means.

23. An apparatus according to claim 22, wherein:

said transfer means comprises an external connector operatively connected with said computer control means and mounted on said unitary case, and an external portable data transfer unit selectively connectable to said external connector to retrieve data stored by said computer control means; and

said portable data transfer unit is adapted to be in turn selectively connected to an external output device to transfer said data to said output device.

24. An apparatus according to claim 22, wherein:

said transfer means comprises a modem mounted within said unitary case, and an external connector operatively connected with said modem and mounted on said unitary case.

25. An apparatus according to claim 14, wherein:

said plurality of control modules comprises a bubbler sensor control module, and said plurality of different types of flow sensing means comprises a bubbler flow sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said bubbler sensor control module.

26. An apparatus according to claim 25, wherein:

said bubbler sensor control module comprises, in addition to said processing means:

an air pump operatively connected with an air reservoir so as to pressurize said reservoir;

air flow restriction means connected to said reservoir; and

first pressure sensing means connected between said air flow restriction means and said reservoir, and second pressure sensing means connected downstream of said reservoir;

said associated one of said connectors is connected to said air pump downstream of said second pressure sensing means;

said microprocessor receives signals from said first and second pressure sensing means, and calculates the difference in pressure between said first and second pressure sensing means; and

said microprocessor is connected to said air pump so as to operate said pump to maintain a predetermined pressure difference between said first and second pressure sensing means.

27. An apparatus according to claim **25**, wherein:

said plurality of control modules further comprises a submerged sensor control module, and said plurality of different types of flow sensing means further comprises a submerged sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said submerged sensor control module.

28. An apparatus according to claim **27**, wherein:

said plurality of control modules further comprises an ultrasonic sensor control module, and said plurality of different types of flow sensing means further comprises an ultrasonic sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said ultrasonic sensor control module.

29. An apparatus according to claim **28**, wherein:

each of said submerged, bubbler, and ultrasonic control modules and its respective associated connector and sensor defines a fluid depth measuring subsystem;

said plurality of control modules further comprises a velocity sensor control module, and said plurality of flow sensing means further comprises a velocity sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said velocity sensor control module;

said velocity sensor control module, said associated connector, and said velocity sensor comprising a fluid velocity measurement subsystem; and

a selected one of said fluid depth measuring subsystems and said fluid velocity measurement subsystem together define an area-velocity sensor system.

30. A bubbler-type fluid flow monitoring apparatus for monitoring at least one variable related to fluid flow in a channel, comprising:

an integral operating unit provided in a unitary case, said integral operating unit including computer means for controlling said apparatus;

a bubbler sensor connector mounted on an external portion of said unitary case and being selectively connectable with a bubbler sensor so as to receive signals related to fluid flow in said channel produced by said bubbler sensor;

power means for supplying power to each element of said apparatus;

said integral operating unit further including bubbler sensor control means connected with said bubbler sensor connector, said bubbler sensor control means comprising:

means for processing said signals for input to said computer control means;

an air pump operatively connected with an air reservoir so as to pressurize said reservoir;

air flow restriction means connected to said reservoir; and

first pressure sensing means connected between said air flow restriction means and said reservoir, and second pressure sensing means connected downstream of said reservoir;

said bubbler sensor connector being connected to said air pump downstream of said second pressure sensing means;

said computer control means comprising a microprocessor, program memory and data memory, wherein:

said data memory stores user-selected input parameters including at least one fluid flow-related parameter; and

said microprocessor receives signals from said first and second pressure sensing means, and calculates the difference in pressure between said first and second pressure sensing means;

said microprocessor is connected to said air pump so as to operate said pump to maintain a predetermined pressure difference between said first and second pressure sensing means; and

said microprocessor receives said signals related to fluid flow from said processing means and calculates values of said at least one flow-related variable based on said signals and said user-input fluid flow-related parameter.

31. An apparatus according to claim **30**, wherein:

said program memory stores a plurality of equations for computing values of said at least one flow-related variable;

said data memory stores fluid flow-related data;

said at least one flow-related variable comprises fluid depth, fluid flow rate and total flow; and

said microprocessor calculates values of said at least one flow-related variable based on said signals, said user-input fluid flow-related parameter, and a selected one of said stored equations.

32. An apparatus according to claim **31**, further comprising:

display screen means for selectively displaying said data stored in said data memory in either text or graphics form, said display screen means being mounted on an exterior portion of said unitary case;

means for selectively transferring said stored data to an external output device; and

said display means and said transfer means being controlled by said computer control means.

33. An apparatus according to claim **31**, wherein:

said integral operating unit further comprises at least one fluid condition monitoring module;

said fluid condition monitoring module being connected with an external connector mounted on an external portion of said unitary case;

said external connector being selectively connectable to a fluid condition sensor means for detecting at least one variable related to a condition of said fluid and outputting signals proportional thereto;

said fluid condition monitoring module including means for processing said signals for input to said computer control means;

said program memory being programmed for computing values of said fluid condition;

said microprocessor receives said fluid condition signals via said fluid condition monitoring module and utilizes said program memory to calculate values of said fluid condition based on said signals; and

said data memory stores said fluid condition data.

34. An apparatus according to claim **30**, wherein:

said at least one flow-related variable comprises fluid depth in said channel; and including:

a keypad operably connected to said microprocessor for entering information into said microprocessor;

a fluid velocity measuring system operably connected to said microprocessor;

said fluid velocity measuring system operates on the principle of Doppler frequency shift of a transmitted electromagnetic wave;

said fluid velocity measuring system sends to said microprocessor signals representing average velocity of said fluid flow in said channel;

said microprocessor calculates cross-sectional area of said fluid in said channel based on channel geometry information entered by a user via said keypad and said fluid depth variable; and

said microprocessor calculates average flow rate by the equation average flow rate equals average velocity multiplied by said calculated channel cross-sectional area.

35. An apparatus according to claim **34**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

36. An apparatus according to claim **34**, wherein:

said fluid velocity measuring system includes means for obtaining a Doppler shifted frequency signal which is proportional to the speed of moving particles in said fluid;

said fluid velocity measuring system also includes a spectrum analyzer circuit to which said Doppler shifted frequency signal is fed as an input; and wherein the output of said spectrum analyzer circuit is a weighted frequency distribution of its input signal over discrete frequency intervals, and wherein the weighting of each frequency component corresponds to the strength of scattered energy at each velocity interval; and

to obtain average velocity, the centroid of said frequency distribution is calculated and the result is used by said microprocessor for calculating said average flow rate.

37. An apparatus according to claim **36**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

38. An apparatus for monitoring at least one variable related to fluid flow, and at least one non-flow related fluid condition variable, of fluid in a channel, comprising:

an integral operating unit provided in a unitary case, said integral operating unit including computer means for controlling said apparatus and first input means for receiving detected signals related to said fluid flow in said channel;

said first input means being selectively connectable to any selected one or more of a plurality of different types of flow-sensing means for producing signals related to said fluid flow in said channel;

said integral operating unit further including first means for processing said signals from each of said plurality of different types of flow-sensing means, for input to said computer control means;

said integral operating unit further including second input means for receiving detected signals related to at least one fluid condition in said channel, said second input means being selectively connectable to at least one fluid condition sensor means for detecting at least one fluid condition and outputting signals proportional thereto;

said second input means including second means for processing said signals from said at least one fluid condition sensor means, for input to said computer control means;

power means for supplying power to each element of said apparatus; and

said computer control means comprising a microprocessor, program memory and data memory, wherein:

said program memory stores a plurality of equations for computing values of said at least one flow-related variable;

said program memory is programmed for computing values of said at least one fluid condition;

said data memory stores user-selected input parameters including at least one fluid flow-related parameter, and further stores fluid flow-related data and fluid condition data;

said microprocessor receives said signals related to fluid flow from said first processing means and calculates values of said at least one flow-related variable based on said signals, said user-input fluid flow-related parameter, and a selected one of said stored equations; and

said microprocessor receives said signals related to said at least one fluid condition from said second processing means and utilizes said program memory to calculate values of said at least one fluid condition based on said signals.

39. An apparatus according to claim **38**, wherein:

said at least one fluid condition comprises pH; and

said at least one fluid condition sensor means comprises a pH sensor.

40. An apparatus according to claim **38**, wherein:

said at least one fluid condition comprises solution conductivity; and

said at least one fluid condition sensor means comprises a conductivity sensor.

41. An apparatus according to claim 38, wherein:

said at least one fluid condition comprises oxygen reduction potential (ORP); and

said at least one fluid condition sensor means comprises an ORP sensor.

42. An apparatus according to claim 38, wherein:

said at least one fluid condition comprises dissolved oxygen; and

said at least one fluid condition sensor means comprises a dissolved oxygen sensor.

43. An apparatus according to claim 38, further comprising:

display screen means for selectively displaying said data stored in said data memory in either text or graphics form, said display screen means being mounted on an exterior portion of said unitary case;

means for selectively transferring said stored data to an external output device; and

said display means and said transfer means being controlled by said computer control means.

44. An apparatus according to claim 38, wherein:

said integral operating unit further comprises interface means for an external automatic sampling apparatus, said interface means being connected with an external connector mounted on an external portion of said unitary case;

said automatic sampling apparatus interface means including means for processing signals for input to, and output from, said computer control means;

said user-selected input parameters includes a predetermined value of said flow-related variable; and

said microprocessor sends control signals to said automatic sampling device, via said interface means, to initiate sampling operations by said automatic sampling apparatus on the basis of said user-input predetermined value of said flow-related variable.

45. An apparatus according to claim 38, wherein:

said integral operating unit further comprises interface means for an external automatic sampling apparatus, said interface means being connected with an external connector mounted on an external portion of said unitary case;

said automatic sampling apparatus interface means including means for processing signals for input to, and output from, said computer control means;

said user-selected input parameters includes at least one predetermined value of said fluid condition; and

said microprocessor sends control signals to said automatic sampling device, via said interface means, to initiate sampling operations by said automatic sampling apparatus on the basis of said user-input at least one predetermined value of said fluid condition.

46. An apparatus according to claim 38, wherein:

said integral operating unit further comprises interface means for an external rain gauge, said interface means being connected with an external connector mounted on a portion of said unitary case;

said rain gauge interface means including means for processing signals for input to said computer control means;

said data memory stores rainfall data measured by said rain gauge;

said user-selected input parameters includes a predetermined rainfall value; and

said microprocessor initiates flow monitoring operations on the basis of said predetermined rainfall value.

47. An apparatus according to claim 38, wherein:

said integral operating unit further comprises interface means for an external pump, said interface means being connected with an external connector mounted on a portion of said unitary case;

said pump interface means including means for processing signals for input to, and output from, said computer control means;

said user-selected input parameters includes a predetermined flow-related variable value; and

said microprocessor initiates operation of said pump on the basis of said predetermined flow-related variable value.

48. An apparatus according to claim 38, wherein:

said first processing means comprises a plurality of control modules, each of said control modules being respectively operatively associated with one of said plurality of different types of flow sensing means;

said first input means comprises a plurality of connectors mounted on an external portion of said unitary case, each of said connectors being selectively connectable with an associated one of said plurality of flow sensing means; and

each of said control modules is operably connected between an associated one of said plurality of connectors and said computer control means.

49. An apparatus according to claim 48, wherein:

said plurality of control modules comprises a bubbler sensor control module, and said plurality of different types of flow sensing means comprises a bubbler flow sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said bubbler sensor control module.

50. An apparatus according to claim 49, wherein:

said plurality of control modules further comprises a submerged sensor control module, and said plurality of different types of flow sensing means further comprises a submerged sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said submerged sensor control module.

51. An apparatus according to claim 50, wherein:

said plurality of control modules further comprises an ultrasonic sensor control module, and said plurality of different types of flow sensing means further comprises an ultrasonic sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said ultrasonic sensor control module.

52. An apparatus according to claim 51, wherein:

said plurality of control modules further comprises a velocity sensor control module, and said plurality of different types of flow sensing means further comprises a velocity sensor which is selectively connectable to an associated one of said connectors so as to be operably connected with said velocity sensor control module.

53. An apparatus according to claim 38, wherein:

said flow-sensing means includes a fluid level measuring system for measuring fluid depth in said channel and for sending to said microprocessor signals representing depth of fluid in said channel;

said flow-sensing means includes a fluid velocity measuring system operably connected to said microprocessor;

said fluid velocity measuring system operates on the principle of Doppler frequency shift of a transmitted electromagnetic wave;

said fluid velocity measuring system sends to said microprocessor signals representing average velocity of said fluid flow in said channel;

there is provided a keypad operably connected to said microprocessor for entering information into said microprocessor;

said microprocessor calculates cross-sectional area of said fluid in said channel based on channel geometry information entered by a user via said keypad and said signals representing depth of fluid in said channel; and

said microprocessor calculates average flow rate by the equation average flow rate equals average velocity multiplied by said calculated channel cross-sectional area.

54. An apparatus according to claim **53**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

55. An apparatus according to claim **53**, wherein:

said fluid velocity measuring system includes means for obtaining a Doppler shifted frequency signal which is proportional to the speed of moving particles in said fluid;

said fluid velocity measuring system also includes a spectrum analyzer circuit to which said Doppler shifted frequency signal is fed as an input; and wherein the output of said spectrum analyzer circuit is a weighted frequency distribution of its input signal over discrete frequency intervals, and wherein the weighting of each frequency component corresponds to the strength of scattered energy at each velocity interval; and

to obtain average velocity, the centroid of said frequency distribution is calculated and the result is used by said microprocessor for calculating said average flow rate.

56. An apparatus according to claim **55**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

57. An area-velocity sensor system for monitoring fluid flow in a channel, comprising, in combination:

a microprocessor;

a fluid level measuring system for measuring fluid depth in said channel and for sending to said microprocessor signals representing depth of fluid in said channel;

a keypad operably connected to said microprocessor for entering information into said microprocessor;

a fluid velocity measuring system operably connected to said microprocessor;

said fluid velocity measuring system operating on the principle of Doppler frequency shift of a transmitted electromagnetic wave;

said fluid velocity measuring system sending to said microprocessor signals representing average velocity of said fluid flow in said channel;

said microprocessor calculates cross-sectional area of fluid in said channel based on channel geometry information entered by a user via said keypad and said signals representing depth of fluid in said channel; and

said microprocessor calculating the average flow rate by the equation average flow rate equals average velocity multiplied by said calculated channel cross-sectional area.

58. A system according to claim **57**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

59. A system according to claim **57**, wherein:

said fluid velocity measuring system includes means for obtaining a Doppler shifted frequency signal which is proportional to the speed of moving particles in said fluid;

said fluid velocity measuring system also includes a spectrum analyzer circuit to which said Doppler shifted frequency signal is fed as an input; and wherein the output of said spectrum analyzer circuit is a weighted frequency distribution of its input signal over discrete frequency intervals, and wherein the weighting of each frequency component corresponds to the strength of scattered energy at each velocity interval; and

to obtain average velocity, the centroid of said frequency distribution is calculated and the result is used by said microprocessor for calculating said average flow rate.

60. A system according to claim **59**, wherein:

flow direction is obtained by detecting a relative phase difference between said transmitted electromagnetic wave and a quadrature shifted transmitted electromagnetic wave;

and means are provided for processing said transmitted electromagnetic wave and said quadrature shifted transmitted electromagnetic wave to obtain an actual Doppler wave and a quadrature shifted Doppler wave; and

said actual Doppler wave and said quadrature shifted Doppler wave are input into direction sensing firmware which assigns a direction to the velocity before it is transmitted to said microprocessor.

* * * * *

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United States Patent [19]

Gaston et al.

[11] **Patent Number: 5,743,136**

[45] **Date of Patent: Apr. 28, 1998**

[54] **FLUID LEVEL SENSOR WITH RESISTIVE AND CONDUCTIVE LAYERS**

[75] Inventors: **Robert Duane Gaston**, Dearborn Heights; **Narayanaswamy Rajendran**, Canton, both of Mich.

[73] Assignee: **Ford Motor Company**, Dearborn, Mich.

[21] Appl. No.: **534,780**

[22] Filed: **Sep. 27, 1995**

[51] **Int. Cl.**^{6} **G01F 23/36**; G01F 23/52; G01F 23/60

[52] **U.S. Cl.** **73/313**; 73/308

[58] **Field of Search** .... 73/304 R, 308, 73/313, 317, 319; 338/33

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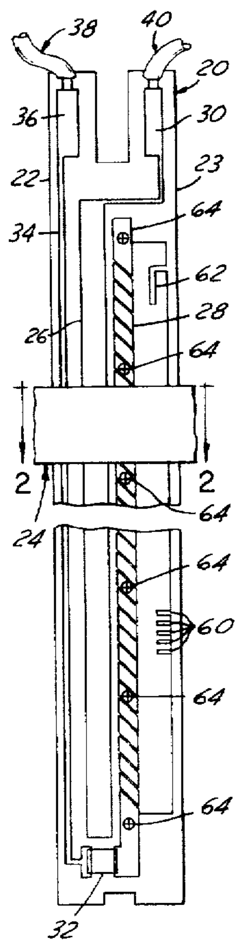
Primary Examiner—William L. Oen
Attorney, Agent, or Firm—Mark S. Sparschu

[57] **ABSTRACT**

In one embodiment of the present invention, a fluid level sensor includes a resistive element and a float coupled to a contact. The float moves in response to the fluid level, causing the contact to follow a path on the resistive element. The resistive element includes a layer of resistive material disposed on an insulating substrate. The resistive element also includes a layer of conductive material disposed on the layer of resistive material. The conductive material is disposed in segments along the path followed by the contact. This embodiment of the present invention provides a high-durability fluid level sensor which further provides low electrical noise.

9 Claims, 3 Drawing Sheets



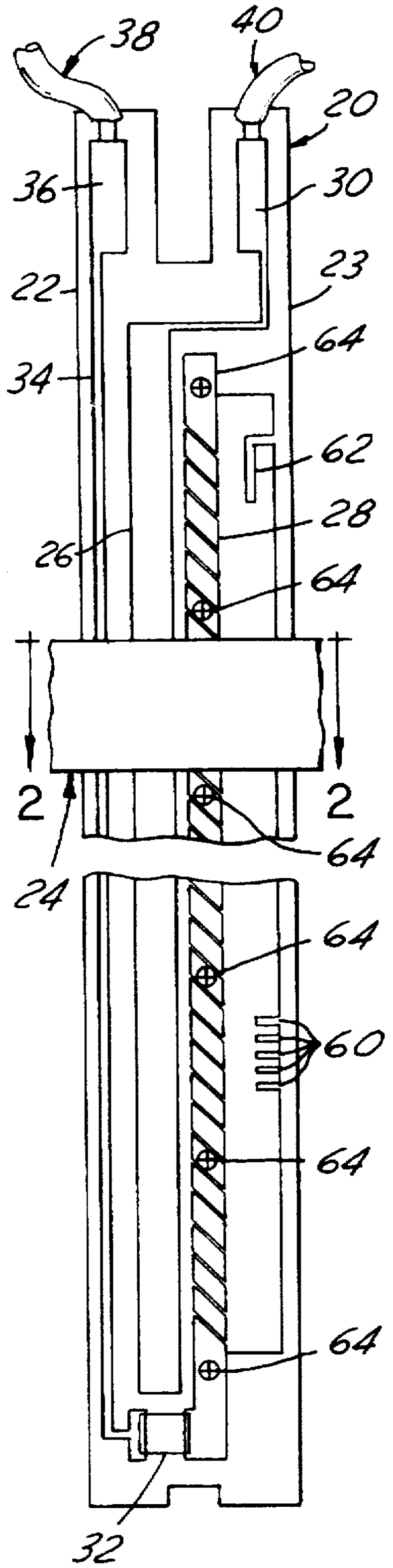


FIG. 1

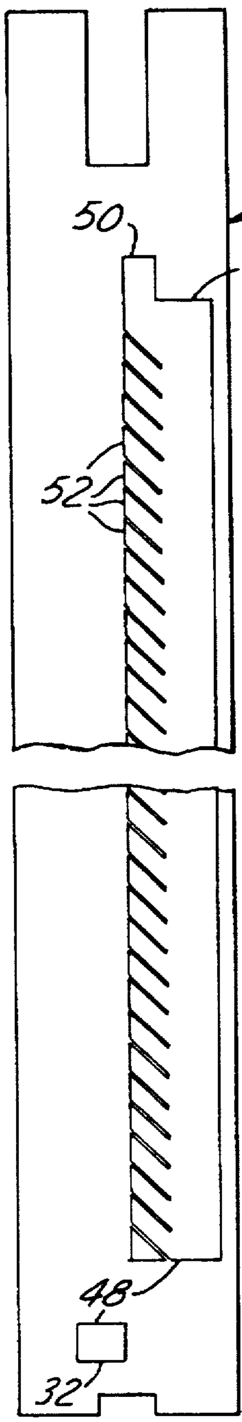


FIG. 3

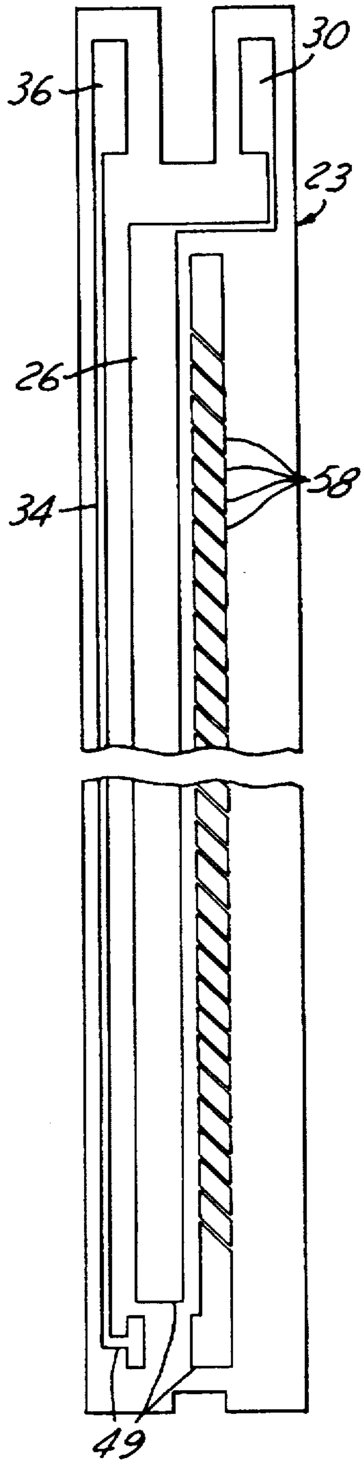


FIG. 4

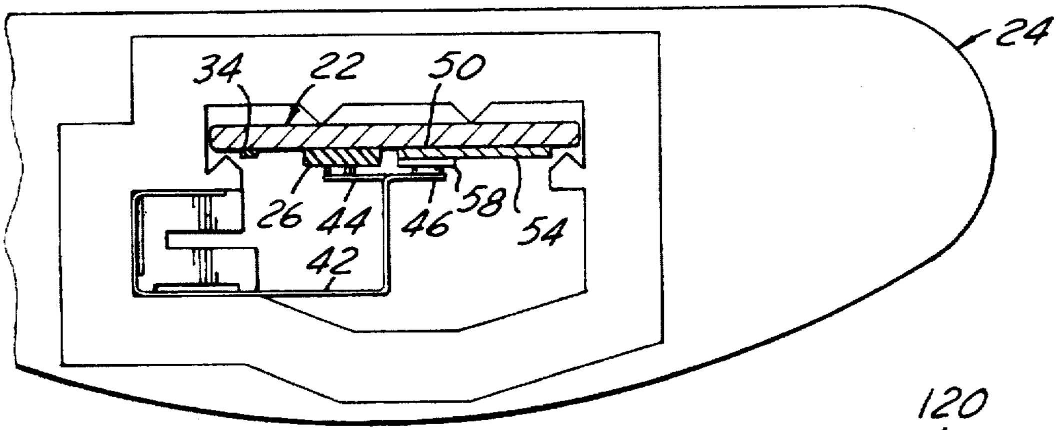

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FIG.2

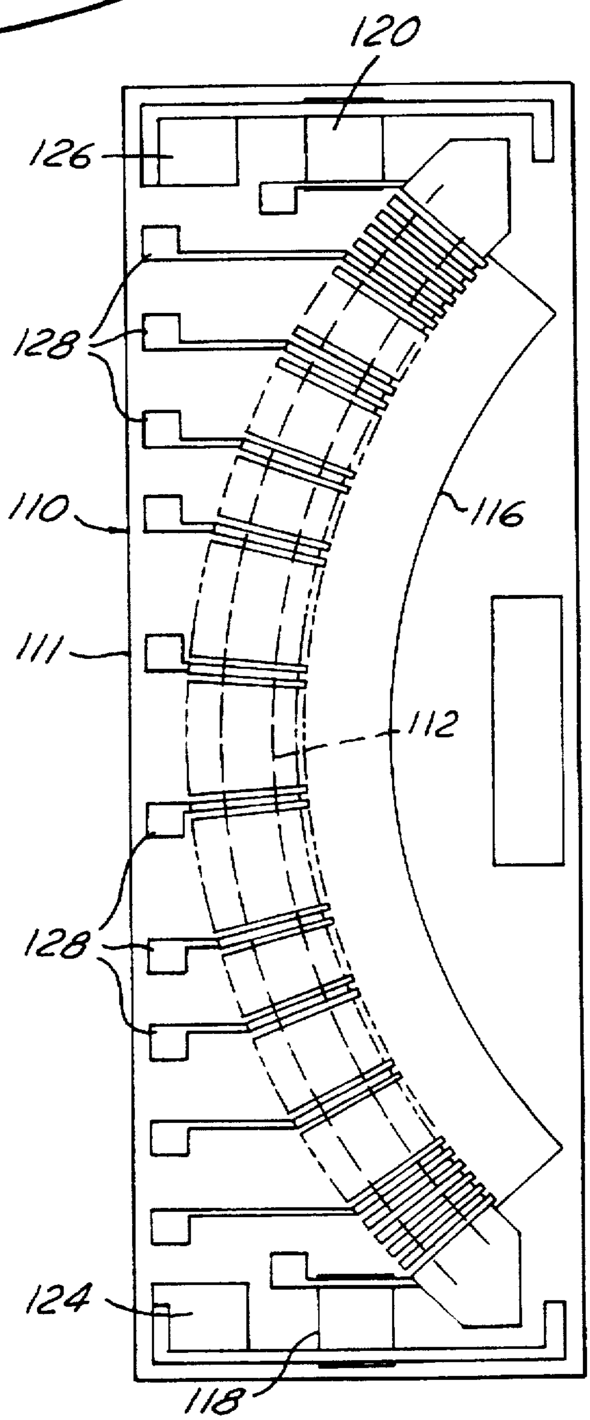
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FIG.5

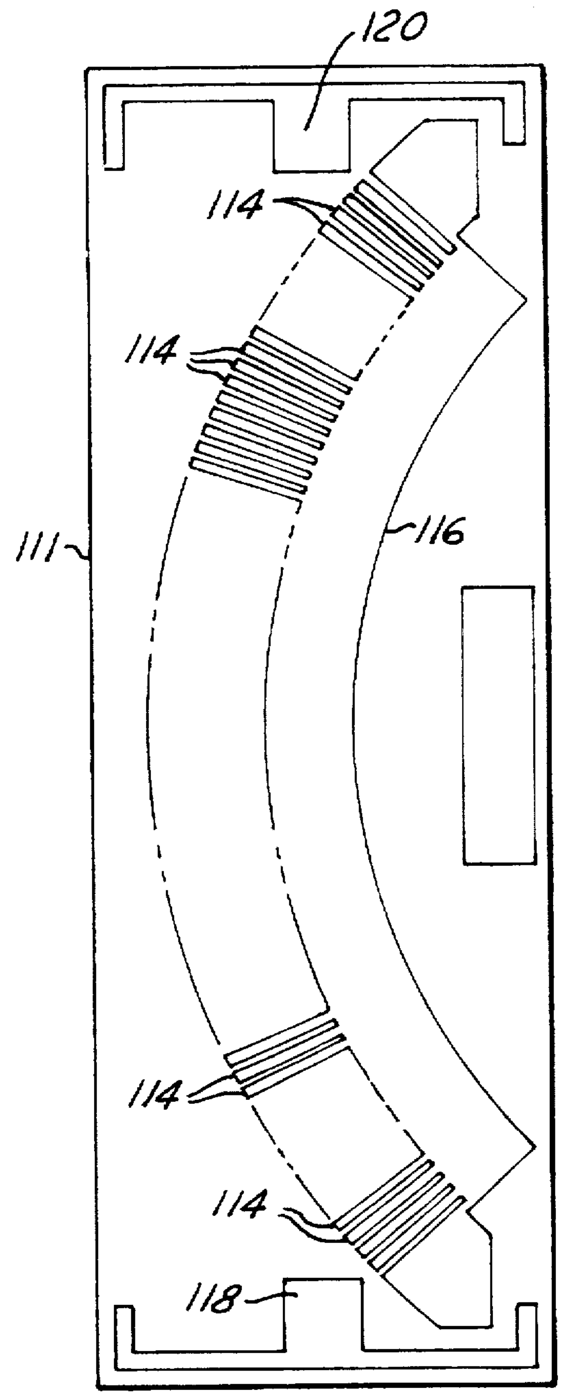

FIG. 6

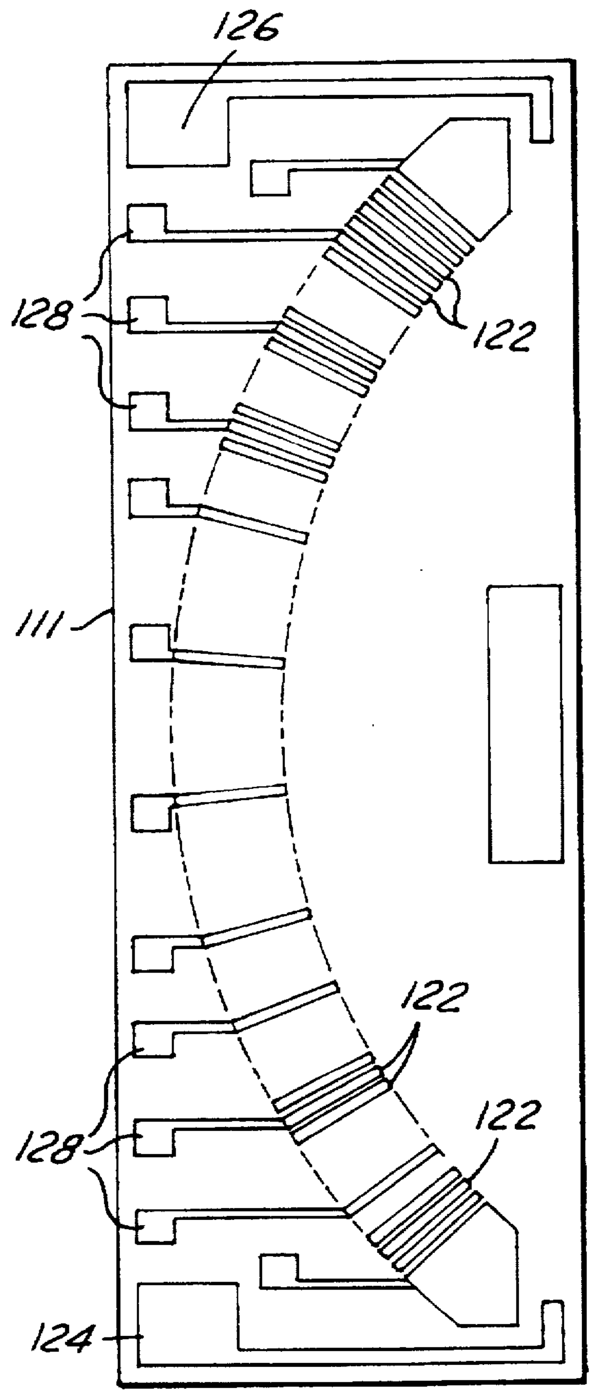

FIG. 7

FLUID LEVEL SENSOR WITH RESISTIVE AND CONDUCTIVE LAYERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to fluid level sensors.

2. Description of the Related Art

In sensing the level of fuel in the fuel tank of a motor vehicle, a conventional fuel level sensor has a resistor card. The conventional fuel level sensor also has a float which follows the level of fuel in the fuel tank. Responsive to the movement of the float is a contact which follows a path on the resistor card. Through this movement of the contact in response to the fuel level in the tank, a variable resistance is provided by the fuel level sensor. A fuel gauge electrically coupled to the fuel level sensor measures the variable resistance and displays the level of fuel in the fuel tank.

In a conventional fuel level sensor, the path followed by the contact is along metallized conductors running transverse to the path followed by the contact. The conductors are all in electrical contact with resistive ink applied to the resistor card. A concern with such a configuration is that the contact will, under some circumstances, wear through the conductors. This will cause an open circuit in the fuel level sensor for some fuel levels.

A solution to this problem has been proposed in U.S. Pat. No. 4,931,764, issued to Gaston. In the '764 patent, a layer of resistive material is applied over the conductors ("overprinted") to provide added wear resistance.

Although the approach in the '764 patent is extremely effective in preventing wear of the conductors, the overprinted resistive material is less "friendly" of a material on which to travel for the contact of the fuel level sensor. One manifestation of this situation is that the relatively coarse resistive material provides a somewhat electrically "noisy" signal. In some fuel gauges, this noisy signal can provide a concern regarding proper operation of the gauge.

One proposed solution to this shortcoming of the design of the '764 patent is the addition of an additional overprint of conductive material on top of the resistive overprint. As can be appreciated, this design begins to get very expensive, having three layers (conductors, resistive overprint and conductive overprint) printed on the resistor card.

Therefore, a highly-durable fluid level sensor which reduces electrical noise without requiring three printed layers will provide advantages over alternative fuel level sensor designs.

SUMMARY OF THE INVENTION

The present invention provides a sensor for measuring a level of liquid in a vessel. The sensor comprises a resistor element having an insulating substrate and a float adapted to move in response to the liquid level. Also, the sensor includes a contact responsively coupled to the float and disposed to travel in a path on the resistor element, the travel responsive to the movement of the float in response to the liquid level. Additionally, the sensor comprises a resistive layer deposited on the insulating substrate, at least a portion of the resistive layer located along the path followed by the contact. Further, the sensor includes conductive segments deposited on the resistive layer along the path, the conductive segments disposed such that travel of the contact along its path will result in the contact successively contacting the segments.

The present invention also provides a resistor element for a fluid level sensor. The resistor element comprises an insulating substrate and a path adapted for travel by an electrical contact in response to the fluid level. Further, the resistor element includes a resistive layer deposited on the insulating substrate, at least a portion of the resistive layer located along the path. Also, the resistor element comprises conductive segments disposed on the resistive layer along the path, the conductive segments disposed such that travel of the contact along the path will result in the contact successively contacting the conductive segments.

The present invention provides a highly-durable fluid level sensor having low electrical noise. These advantages are provided without needing three printed layers of conductive and/or resistive material in the sensor. The present invention thus provides substantial advantages over alternative designs.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front view of a fluid level sensor **20** according to one embodiment of the present invention

FIG. **2** is a top cross-sectional view of fluid level sensor **20** taken through line **2—2** of FIG. **1**.

FIG. **3** is a front view of the substrate **23** of fluid level sensor **20** with a resistive layer **48** applied.

FIG. **4** is a front view of the substrate **23** of fluid level sensor **20** with a conductive layer **49** applied.

FIG. **5** is a front view of a resistor card **110** for a fluid level sensor according to a second embodiment of the present invention.

FIG. **6** is a front view of the substrate **111** of resistor card **110** with a resistive layer applied.

FIG. **7** is a front view of the substrate **111** of resistor card **110** with a conductive layer applied.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, a fuel level sensor **20** according to one embodiment of the present invention will be described. Fuel level sensor **20** includes a resistor element **22** and a float **24**. Fuel level sensor **20** is preferably suspended vertically in a fuel tank of a motor vehicle. Float **24** moves up and down with the level of fuel in the fuel tank.

Resistor element **22** has a substrate **23** preferably comprising metal coated with electrically-insulating ceramic material. Disposed on the substrate **23** of resistor element **22** are two tracks **26** and **28**. Track **26** is made of high-conductivity material and is connected to solder pad **30**. Track **28** is connected via fixed resistor **32** and conductor **34** to solder pad **36**. Track **28** is designed to be electrically resistive. The construction of track **28** will be described in more detail below.

Wires **38** and **40** are soldered to solder pads **30** and **36** for connection of fuel level sensor **20** to an analog or digital fuel gauge (not shown).

As an alternative to soldering wires **38** and **40** directly to resistor element **22**, an edge-board-type connector having spring-loaded terminals crimped and/or soldered to wires **38** and **40** can be employed. With the edge-board connector in place on resistor element **22**, the terminals would be biased against pads **30** and **36**.

With the two electrical termination points for resistor element **22** preferably at the top of resistor element **22**, the potential for float **24** to become entangled with wires **38** and **40** is very low. This is to be compared with the somewhat greater potential for entanglement if the termination points for wires **38** and **40** are at the bottom of resistor element **22**.

Referring now additionally to FIG. 2, it is seen that float 24 includes a contact member 42 having contacts 44 and 46 which are electrically coupled to one another and are further biased against resistor element 22. Contact 44 rides in contact with track 26 as float 24 moves up and down. Likewise, contact 46 rides in contact with track 28 as float 24 moves up and down. Thus, as float 24 moves up and down with the level of fuel in the fuel tank, a variable resistance is coupled between solder pads 30 and 36. When float 24 is at its lowest extent (i.e., when the fuel tank is empty), fixed resistor 32 is coupled between solder pads 30 and 36.

If more information about the design of float 24 and contact member 42 is required, the reader is directed to U.S. Pat. No. 5,267,475, issued to Gaston, the disclosure of which is hereby incorporated by reference.

The construction of resistor element 22 will be described with reference to FIG. 3. Resistor material 48 is applied to the insulating substrate of resistor element 22. The resistor material 48 includes a first portion 50 along the path followed by contact 46 of float 24 (FIG. 2). This first portion 50 is divided into discrete segments 52.

Resistor material 48 further comprises a trim section 54. This trim section 54 is joined to segments 52 of first portion 50.

Resistor material 48 also comprises fixed resistor 32.

Resistor material 48 can be a number of materials, among them palladium-type or ruthenium-type resistive ink. The ink is preferably applied by a silk-screen thick-film process.

Now, with additional reference to FIG. 4, conductor material 49 is applied in the locations shown in FIG. 4. Note that the resistor material 48 described with reference to FIG. 3 is not shown in FIG. 4 for clarity of presentation.

The conductor material 49 includes track 26, conductor 34 and solder pads 30 and 36, as previously described with reference to FIG. 1. The conductor material 49 also includes a series of discrete pads 58. Pads 58 are electrically isolated from one another (but for the fact that they are in electrical communication with one another through resistor material 48 (FIG. 3). Pads 58 are located coincidentally on top of segments 52 of resistor material 48. Pads 58 are spaced such that contact 46 (FIG. 2) is always in contact with at least one pad 58, unless perhaps when float 24 is at the extreme top or bottom of its travel. That is, contact 46 will experience no discontinuities between pads 58.

The conductor material 49 can be a number of high-conductivity materials including high-silver-content silver-palladium ink. The ink is preferably applied by a silk-screen thick-film process.

It should be noted that both resistive segments 52 and conductive pads 58 are angled downward, in the direction that float 24 (FIG. 1) travels as the fuel level in the fuel tank is decreasing. This downward angling helps assure that contact 46 of float 24 does not get "hung up" (that is, stuck) at the boundary between two pads 58. This concern about contact 46 getting "hung up" is really only a potential concern when fuel level is decreasing. When fuel level is increasing (that is, when the fuel tank is being filled), float 24 has sufficient buoyancy to be reliably raised by the increasing fuel level.

The high reliability with which float 24 will move downward in the present design means that float 24 can be made less massive (and therefore smaller) than would otherwise be required. The reduced size of float 24 means that float 24 can move closer to the bottom and top of resistive element

22 in sensing fuel level. This provides increased flexibility in designing a fuel tank/fuel level sensor system.

As can be appreciated from the preceding discussion of FIGS. 1–4, as fuel level varies and float 24 moves up and down, a variable resistance will be provided between solder pads 30 and 36. This variable resistance is indicative of the fuel level in the fuel tank. When the fuel tank is empty and float 24 is at the bottom of its travel, fixed resistor 32 is coupled between solder pads 30 and 36.

As needed, trim section 54 of the resistor material 48 of fuel level sensor 20 can be trimmed to assure that the resistance provided by fuel level sensor 20 at test points 64 is precisely to specification. The trimming can include straight trims 60; "L"-shaped trims 62 or abrasions in the trim section 54 to modify the resistance of fuel level sensor 20.

The design of fuel level sensor 20 reduces electrical noise which can otherwise be generated by contact 46 riding on relatively coarse resistive material. As was illustrated with reference to FIGS. 3 and 4, only two printing steps (versus three in alternative designs) are used.

Referring now to FIG. 5, an angular resistive element 110 for a fuel level sensor will be described. Resistive element 110 is designed for use in conventional fuel level sensors having a float attached to an arm. The float moves up and down with fuel level, moving a contact along a path 112. Resistive element 110 comprises a resistive layer and a conductive layer applied to an insulating substrate 111.

FIG. 6 shows a resistive layer applied to substrate 111. This resistive layer includes resistor material disposed in segments 1 14 disposed along path 112 (FIG. 5). These segments 114 are spaced apart by a small spacing. Segments 114 all contact a trim section 116. Fixed resistors 118 and 120, formed of resistor material, are also provided.

FIG. 7 shows a conductive layer which is added after the resistive layer. Note that the resistive layer of FIG. 6 is omitted in FIG. 7 for clarity of presentation. The conductive layer includes discrete pads 122, which are disposed coincidentally on segments 114 of resistor material. The conductive layer further includes solder pads 124 and 126. Additionally, the conductive layer includes test pads 128, for testing the resistance of the fuel level sensor containing resistive element 110.

Referring again to FIG. 5, a wire (not shown) is soldered to solder pad 124 or 126, depending upon which end of resistor element 112 is approached by the contact as the fuel level in the fuel tank decreases. A second wire is customarily coupled to the contact which moves along path 112 as the fuel level in the fuel tank changes. A variable resistance between those two wires is thus provided. This resistance is a function of the fuel level in the fuel tank and can be measured by a fuel gauge.

Depending upon which solder pad 124 or 126 is employed, fixed resistor 118 or 120 provides a fixed resistance value when the fuel level in the fuel tank is empty.

Trim section 116 can be trimmed as necessary such that the resistance of resistive element 110 is within specification at all test points 128. This trimming can be done in any of the variations discussed in relation to FIG. 1.

Various other modifications and variations will no doubt occur to those skilled in the arts to which this invention pertains. Such variations which generally rely on the teachings through which this disclosure has advanced the art are properly considered within the scope of this invention. This disclosure should thus be considered illustrative, not limiting; the scope of the invention is instead defined by the following claims.

What is claimed is:

1. A sensor for measuring a level of liquid in a vessel, said sensor comprising:

a resistor element having an insulating substrate;

a float;

a contact responsively coupled to said float and slidably biased against said resistor element, slidable movement of said contact with respect to said resistor element defining a path traveled by said contact along said resistor element;

a resistive layer deposited on said insulating substrate, at least a portion of said resistive layer located along said path; and

conductive segments deposited on said resistive layer along said path, said conductive segments disposed such that travel of said contact along said path will result in said contact successively contacting said segments.

2. A sensor as recited in claim 1, wherein said portion of said resistive layer located along said path comprises segments substantially coincident with said segments of said conductive layer.

3. A sensor as recited in claim 1, wherein said segments are angled toward a direction traveled by said contact when said liquid level drops.

4. A sensor as recited in claim 1, wherein said segments are

said resistive layer comprises a portion from which material has been removed for adjustment of a resistance of said resistor element; and

said portion is located adjacent to an edge of said resistor element.

5. A sensor as recited in claim 1, wherein said path is substantially straight.

6. A sensor as recited in claim 5, wherein said path is substantially vertical.

7. A sensor as recited in claim 6, wherein:

said resistive element further comprises a conductive track generally parallel to said path;

said resistive element further comprises a first electrical termination point adjacent to an uppermost portion of said resistive element and in electrical communication with said conductive track; and

said resistive element further comprises a second electrical termination point adjacent to an uppermost portion of said resistive element and in electrical communication with said resistive layer.

8. A sensor as recited in claim 7, wherein said electrical termination points comprise solder pads formed of conductive material disposed on said resistive element.

9. A sensor as recited in claim 1, wherein said path is substantially arcuate.

* * * * *

US006269695B1

(12) **United States Patent**
Cesternino et al.

(10) **Patent No.: US 6,269,695 B1**
(45) **Date of Patent: Aug. 7, 2001**

(54) **ANALOG LIQUID LEVEL SENSOR**

(75) Inventors: **Kimberly Cesternino**, Kentwood; **Peter H. Strom**, Big Rapids, both of MI (US)

(73) Assignee: **Nartron Corporation**, Reed City, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/035,712**

(22) Filed: **Mar. 5, 1998**

(51) **Int. Cl.**[7] **G01F 23/36**; G01F 23/52; G01F 23/60; G01F 23/56; H01C 10/14

(52) **U.S. Cl.** .... **73/313**; 73/290 R; 73/305; 73/319; 338/33

(58) **Field of Search** .... 73/313, 319, 322.5 R, 73/304 R, 305; 338/33

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* cited by examiner

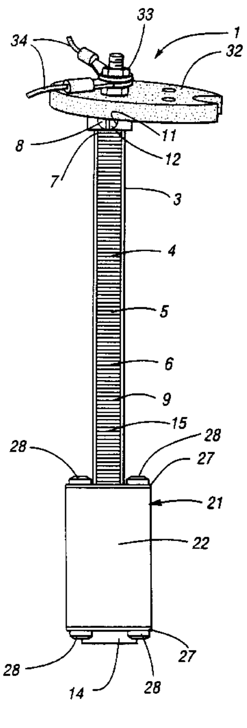
Primary Examiner—Hezron Williams
Assistant Examiner—Dennis Loo

(74) *Attorney, Agent, or Firm*—Brooks & Kushman P.C.

(57) **ABSTRACT**

Two embodiments of an analog liquid level sensor are provided for measuring the level of a liquid in a container having a volume/depth relationship wherein each sensor has a resistance-to-float-displacement profile matched to the volume/depth relationship of the container. Each sensor includes a dielectric coated metal bar which acts as a heat sink and a ground plane. A pair of electrically spaced terminals and a printed circuit including a thick film resistor pattern and a metallization pattern having metallized graduations are formed on the metal bar for reduced electrical noise characteristics and improved hysteresis. The resistance of the resistor pattern is electrically coupled between the terminals and has a resistance which varies at different positions between the terminals. The metallization pattern is formed on the resistor pattern which, in turn, is formed on opposite sides of the dielectric coated metal bar. A float assembly including a buoyant housing and a contact assembly is connected to the dielectric coated metal bar to reciprocate in a generally vertical direction in response to the level of the liquid in the container. The contact assembly is connected to the buoyant housing in a fixed vertical relationship thereto for making electrical connection with the metallization pattern and for changing the effective resistance of the resistor pattern between the terminals. The contact assembly includes a pair of spring-loaded wiper contacts for making electrical connection with the graduations of the metallization pattern on opposite sides of the metal bar. The terminals provide an electrical signal which is a function of the vertical position of the wiper contacts along the metal bar.

12 Claims, 4 Drawing Sheets



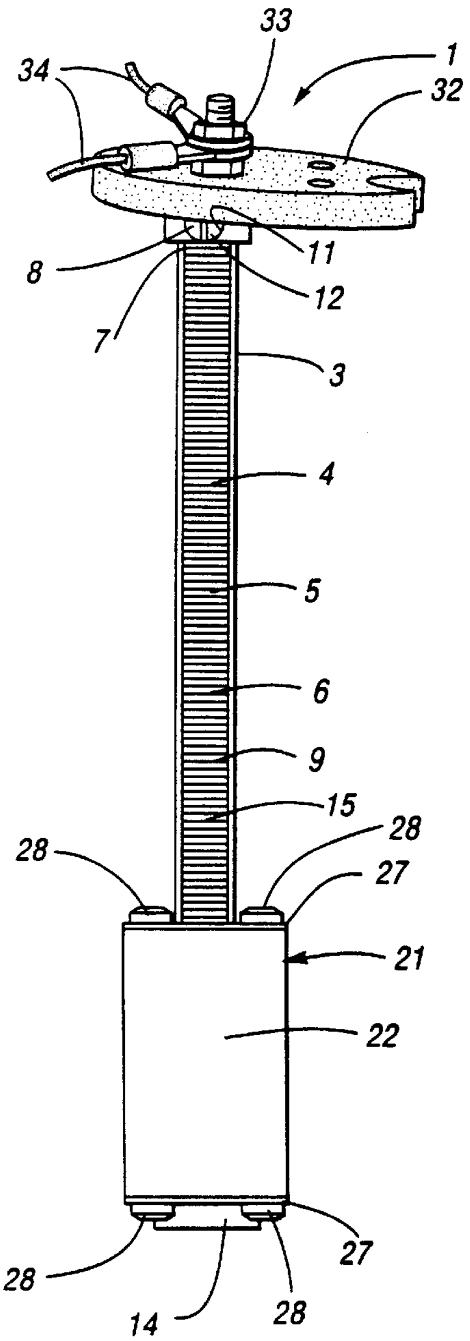


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Fig. 1a

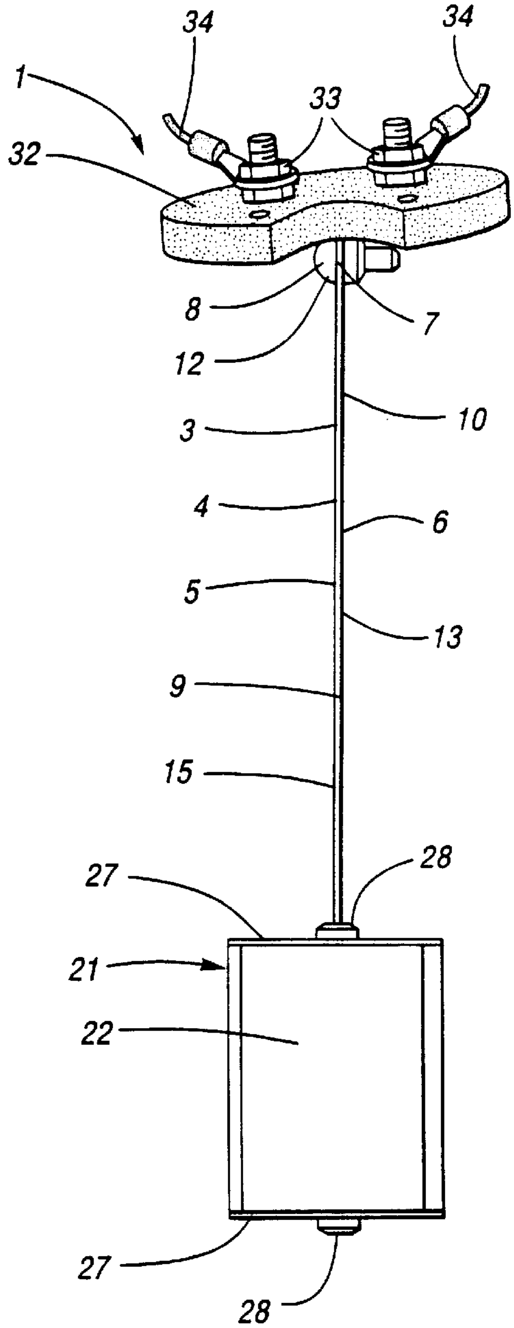

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Fig. 1b

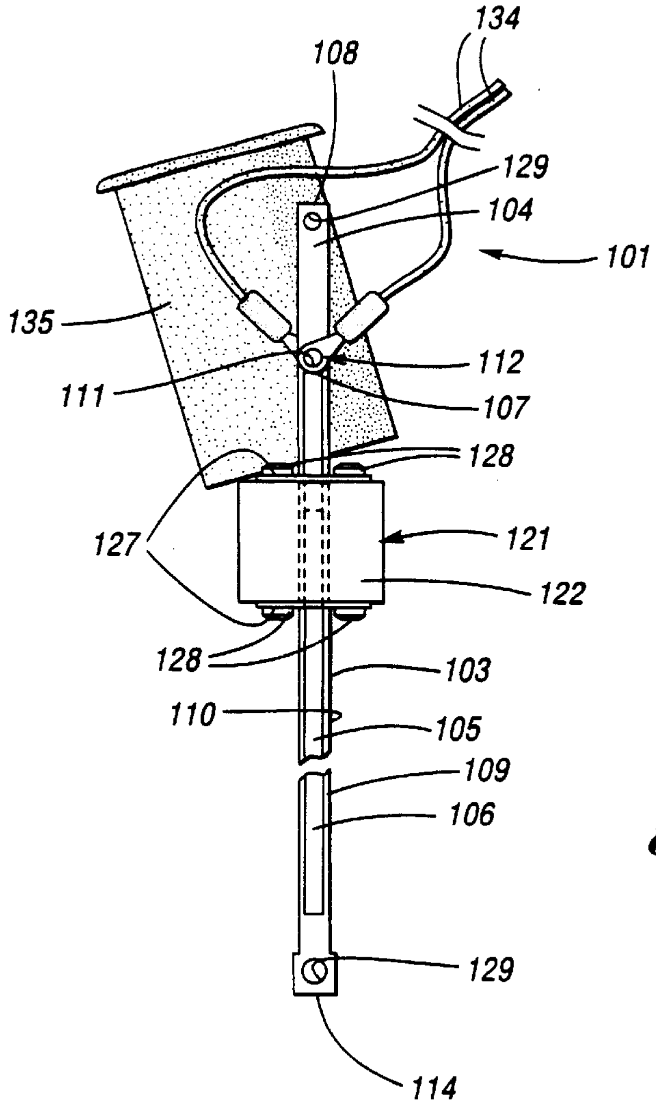
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Fig. 2

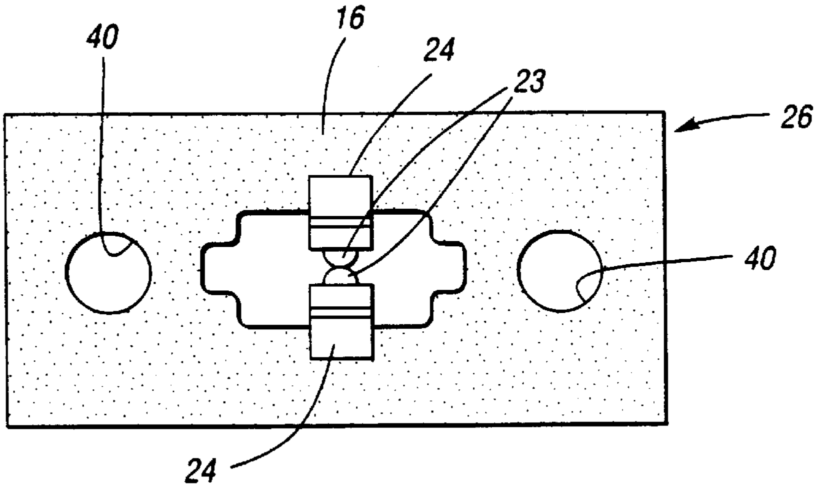
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Fig. 3a

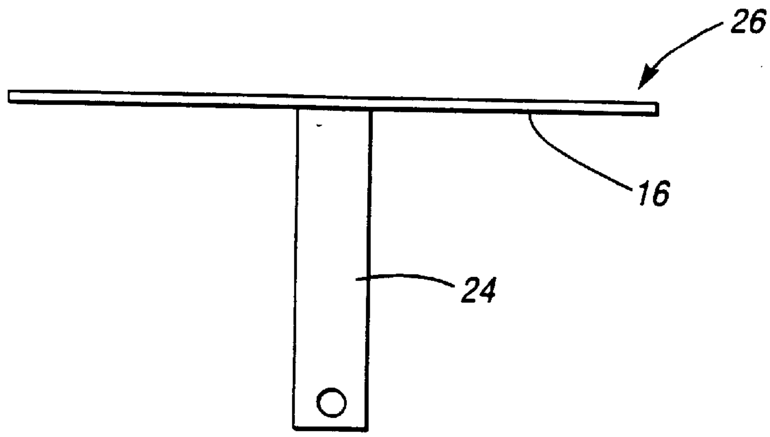

Fig. 3b

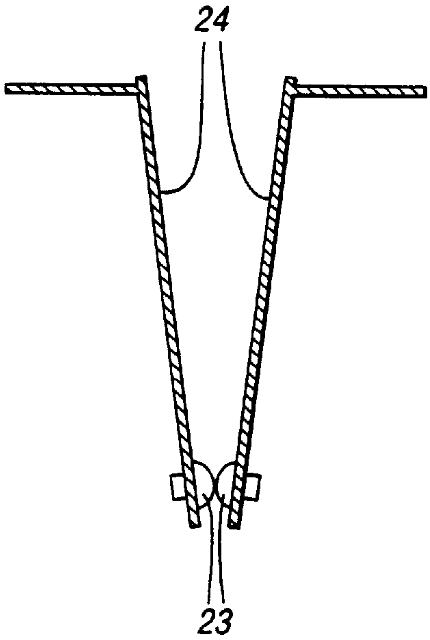

Fig. 3c

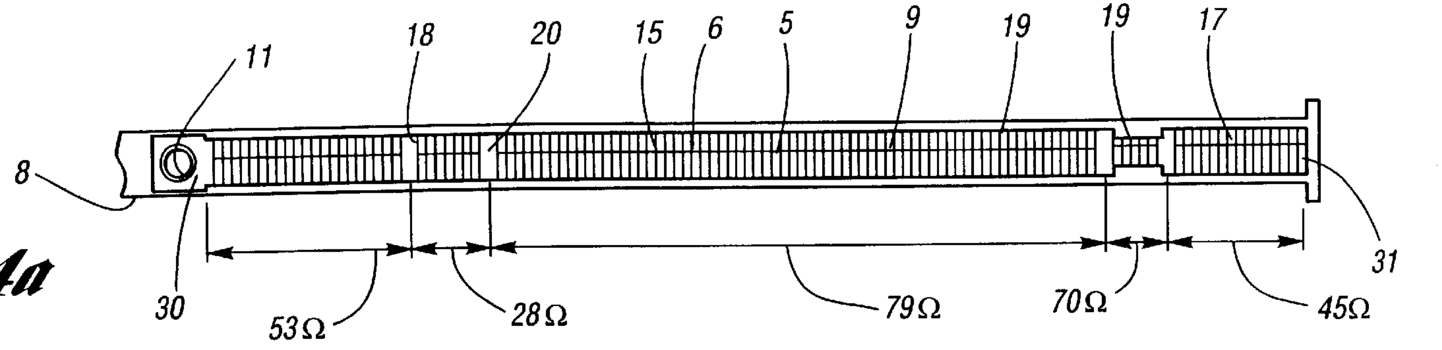

Fig. 4a

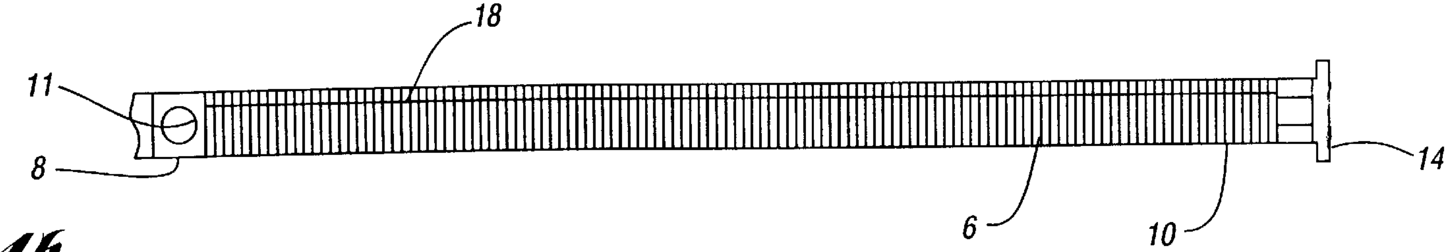

Fig. 4b

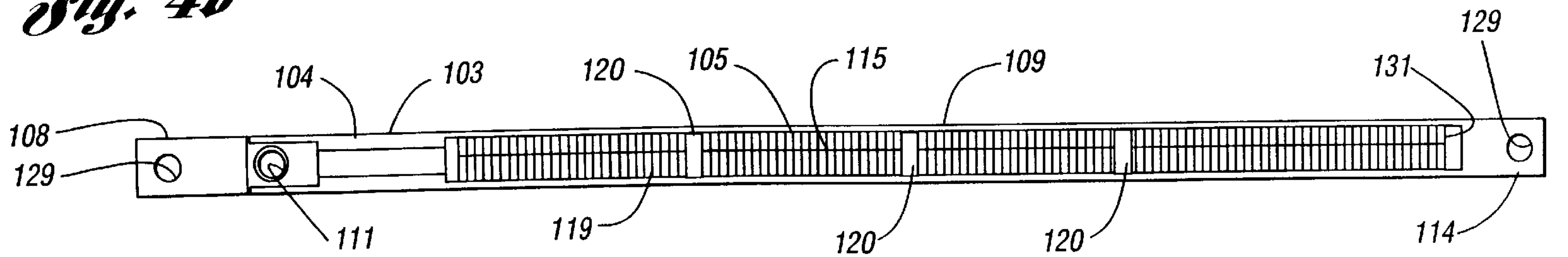

Fig. 5a

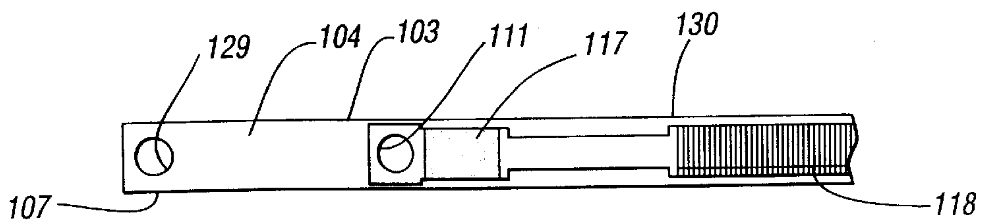

Fig. 5b

ANALOG LIQUID LEVEL SENSOR

TECHNICAL FIELD

This invention relates to liquid level sensors and, in particular, to analog liquid level sensors.

BACKGROUND ART

A large number of sensing approaches and transducer types have been developed for the determination of the level of liquids in open or closed vessels or containers. Not only is the knowledge of the level itself important, but other measurements can be inferred from the level. For example, if the container geometry and dimensions are additionally known, the volume of the liquid can be determined. If additionally, the density of the liquid is known, its mass can be calculated.

Relatively high technology methods to sense liquid level by measurement of properties such as distance, time, and pressure include: sonic and ultrasonic surface reflection, optical surface reflection, optical transmission, rotation of polarized light, capacitive property sensing, dielectric conduction between electrodes, inductive property sensing, mechanical resonance damping, float device containing a magnet affecting pulse reflection of a ferromagnetic strip, float containing an end of a linear variable differential transformer, pressure sensor at bottom of the tank, differential pressure sensor bubbling tube at bottom of the tank, long vertical float buoyancy force, long vertical negative buoyancy force, sight gauge with multiple optical level discrimination, multiple thermistors, tank sonic resonance spectra correlations, and the like. These methods typically have cost and complexity as their major detriment.

Liquid level is generally sensed by one of two methods: obtaining a discrete indication if a predetermined level has been reached (i.e. point sensing) or obtaining an analog representation of the level as it changes (i.e. continuous sensing). One commonly employed apparatus for continuously sensing the level of liquid, such as a fuel, in fuel storage tanks is the use of a float mechanism.

Relatively low technology methods currently being used to sense liquid levels by measurement of various properties use techniques such as: ohmic conduction between electrodes, variable force sensitive resistive conductors, float moving a plunger, and float on a mechanical pivot arm moving a wiper contact element across a wire wound or thick film resistor. The ohmic conduction method is prone to detrimental accuracy impairing contamination and electrolytic effects on the electrodes. Variable force sensitive resistors inherently suffer from poor accuracy and are seldom used. The float moving a plunger method is capable of good accuracy and precision but is cumbersome and requires some additional sensing method to convert position into a sensor signal. The method by which a float rotating a mechanical pivot arm to move an electrical wiper contact across a variable resistor type of liquid level sensor is of primary commercial interest because of its large number of existing and potential applications, relative simplicity, and low cost.

The following listed features pertaining to liquid level sensing via floats on pivot arm mechanisms, however, are less than desirable:

- Requires a relatively large volume of space for pivot arm motion;
- Often requires specific orientation to allow for pivot arm motion;

- Cumbersome to install and remove;
- Large size;
- High weight;
- High parts count;
- Mechanism if often flimsy—heavier mechanism requires a larger float;
- Mechanism has inherent modes of mechanical vibration—potential failures;
- Mechanism is inherently poor in mechanical impact testing—potential failures;
- Relatively large pivot arm movement is reduced to smaller motion of the wiper arm on the wire wound or film resistor—loss of resolution and accuracy;
- Mechanical play, articulation, and tolerance of numerous components introduces hysteresis and adversely affects accuracy;
- Wear of articulating mechanical components increases modes of failure;
- Nonmetallic substrate of the wire wound or thick film resistor acts as a thermal insulator allowing heat build up in events of an incorrect electrical connection—a potential source of ignition for a dangerous incendiary incident;
- Small size of the wire wound or thick film resistor promotes concentration of heat generation and higher temperatures in events of an incorrect electrical connection—an additional potential source of ignition for a dangerous incendiary event;
- Location of the articulating electrical wiper contact with the wire wound or thick film resistor can be above liquid level such that mechanical play can potentially produce a source of sparking and/or heat production—a safety concern;
- Nonmetallic substrate of the wire wound or thick film resistor offers no shielding from spurious magnetic fields that can cause signal noise;
- Nonmetallic substrate of the wire wound or thick film resistor offers no shielding from spurious electric fields that can cause signal noise.

The above detrimental points and limitations present numerous opportunities for improvements.

U.S. Pat. No. 4,779,460 discloses a sensor and system for measuring the level of a liquid and which includes a linear potentiometer having a resistance circuit element and a mechanism for changing the resistance of the circuit element including a conductor formed from a semiconducting composition having a resistance inversely proportional to the horizontal force it experiences.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an improved analog liquid level sensor including a printed circuit having a resistance which varies at different positions on the printed circuit wherein the sensor is provided for a container having a volume/depth relationship and wherein the sensor has a resistance-to-displacement profile matched to the container's volume/depth relationship.

Another object of the present invention is to provide an analog liquid level sensor for a container which is simple to assemble, install and thereafter remove from the container.

Still another object of the present invention is to provide an analog liquid level sensor including a support structure and a printed circuit having a resistance formed on the support structure wherein the support structure acts as a heat sink in order to dissipate any heat build up.

Yet still another object of the present invention is to provide an analog liquid level sensor including at least one metallization pattern having graduations formed on a printed circuit having a resistance for reduced electrical noise characteristics and improved hysteresis.

In carrying out the above objects and other objects of the present invention, in a system for measuring the level of a liquid in a container having a volume/depth relationship, an analog liquid level sensor is provided. The sensor includes a support structure adapted to be received and retained within the container, a pair of electrically spaced terminals, and a printed circuit formed on the support structure and electrically coupled between the terminals and having a resistance which varies at different positions on the printed circuit between the terminals. The sensor also includes a float assembly connected to the support structure to reciprocate in a generally vertical direction relative to the support structure in response to the level of the liquid in the container. The float assembly includes a hollow buoyant housing and a contact assembly supported within the buoyant housing in fixed vertical relationship thereto for making electrical connection with the printed circuit for changing the effective resistance of the printed circuit between the terminals. The terminals provide an electrical signal which is a function of the generally vertical position of the contact assembly along the support structure. The sensor has a resistance-to-float-displacement profile matched to the volume/depth relationship of the container.

Preferably, the support structure is a dielectric coated metal bar which acts like a heat sink.

Also, preferably, the printed circuit includes a resistor pattern and a metallization pattern having metallized graduations formed on opposite sides of the metal bar for reduced electrical noise characteristics and improved hysteresis.

Still further, preferably, the resistor pattern is a thick film resistor pattern and wherein the metal bar acts as a ground plane for the thick film resistor pattern.

Still, preferably, the resistor pattern includes a temperature compensating resistor.

Preferably, the contact assembly includes a pair of spring-loaded wiper contacts for making electrical connection with the graduations of the metallization pattern formed on opposite sides of the metal bar.

In one embodiment, the sensor further includes a mount coupled to the support structure and adapted to mount the support structure to a surface location on the container so that the support structure is allowed to hang within the container in a generally vertical orientation.

The analog liquid level sensor includes material and design enhancements, especially for fuel level applications, which result in numerous improvements in such aspects as: wiring fault condition safety resolution, precision, accuracy, mechanical durability, simple mounting requirements, volume, weight, design flexibility, ease of end use insertion and removal, part count, assembly, size, source impedance and transfer function, submerged articulating electrical contacts, electromagnetic compatibility, and reliability. An analog electrical signal provided by the sensor is intended to be sent to a dedicated electrical gauge or other means of data acquisition.

These improvements are generally realized by an engineered design approach that features integration and simplification of two major functional components resulting in a multiplicity of improvements over existing types of pivot arm liquid level sensors. The first feature is the sturdy dielectric coated steel substrate bar onto which has been deposited the various film resistor patterns and metallization patterns, also called the printed circuit (i.e. PC). The second feature is the float assembly including a buoyancy adjustment capability, close tolerance slide guides, and at least two integral spring loaded wiper contacts to make electrical connection with the metallization patterns of the PC. By moving up and down in a generally vertical manner on the PC, the float assembly level, as buoyed by the liquid, will vary the net or effective PC resistance seen at two electrical terminals usually located at the top of the bar. This combination of features allows for additional application specific simplification enhancements to aspects such as cost, performance, assembly, potential mounting methods, insertion into the application, and removal from the application.

The present invention provides the following advantages over the prior art:

- Sturdy design;
- Fewer parts;
- Less contamination of components by integral and/or surface additives;
- Fewer moving parts;
- Low mass;
- Low cost;
- Simple assembly;
- Design flexibility for float assembly shape and size;
- Design flexibility for mounting configuration;
- Design flexibility for mounting location;
- Simple insertion;
- Simple removal;
- Requires less operation volume within the tank;
- Improved resolution;
- Decreased hysteresis;
- Improved accuracy and stability—due to metallization strips;
- Integral temperature compensation capability;
- Steel substrate acts as a heat sink thus reducing ignition potential;
- Laser trimming for minimum resistance;
- Laser trimming for maximum resistance;
- Laser trimming for transfer function profile accuracy;
- Steel substrate acts as a ground plane for the film resistor for reduced noise attributable to electric and/or magnetic fields; and
- Steel substrate performs also as a structural member.

The above objects and other objects, features, and advantages of the present invention are readily apparent from the following detailed description of the best mode for carrying out the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1***a* and **1***b* are front and side views, respectively, of a specific version of a non-linear liquid level sensor having a "D-shaped" float housing in a fuel "empty" position and a top mounting bracket incorporating two axis angle corrections (i.e. 7° and 12°) for a motorcycle fuel tank level application of the sensor;

FIG. **2** is a front view of a specific version of a liquid level sensor in its fuel "full" position shown without a mounting bracket for a motorcycle fuel tank level application; electrical terminations are made directly to electrical terminal pads of a printed circuit (i.e., PC);

FIGS. **3**a, **3**b and **3**c are top, front and side views, respectively, of a wiper plate terminal assembly and its components which are part of the float assembly of the fuel level sensors of FIGS. **1**a and **1**b and FIG. **2**; the terminal assembly includes a wiper plate preferably made of phosphor bronze and has close clearance tolerances for a very close slip fit with the printed circuit over which it slides, the terminal assembly also preferably includes silver button sliding contacts staked to leaf springs which are preferably resistance welded to the wiper plate;

FIG. **4**a is a front view of a printed circuit formed on a bar for use with the liquid level sensor shown in FIGS. **1**a and **1**b wherein various metallization and resistor patterns are illustrated; resistances are specified versus position and between relative positions of the printed circuit;

FIG. **4**b is a back view of the printed circuit corresponding to the front view of FIG. **4**a;

FIG. **5**a is a front view of a printed circuit formed on a bar for use with the liquid level sensor shown in FIG. **2**; and

FIG. **5**b is an enlarged, broken away view of the printed circuit of FIG. **5**a wherein details of the film layout patterns for the resistors and metallizations are illustrated.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to FIGS. **1**a, **1**b and **2**, two embodiments of an analog liquid level sensor, generally indicated at **1** and **101**, constructed in accordance with the present invention are illustrated. Both embodiments are described concurrently herein.

The sensors **1** and **101** include support structures in the form of low carbon steel substrate bars **3** and **103**, respectively, (each of which has approximate dimensions of 1/16 inch thick×5/16 inch wide×15 inch long), onto which is fired a ceramic dielectric coatings **4** and **104**, ELPOR®, respectively, onto which is deposited a thick film resistor patterns **5** and **105**, respectively. Palladium metallization patterns **6** and **106** are placed onto both the ceramic coatings **4** and **104**, respectively, and the thick film resistor patterns **5** and **105**, respectively. The coated bars **3** and **103**, with the coatings **4** and **104** and the patterns **5**, **6**, **105** and **106** formed thereon, are commercially available from Ferro-ECA Electronics Co. The patterns **5**, **6**, **105** and **106** are collectively referred to as a printed circuit (PC).

The electrical circuits of the sensors **1** and **101** begin and end with the metallization patterns **6** and **106**, respectively, as electrical termination pads **7** and **107**, respectively, near the tops **8** and **108**, respectively, of the bars **3** and **103**, respectively. For example, they may be located one and one-half inches from the tops **8** and **108**, on both the front faces **9** and **109** and back faces **10** and **110** of the bars **3** and **103**, respectively, and proximate through holes **11** and **111** for mounting mechanical terminals **12** and **112**, respectively.

On the back faces **10** and **110** the metallization patterns **6** and **106**, respectively, are relatively wide rectangular strips (having approximate dimensions of 3/16 inch×13 inch), running nearly to the bottoms **14** and **114** of the bars **3** and **103**, respectively. For example, the patterns **6** and **106** run to approximately two-thirds of an inch from the bottoms **14** and **114**, respectively.

On the front faces **9** and **109**, the metallization patterns **6** and **106**, respectively, are laid out in multiple horizontal stripes **15** and **115** (FIG. **5**a) (approximate dimensions 1/80 inch×5/32 inch), for purposes of contact with an electrical wiper **16** of an assembly **26** (FIGS. **3**a–**3**c), yet allowing the resistive impedance of the thick film resistor patterns **5** and **105** to dominate as the effective impedance of all of the thick films.

Thick film resistive rectangles **17** and **117**, (approximate dimensions of ¼ inch×⅜ inch), near the termination pads **7** and **107**, respectively, allow for laser trimming of the resistance maximum and/or minimum value for the patterns **5** and **105**, respectively.

Running the length of the multiple metallization pattern stripes **15** and **115** laid out on top of the thick film resistor pattern **5** and **105**, respectively, are narrow vertical strips **18** and **118** (FIG. **5**b) devoid of the metallization stripes **15** and **115** and separating another group of multiple horizontal stripes **19** and **119**, (approximate dimensions 1/80 inch×1/16 inch), respectively, from the similar but longer horizontal stripes **15** and **115** described above.

The narrow vertical strips **18** and **118**, which are devoid of metallization, are located to allow direct access for vertical laser trimming of areas of the thick film resistors **5** and **105**, respectively, to affect a customized resistance profile versus distance along the bars **3** and **103**, respectively. At various spaced increments along the bars **3** and **103**, there exist wider and longer horizontal metallization stripes **20** and **120**, (approximate dimensions 1/16 inch×¼ inch), respectively, without the metallization devoid area **18** and **118** as described above. These metallization stripes **20** and **120** delineate the effective resistance of the PC into various zones for the required liquid level sensor **1** and **101** resistance profile transfer function to interface with specific motorcycle fuel gauge calibration points corresponding to indications of E, ¼, ½, ¾, and F.

In summary, the substrates or coated bars **3** and **103** can be of various shapes and contours, including profiles that are flat, circular, semicircular, square, oval, irregular shaped, and the like. The bars **3** and **103** can be of a dielectric type of non-electrical conducting material or a conductive material. With metallic and/or conductive bars **3** and **103** being used primarily for their mechanical properties, it typically becomes necessary to apply the dielectric insulative coatings **4** and **104**, respectively, such as a polymer, glass, or ceramic. Metallic substrates offer stronger mechanical properties with electromagnetic shielding properties and significant improvements in heat sinking capability that provide cooler and safer operation in the event of misapplication of excessive voltage.

Also, in summary, over the coated bars **3** and **103** are placed resistors in series and/or parallel with patterns varied by length, width, thickness, and resistivity. These resistors can be of types such as thin film, thick film, conductive polymer, ceramic, and discrete component. Miniaturization of low profile surface mount resistor components allows discrete component resistors to be viable alternatives for placement on the coated bars **3** and **103**. The resistor patterns can be trimmed by such methods as mechanical abrasion and laser ablation.

Electrical contact is made by one or more pairs of metal contacts that move with the float assemblies (as described hereinbelow) on the film resistors and/or metallization patterns (i.e. PCs) deposited on the coated bars **3** and **103**. Preferred contact metals exhibit properties including: low chemical reactivity, soft corrosion products, hard for wear durability, and soft for low resistance contact. Such various types include metals such as: noble—chemically nonreactive (gold and platinum), precious—relatively nonreactive and expensive (palladium and silver), metallurgical alloys, tin, antimony, copper, and the like. Electrical terminations to the coated bars **3** and **103** are made by methods such as soldering, welding, and mechanical force from a fastener or crimp. Addition of lubrication materials to the PC is an option discussed below.

Float assemblies, generally indicated at **21** and **121**, are designed to freely move up and down the PCs with the liquid level and make electrical contact with the metallization patterns **6** and **106** of both the front faces **9** and **109** and back faces **10** and **110**, respectively, to effectively vary the net resistive impedance seen at the two electrical termination pads **7** and **107** formed on the bars **3** and **103**, respectively.

The assemblies **21** and **121** include float bodies **22** and **122**, respectively, for buoyancy. The bodies **22** and **122** are a chemically stable closed cell sulfur cross-linked material with capability for custom geometry features as thermoset foam known as Nitrophyl™ by Rogers Corporation.

Miniature electrical sliding button contacts **23** make electrical contact with the metallization patterns **6** and **106** on the bars **3** and **103**, respectively. Mechanical force of the electrical contacts **23** to the PCs is maintained by mechanical leaf springs **24** and/or coil springs. Although it is possible that these springs **24** are made of electrically nonconductive material, it is usually the practice to use metallic springs such as steel alloy or phosphorus bronze (phos bronze) so that the spring body can also functionally carry the electrical circuit current and thus eliminate the undesirable necessity to add flexible wire to the assemblies **21** and **121**.

The metallic springs **24** can be connected to the electrical contacts **23** and associated float assembly hardware by such methods as soldering, brazing, welding, and mechanical fastening.

As shown in FIGS. **3***a* and **3***b*, a subassembly **26** is formed by resistance welding the leaf springs **24** to the wiper plate **16** having holes **40** for assembly with fasteners **28** and **128** to one or both end caps **27** and **127**, respectively. The end caps **27** and **127** are provided on opposite sides of the float bodies **22** and **122**, respectively, to provide buoyancy adjustment and a low friction and wear sliding surface with the ceramic coatings **4** and **104**, and reduction in mechanical play and thus reduction in wear of the float assemblies **21** and **121** which are lubricated by polyacetal Delrin AF™ from EI DuPont. The fasteners **28** and **128** extend through the holes **40** of the wiper plates **16** and into the float bodies **22** and **122**, respectively, to secure the end caps **27** and **127** to the float bodies **22** and **122**.

The wiper plates **16** acts as electrical terminals and provides a low friction and low wear sliding surface with the ceramic coatings **4** and **104**, and reduction in mechanical play and thus reduction of wear of the float assemblies **21** and **121** on the PCs.

The electrical contacts **23** could be secured on the top end caps **27** and **127** and/or the bottom end caps **27** and **127** of the float assembly through one or more wiper plates **16** for additional contact signal reliability.

In summary, a major component of the float assemblies **21** and **121** are the float bodies **22** and **122**, respectively, typically made of one of a diversity of materials such as: thermoset polymers, thermoplastic polymers, glasses, metals such as aluminum or brass, and the like. The float bodies **22** and **122** can be a structural and hollow device and/or a closed cell foam type device of rigid and/or soft material. Density of the float bodies **22** and **122** can be varied to accommodate requirements for buoyancy with various liquids.

A fluid within the float can be of various composition liquid and/or gas for purposes of net buoyance adjustment, floating orientation stability, and chemical compatibility. The float bodies **22** and **122** can take outer shapes including: spherical, cylindrical, right rectangular prism, irregular, and the like. The size and shape of the float bodies **22** and **122** can be configured to fit various tank mount insertion apertures.

The float assemblies **21** and **121** feature a through hole for passage of the coated bars **3** and **103**, respectively, such that the through hole will be generally vertical and generally through the center of buoyancy of the float bodies **22** and **122**, respectively, as they float in a stable and preferred floating orientation.

Optional material addition of coatings and/or fillers to the coated bars **3** and **103** and/or float bodies **22** and **122**, respectively, can be beneficial in various ways.

A very good example of such a material is polytetrafluoroethylene (PTFE), also known as Teflon® by EI DuPont. PTFE is a very high surface energy material with high surface tension and exhibits application beneficial properties resulting in improved long term sensor accuracy and precision by such mechanisms as: non-wetting so it repels liquids and adherence of buoyancy-changing contaminants on the float body; increased float buoyancy by virtue of a lower meniscus of the sensed liquid; lowers friction directly between the float assemblies **21** and **121** and the coated bars **3** and **103**, respectively; and reduced friction between the float assemblies **21** and **121** and the coated bars **3** and **103**, respectively, by reduction of liquid capillary wetting with its resultant frictional drag. Total volume of the float bodies **22** and **122** is based upon the minimum buoyancy requirement necessary to overcome all anticipated modes of friction and sticking.

The moving electrical contacts **23** (of flat or contoured shape) should be at least coated with metals having suitable properties as discussed previously for good wear, low corrosion, soft corrosion products, and low resistance electrical contact. When cost is not a major concern, it is often preferred to use solid electrical contacts for longer wear life. For reliable operation with a continuous signal of low noise, it is intended that a minimum current greater than 5 mA should pass through each electrical contact to maintain electrical conductivity as driven by voltage, for example five volts, sufficient to start and maintain the current through minor anticipated resistive films on the electrical contacts **23** such that the resultant electrical contact will not suffer from problems called "dry contact". An optional configuration uses rolling electrical contacts along the PCs. Tradeoffs to make for such rolling contacts are increased wear life of both the rolling contacts and the PCs for a reduction of electrical contact conductivity when compared with a typical wiping contact which wipes away contaminants.

In summary, the float assemblies **20** and **120** include various mechanical and functional components including: wear guides, wiper plate terminals, and fasteners. These components all can be sized to alter the net buoyancy of the float assemblies **20** and **120**. The wear guides can be of various materials that have low wear and low friction with wear contacting materials of the coated bars **3** and **103**. Typical examples of low friction materials are either very hard substances such as metals and ceramics or plastics having intrinsic and/or supplemental lubrication filler(s) such as PTFE and/or oil filled polyacetal and/or nylon.

One example of a very good wear guide material is PTFE, as previously disclosed. Close fitting tolerances of the wear guide material to the coated bars **3** and **103** will maintain the float in a preferred orientation to reduce mechanical friction and reduce mechanical damage potential anticipated from vibration with loose fitting components. The wiper plates **16** can be metallic to be part of the electrical circuit and to enable the leaf springs **24** to be directly connected by welding, brazing, mechanical fastening, or other suitable process. Fastening of float assembly components can be implemented by methods including: bolts, washers, nuts, adhesive, clips, over molding, and the like for maintaining all of the components of the float assemblies **21** and **121** in proper mechanical orientation to achieve all functional purposes.

Rigid mounting of the liquid level sensor **1** and **101** is achieved with a mechanical connection at the top **8** and **108** and/or the bottom **14** and **114** of the coated bars **3** and **103**, respectively, including the float assemblies **21** and **121**, by mechanical fasteners (not shown) which extend through holes in the coated bars **3** and **103**. The hole in the bar **103** is shown at **29**. The hole in the bar **3** is not specifically shown.

For added rigidity with single end mounting, at least one low profile "U" mounting bar (not shown) or a similar structural member is attached to the tops **8** and **108** and bottoms **14** and **114** of, and generally parallel with, the coated bars **3** and **103**, respectively, such that the resultant frame structure is simple, rigid, and sturdy.

FIG. **2** shows a specific design that is rigidly fixed with a very short "U" bracket (not shown) mechanically attached to both the top **108** and bottom **114** of the coated bar **103** for added rigidity in the specific motorcycle fuel tank application including a filler tube **135**.

Referring to FIGS. **1***a* and **1***b*, a sealing gasket (not shown) is typically placed between a flange mount **32** and the mating mount location on the tank. Mounting is secured by simple mechanical fasteners such as machine screws (not shown).

The mounting flange with associated flange connectors can be configured to be adaptable to practically any surface location on the container if the coated bar can be held in a substantially vertical orientation. The mounting flange is free to be any practical shape and can include metallic, non-metallic, and composite materials. Metallic flange design usually has some means of dielectric connection to the coated bar to maintain the coated bar at an electrical floating potential, although it is possible that in some applications it might be preferred to have the coated bar at some driven potential or at ground potential. External conductive electrical connections are a practical option for electrical termination. Conductive components then connect to the coated bar via additional electrical terminations that can also provide mechanical connection. Alternatively, the electrical wire terminations such as connectors **33** connected to wire leads **34** (**134** in FIG. **2**) can simply pass through the flange with or without mounting flange sealing for direct electrical termination to the coated bar.

Seal gaskets are often used between the mounting flange and the fuel tank. Such gaskets are typically made of plastic, elastomer, rubber, metal, composite construction, and the like. An option for applications in which both the tank and the liquid are relatively static is to provide a two-axis pivot mount, as illustrated in FIGS. **1***a* and **1***b*, or a ball joint mount that allows the PC board to freely hang vertically thus providing maximum device accuracy attributable to the vertical alignment and the resultant minimal friction forces between the float assembly **21** and the coated bar **3**. It is possible that the mounting location flange can be on the side of a tank with the sensing mount configured as either a fixed angle or a swivel. For applications having relatively small ranges of liquid levels with relatively low levels of mechanical motion and/or vibration using only a single end mount is possible. It is possible that the mount can be made from the bottom of a tank, although this has the detrimental possibility of being messy to do maintenance unless the tank is fully empty. The simple up and down motion of the float assembly requires only that the mechanical mount for the coated bar maintain the device in a predominantly vertical orientation.

With respect to FIGS. **1***a* and **1***b*, the mount **32** has the external mechanical threaded connectors **33** that electrically feed through with a conductive bracket to make mechanical and electrical connection with the electrical termination pads **7** of the coated bar **3**. The vertical scale of fuel level (quarts) is non-linear with vertical position and corresponds to the changing area profile of the motorcycle tank with height. This liquid level sensor **1** is relatively short and rigid so that no bottom support is needed.

The values of the PC resistors can be varied by laser trimming and/or mechanical ablation methods to modify the transfer function of resistance versus float assembly position. Such specifications typically include such characteristics as: maximum resistance, minimum resistance, resistance values and ranges at various locations, and continuous window of resistance range tolerance over the entire float assembly range of motion. Depending upon the interface circuitry, the liquid level sensor transfer function can have various characteristic output function qualities such as: resistance versus position, voltage versus position, ratiometric voltage versus position, and temperature compensation.

Temperature compensation can be implemented via inclusion of series and/or parallel resistors of positive temperature coefficient (PTC) and/or negative temperature coefficient (NTC), and/or engineering to cancel the inherent temperature coefficient (tempco) of the resistance of the PC at one specific point of calibration. Full temperature compensation by the liquid level sensor over the entire liquid level range requires that the compensation resistance also change relative to the position of the float assembly. This can be done by addition of compensation resistors to the PC. Temperature compensation can be implemented by placing appropriate resistors such places as: on the coated bar, at the electrical terminal, within the mounting bracket, within an electrical connector at the mounting bracket, within the wiring (**34**, **134**), or incorporated with an interface circuit (which allows complete compensation although perhaps from a different temperature environment).

The resistor values of the PCs are trimmed to ranges corresponding to positions of the float assemblies **21** and **121**. For example, maximum height positions **30** and **130** of the float assemblies **21** and **121**, respectively, correspond to a resistance value from 7.0 to 14.0 Ohms and minimum height positions **31** and **131** of the float assemblies **21** and **121**, respectively, corresponds to a resistance value from 74.5 to 95.0 Ohms. Resistance values are required at specified locations between are achieved by laser trimming as described above. The resistance profile monotonically decreases with a vertical position increase.

The complete liquid level sensors **1** and **101** are readily inserted straight into a liquid tank mounting orifice by virtue of their sleek design. The cross-sectional area of each of the float assemblies **21** and **121** is round and is the limiting component size factor to consider for insertion of the liquid level sensors **1** and **101** in this application.

Specific material and component choices and configurations are based upon the application specifications. Customer specifications typically cover environmental aspects such as: operating temperature, thermal shock, mechanical impact and/or drop, vibration, application torque, overvoltage operation, high voltage breakdown, relative humidity, high altitude operation, salt spray corrosion, wire pull force, fluid compatibility, life cycles, dither wear, signal impedance, signal transfer function precision, signal transfer function accuracy, allowable signal noise, and signal drop-out times. The range of optional component materials and configurations herein discussed is appropriate for engineering design for many applications.

Potential uses of this type of liquid level sensor include, but are not limited to: automobiles, motorcycles, lawnmowers, snowmobiles, all terrain vehicles (ATVs), watercraft, aircraft, power generators, trains, buses, heavy equipment, chemical processes, food processing, refrigeration systems, washing machines, dishwashers, and the like. Potential liquids for which this type of sensor can apply include, but are not limited to: gasoline, gasohol, fuel oil, propane, diesel fuel, ethylene glycol (antifreeze), propylene glycol (antifreeze), glycol and water solutions (antifreeze), methanol water solutions (windshield washer fluid), ammonia and water (cleaning solution), detergent and water solutions, water, refrigerants, hydraulic fluid, beverages, and the like.

While the best mode for carrying out the invention has been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.

What is claimed is:

1. In a system for measuring the level of a liquid in a container having a volume/depth relationship, an analog liquid level sensor comprising:

a support structure adapted to be received and retained within the container;

a pair of electrically spaced terminals;

a printed circuit formed on the support structure and electrically coupled between the terminals and having an effective resistance which varies at different positions on the printed circuit between the terminals wherein the printed circuit includes a resistor pattern and a metallization pattern having metallized graduations formed on opposite sides of the support structure for reduced electrical noise characteristics and improved hysteresis; and

a float assembly connected to the support structure to reciprocate in a generally vertical direction relative to the support structure in response to the level of the liquid in the container, the float assembly including a hollow, buoyant housing and a contact assembly supported within the buoyant housing in fixed vertical relationship thereto for making electrical connection with the graduations of the metallization pattern on opposite sides of the support structure for changing the effective resistance of the printed circuit between the terminals, the terminals providing an electrical signal which is a function of the generally vertical position of the contact assembly along the support structure, and wherein the sensor has a resistance-to-float-displacement profile matched to the volume/depth relationship of the container.

2. The sensor as claimed in claim **1** wherein the support structure is a dielectric coated metal bar which acts like a heat sink.

3. The sensor as claimed in claim **2** wherein the resistor pattern is a film resistor pattern and wherein the metal bar acts as a ground plane for the film resistor pattern.

4. The sensor as claimed in claim **1** wherein the resistor pattern includes a temperature compensating resistor.

5. The sensor as claimed in claim **2** wherein the contact assembly includes a pair of spring-loaded contacts for making electrical connection with the graduations of the metallization pattern on opposite sides of the metal bar.

6. The sensor as claimed in claim **1** further comprising a mount coupled to the support structure and adapted to mount the support structure to a surface location on the container so that the support structure is allowed to hang within the container in a generally vertical orientation.

7. In a system for measuring the level of a liquid in a container having a volume/depth relationship, an analog liquid level sensor comprising:

a dielectric coated conductive bar which acts like a heat sink and is adapted to be received and retained within the container;

a pair of electrically spaced terminals;

a resistor pattern and a metallization pattern electrically coupled between the terminals, the metallization pattern having metallized graduations formed on opposites sides of the conductive bar for reduced electrical noise characteristics and improved hysteresis, wherein an effective resistance of the resistor pattern varies at different positions on the conductive bar between the terminals; and

a float assembly connected to the conductive bar to reciprocate in a generally vertical direction relative to the conductive bar in response to the level of the liquid in the container, the float assembly including a hollow buoyant housing and a contact assembly including a pair of spring-loaded contacts for making electrical connection with the graduations of the metallization pattern on opposite sides of the conductive bar, the contact assembly being supported within the buoyant housing in fixed vertical relationship thereto for changing the effective resistance of the resistor pattern between the terminals, the terminals providing an electrical signal which is a function of the generally vertical position of the contacts along the conductive bar and wherein the sensor has a resistance-to-float-displacement profile matched to the volume/depth relationship of the container.

8. The sensor as claimed in claim **7** wherein the container is a vehicle fuel tank.

9. The sensor as claimed in claim **7** wherein the resistor pattern is a film resistor pattern.

10. The sensor as claimed in claim **9** wherein the film resistor pattern is a thick film resistor pattern.

11. The sensor as claimed in claim **7** wherein the dielectric coated conductive bar is a ceramic coated metal bar.

12. The sensor as claimed in claim **7** wherein the contacts are sliding contacts.

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(54) Titulo **Transmissor de Nível com Detector de Não-Abastecimento. E Receptor Indicador de Nível e Não-Abastecimento, Com Liga/Desliga Atomático Para Bombas**

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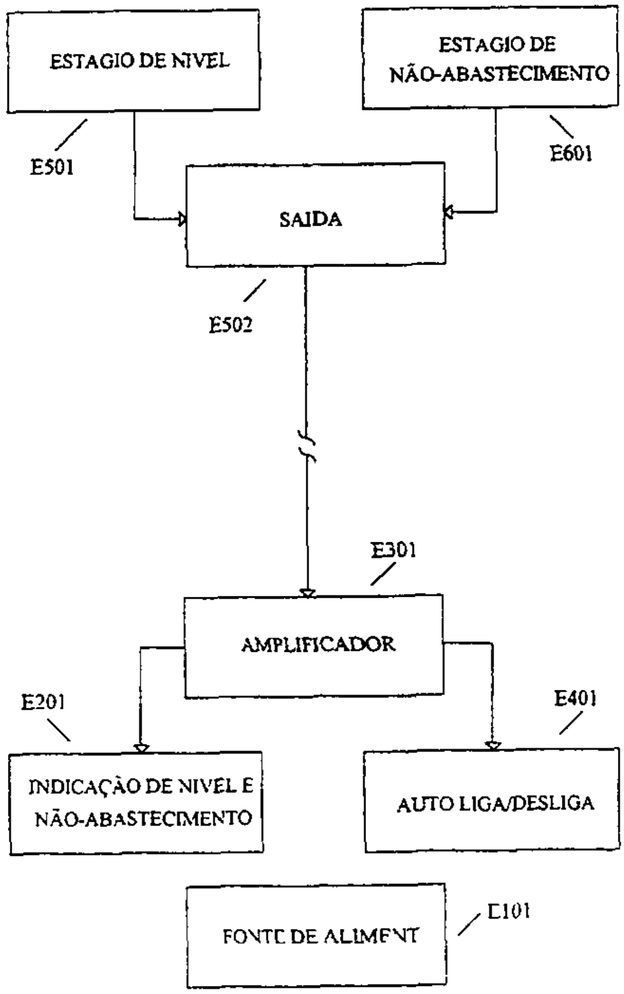
(57) Resumo "TRANSMISSOR DE NIVEL COM DETECTOR DE NÃO-ABASTECIMENTO E RECEPTOR INDICADOR DE NIVEL E NÃO ABASTECIMENTO, COM LIGA/DESLIGA AUTOMATICO PARA BOMBAS" A presente invenção se refere a um novo aparelho eletrônico para medir e indicar o nivel de reservatorios, bem como indicar se o referido nivel esta ou não sendo abastecido e, alem disso, automaticamente, liga e desliga bombas, valvulas solenoides, etc O invento conjuga um transmissor (E501, E502 e E601) e um receptor (E101, E201,E301 e E401) Ressaltando que o transmissor, alem do estagio de nivel (E501), possui um estagio detector de não-abastecimento (E601) O sinal de nivel, no receptor, serve para acionar os leds indicadores de nivel (D201, D210) bem como para fazer funcionar o auto liga/desliga (E401), ja o sinal de não-abastecimento serve para fazer piscar os leds indicadores do nivel (D201 a D210) E, desta forma (piscando) indicar ao usuario a falta de reposição de nivel



"TRANSMISSOR DE NÍVEL COM DETECTOR DE NÃO-ABASTECIMENTO E RECEPTOR INDICADOR DE NÍVEL E NÃO-ABASTECIMENTO, COM LIGA/DESLIGA AUTOMÁTICO PARA BOMBAS"

A presente invenção se refere a um novo aparelho eletrônico para medir e indicar o nível de reservatórios, bem como indicar se o referido nível está ou não sendo abastecido e, além disso, automaticamente, ligar e desligar bombas, válvulas solenóides, etc

Os instrumentos convencionais para nível são, sem dúvida, muito úteis e imprescindíveis para o controle de nível nas indústrias de processos. Os elementos primários convencionais destes instrumentos, entretanto, apresentam o inconveniente de não serem lineares em certos tipos de reservatórios (os cônicos, os esféricos, os cilíndricos na posição horizontal, etc) Outro inconveniente é quando o transmissor utiliza o potenciômetro movimentado por flutuador (bóia), pois, devido ao atrito, este componente (o potenciômetro) costuma durar muito pouco, principalmente quando em líquidos muito turbulentos, os combustíveis nos tanques de veículos, por exemplo.

Hoje, porém, nota-se que não é somente a indústria que necessita de indicadores de nível Nos lares, torna-se imediatamente necessário possuí-los também, porquanto é crescente a falta d'água devido ao aumento da população, aos desperdícios, às estiagens e aos desmatamentos com consequente desaparecimento de mananciais Em certos lugares já está ficando comum se abrir uma torneira e ter a decepção de não encontrar o que nela se procura, ou então, quando menos se espera falta água, interrompendo-se o que se está realizando (durante o banho, por exemplo) Sem falar na situação de quem reside nos pontos mais altos de uma localidade, onde, às vezes, fica-se o dia todo sem a reposição deste líquido tão precioso - a água Por isso o lar carece, e muito, de um instrumento indicador de nível De preferência que seja dedicado ao uso doméstico e que, além de indicar o nível, possa indicar se o reservatório está ou não com reposição. Até porque, atualmente, a maioria das residências e indústrias dependem de fontes externas (as companhias de abastecimento de água).

No intuito de solucionar tais inconvenientes, principalmente no ambiente doméstico, desenvolveu-se este invento E a fim de adequar-se a este ambiente o mesmo reúne diversas funções (transmissor de nível com detector de não-abastecimento; e receptor indicador de nível e não-abastecimento, com liga/desliga automático para bombas) Ademais, para torná-lo acessível à maioria dos lares procurou-se construí-lo com material bem simples e de baixo custo A começar pela indicação a leds, e pelos sensores constituídos por fios elétricos. Adotou-se o fio como elemento primário porque, ao revesti-lo, este passa a não sofrer desgaste pela maioria dos líquidos. E também, graças ao revestimento, dois fios dentro de qualquer líquido exercem a função de placas capacitivas, enquanto o líquido, por sua vez, a função de dielétrico variável. Além disso, o fio por ser dúctil, oferece facilidade para enrolá-lo em espiras Para que assim, em espiral, possa medir corretamente o nível de alguns tipos de reservatórios (os cônicos, os esféricos, etc.) nos quais a altura da coluna líquida não é proporcional ao volume Neste caso, faz-se com que haja uma quantidade maior de espiras onde o volume líquido é maior em relação à altura, de modo que o fluído envolva os fios na mesma proporção que preenche o recipiente Desse modo, faz-se com que, nestes reservatórios, a indicação de nível corresponda ao conteúdo. Mas no caso de o reservatório ter o volume proporcional à altura, os fios devem ser retos ou até mesmo em espiras, porém, ao longo do sensor, estas devem ser uniformes no tamanho e na quantidade

Embora o invento seja simples, tem o objetivo de proporcionar economia no consumo de água potável e, por conseguinte, no de energia elétrica

Hoje, a necessidade desta economia se torna cada vez mais clara Inclusive já anda preocupando as autoridades E pelo visto, num futuro não muito distante, muito preocupará a todos nós. Mas, felizmente, essa economia começará a acontecer, naturalmente, quando os consumidores possuírem um instrumento que indique o nível de seus reservatórios Porquanto, todos os dias, o consumo tem os seus períodos de pico onde o nível dos reservatórios tende a ficar muito baixo É justamente aí (vendo o nível baixar) que o usuário, por prevenção, cuidará em controlar o consumo, no intuito de manter o nível sempre o mais alto possível Economia muito maior se fará, entretanto, quando o invento indicar a falta de abastecimento Neste instante, com certeza, suspende-se atividades do tipo lavar o carro, as roupas, a casa, aguar o jardim etc Principalmente porque não se sabe quando haverá o reabastecimento Assim sendo, haverá economia sim, pois ninguém quer que o nível de seu reservatório fique baixo, e muito menos se ver sem nenhuma gota d'água para as suas necessidades prementes Enfim, havendo indicação de nível, o ganho real será para todos, pois quando houver o reabastecimento não será preciso repor tanta água, nem gastar tanta energia elétrica, justamente pelo fato de não ser necessário encher reservatórios totalmente vazios Convém destacar, no entanto, que para os usuários da invenção o ganho será bem maior, pois além de economizarem dinheiro, provavelmente não ficarão privados de um bem vital (a água)

O invento ainda apresenta as seguintes vantagens.

a) a função automática de partida e parada permite que se inverta o sentido liga/desliga e que, também, dois instrumentos operem em conjunto para ligar e desligar o mesmo equipamento,

b) monitoração da função automática de partida e parada pelo funcionamento alternativo de dois leds,

c) fácil ajuste, através de trimpots, para o controle das diversas funções;

d) segurança, por não haver contato direto de corrente elétrica entre o sensor e o líquido; e

Duas partes principais constituem o presente invento Uma das partes, o transmissor, tem a função de enviar dois sinais ao receptor. Um sinal refere-se ao nível, cujo sensor deve ser envolvido pelo conteúdo líquido à medida que o nível sobe; e o outro, à reposição do nível, cujo sensor deve ser instalado a montante ou a jusante da válvula de bóia, para que seja atingido pelo líquido de reposição Já a outra parte, o receptor ou unidade de leitura, se utiliza dos dois sinais enviados pelo transmissor para indicar o nível, o não-abastecimento e para acionar o liga/desliga automático Explicando melhor, o sinal de nível serve para acionar os leds indicadores de nível, bem como para acionar os comparadores responsáveis em ligar e desligar bombas, válvulas solenóides, etc Já o sinal de não-abastecimento são pulsos que, bruscamente, elevam a corrente do transmissor, fazendo com que os leds indicadores de nível fiquem piscando (entre a indicação real à indicação máxima, como se o nível estivesse subindo e descendo, subitamente) Desta forma, pelo piscar dos leds, o usuário fica sabendo que o reservatório está sem reposição. Esta indicação, porém, só é percebida se o nível estiver abaixo de cem por cento (pelo menos um led apagado) Mas à medida que o nível fica mais baixo, mais a indicação chama a atenção do usuário, porquanto pisca uma quantidade maior de leds, alertando-o para evitar gastos adiáveis ou desnecessários, a fim deste não zerar

Com o objetivo de melhor ilustrar o presente relatório descritivo, fazem-se referências aos desenhos anexos, que são apresentados apenas a título de demonstração, não pretendendo assegurar os mesmos um caráter limitativo do alcance de proteção desta patente, onde:

A figura 1 apresenta um diagrama de blocos dos principais estágios do transmissor e do receptor

A figura 2 apresenta, em perspectiva, um transmissor instalado em um reservatório (desenho em corte), onde se pode ver o sensor (fios) de nível

A figura 3 apresenta uma parte do diagrama do receptor, onde se vê o esquema elétrico da fonte de alimentação e do indicador

A figura 4 apresenta a outra parte do diagrama do receptor, onde se vê o esquema elétrico do amplificador de entrada e o sistema liga/desliga automático.

A figura 5 apresenta o esquema elétrico de todos os estágios do transmissor

A figura 6 apresenta os fios que constituem parte do sensor de não-abastecimento

A figura 7 apresenta uma vista, em planta baixa, do niple onde se instalam os fios sensores de não-abastecimento.

A figura 8 apresenta o sensor de não-abastecimento

A figura 9 apresenta o corte AA tomado da figura 7

A figura 10 apresenta o corte AA tomado da figura 7, mas com os fios intactos, isto é, sem corte

Antes de a descrição da presente invenção prosseguir deve ser notado que, nos desenhos anexos, os componentes em diferentes estágios são designados por numerais de referências em diferentes centenas Exemplo· os resistores de um estágio são designados a partir do numeral 101 (R101, R102, R103,), já no estágio seguinte a partir de 201 (R201, R202, R203,). E assim por diante.

O invento conjuga um transmissor e um receptor (figura 1). O transmissor é composto pelos seguintes estágios principais: estágio de nível (E501) que cuida da medição de nível, estágio de não-abastecimento (E601) que cuida em detectar a falta de reposição; e estágio de saída (E502) que cuida em amplificar o sinal de nível e o sinal de não-abastecimento para transmiti-los ao receptor (indicador) Já o receptor é constituído pelos seguintes estágios principais estágio amplificador de entrada do receptor (E301) que trata de amplificar o sinal de nível e o sinal de não-abastecimento, estágio indicador de nível e não-abastecimento (E201) que trata de acender os leds para indicar o nível, e fazer piscar os que estão sem indicar, quando não há reabastecimento, estágio liga/desliga automático (E401) que trata de colocar ou retirar de operação, equipamentos como bombas, válvulas solenóides, etc , e, finalmente, pela fonte (E101) que trata de toda alimentação elétrica do aparelho

O sensor (S501) é o elemento primário de nível. Caracteriza-se por ser constituído por dois fios elétricos e revestidos, incluindo uma das extremidades de cada fio (F501). Devido ao revestimento, estes podem exercer a função de placas capacitivas em um líquido qualquer E à medida que o nível sobe e envolve os fios (F501), isto é, o sensor (S501), o líquido passa a ser um dielétrico variável que, como resultado, faz variar a frequência do oscilador (CI501A), o valor de tensão contínua retificada pelo dobrador de tensão (C501, D501 e D502) e, por fim, a corrente dos transistores (Q501 e Q502) Como o transmissor é alimentado pelo receptor, via o resistor (R303), qualquer variação de corrente nestes transistores é sentida e amplificada pelo operacional de entrada do receptor (CI301A), assim como por um miliamperímetro que esteja, opcionalmente, ligado aos pontos (P305 e P306)

O sinal de nível, proveniente do transmissor e presente no amplificador (CI301A), à medida que sobe, aciona os dez comparadores internos do circuito integrado bargraph (CI201), para que estes acendam os leds indicadores de nível (D201, D202, , D210).

O sinal de nível, ao subir, também aciona os comparadores (CI 301C e CI 301D), fazendo as saídas dos mesmos saltarem do estado baixo para o estado alto Isto ocorre quando a tensão nas entradas não-inversoras destes amplificadores ultrapassa as tensões das entradas inversoras, ajustadas pelos trimpots (R405 e R407), respectivamente. A saída do comparador (CI 301C), no entanto, só volta para o estado baixo quando o comparador (CI 301D) sair do estado alto para o estado baixo, além da tensão de nível ficar baixa Porquanto a saída do comparador (CI 301C), uma vez no estado alto, aí se mantém, firme, por causa do diodo (D401) Quando a saída do comparador (CI 301C) alterna de um estado para outro, os diodos (D402 e D403) também se alternam para, desse modo, monitorar o funcionamento de algum dispositivo remoto

O acionador convencional do transistor (T401) é o comparador (CI301C) que, através do relé (K401), liga e desliga bombas, válvulas solenóides, etc Todavia dois destes instrumentos podem funcionar juntos onde o transistor (T401) do primeiro instrumento, pode ser acionado pelo transistor (T401) ou relé (K401) do segundo instrumento Mas para funcionar assim, é necessário que um dos pontos (P401, P402, P403 ou P404) do segundo instrumento seja ligado à base (P405) do transistor (T401) que pertence ao primeiro instrumento O arranjo de interligar dois instrumentos é muito útil para que, automaticamente, a bomba de um reservatório abasteça um outro reservatório

Além de detectar o nível, o transmissor trabalha com o sensor (S602) para detectar o não-abastecimento Este sensor (S602) caracteriza-se por ser constituído por um niple (N601) e dois fios elétricos e revestidos (F601) Estes fios (F601) exercem a função de placas capacitivas onde, graças ao revestimento, um líquido qualquer pode envolvê-los para que o próprio líquido funcione como dielétrico. A presença do líquido no sensor (S602) altera a freqüência do oscilador (CI501B) Esta alteração de freqüência, convertida em tensão contínua pelo dobrador de tensão (C601, D601 e D602), eleva a tensão na entrada não-inversora do comparador (CI501C) para uma tensão maior que aquela ajustada pelo trimpot (R606) e, neste patamar, força a saída do operacional (CI501C) a mudar do estado baixo para o estado alto que, via o diodo (D603), grampeia em nível alto a entrada inversora do oscilador (CI501D), impedindo-o de oscilar. Mas o contrário ocorre com a ausência de líquido, pois o oscilador (CI501D) fica livre para funcionar e seus pulsos, via o diodo (D604), são aplicados na base do transistor (Q501) para que, no receptor, os leds indicadores de nível que se encontram apagados fiquem piscando, simulando rápidas variações de nível (subidas/descidas), enquanto durar a falta de abastecimento

A realização do invento é muito fácil e sem nenhum segredo tecnológico, porquanto trata-se de dois circuitos muito simples, montados em pequenas placas de circuito impresso e devidamente alojados em caixas que disponham de entrada e saída para os sinais e para a alimentação

O invento de que trata esta patente constitui-se num instrumento de econômica industrialização, bastante útil, simples, prático e funcional. Enfim, reveste-se de características de novidade, motivo pelo qual vem o requerente pleitear a proteção de Patente de Invenção

REIVINDICAÇÕES

1 - "TRANSMISSOR DE NÍVEL", caracterizado por um sensor (S501) que é constituído por um par de fios condutores elétricos (F501)

2 - "TRANSMISSOR DE NÍVEL", de acordo a reivindicação 1, caracterizado pelo fato de o par de fios (F501) ser revestido (incluindo uma das extremidades de cada fio)

3 - "TRANSMISSOR DE NÍVEL", de acordo a reivindicação 1, caracterizado pelo fato de o par de fios (F501) ser reto ou espiralado, quando destinado a medir o nível de reservatório que apresenta volume proporcional à altura, mas, neste caso, com espiras uniformes no tamanho e na quantidade, ao longo do sensor

4 - "TRANSMISSOR DE NÍVEL", de acordo a reivindicação 1, caracterizado pelo fato de o par de fios (F501) ser espiralado, quando destinado a medir o nível de reservatório que apresenta volume desproporcional à altura, para que, neste caso, haja uma quantidade maior de espiras onde o volume líquido é maior em relação à altura, de modo que o líquido envolva os fios na mesma proporção que preenche o recipiente.

5 - "DETECTOR DE NÃO-ABASTECIMENTO", caracterizado por um sensor (S601) para detectar a falta de reposição de nível

6 - "DETECTOR DE NÃO-ABASTECIMENTO", de acordo a reivindicação 5, caracterizado pelo fato de o sensor (S601) ser constituído pelos fios (F601) e o niple (N601)

7 - "RECEPTOR INDICADOR DE NÍVEL E NÃO-ABASTECIMENTO", caracterizado pelo fato de a indicação de nível e de não-abastecimento ser feita por leds (D201 a D210)

8 - "RECEPTOR INDICADOR DE NÍVEL E NÃO-ABASTECIMENTO", de acordo a reivindicação 7, caracterizado pelo fato de a indicação de não-abastecimento ser o piscar dos próprios leds indicadores de nível

(D201 a D210)

9 - "LIGA/DESLIGA AUTOMÁTICO PARA BOMBAS", caracterizado pelo fato de compreender dois comparadores (CI301C e CI301D), dois trimpots (R405 e R407), dois leds (D402 e D402), um transistor (T401) e um relé (K401) para, automaticamente, ligar e desligar bombas, válvulas solenóides, etc

10 - "LIGA/DESLIGA AUTOMÁTICO PARA BOMBAS", de acordo a reivindicação 9, caracterizado pelos leds (D402 e D403) os quais são os monitores da funções desligado e ligado, respectivamente

11 - "LIGA/DESLIGA AUTOMÁTICO PARA BOMBAS", de acordo a reivindicação 9, caracterizado pelo fato de que, na base, o transistor (T401) possui os pontos (P405 e P406), como opção, para permitir que o liga/desliga automático seja acionado por outro instrumento do mesmo tipo

12 - "LIGA/DESLIGA AUTOMÁTICO PARA BOMBAS", de acordo a reivindicação 9, caracterizado pelo fato de que o relé (K401) possui os contatos normalmente aberto e normalmente fechado para permitir a inversão do sentido liga/desliga

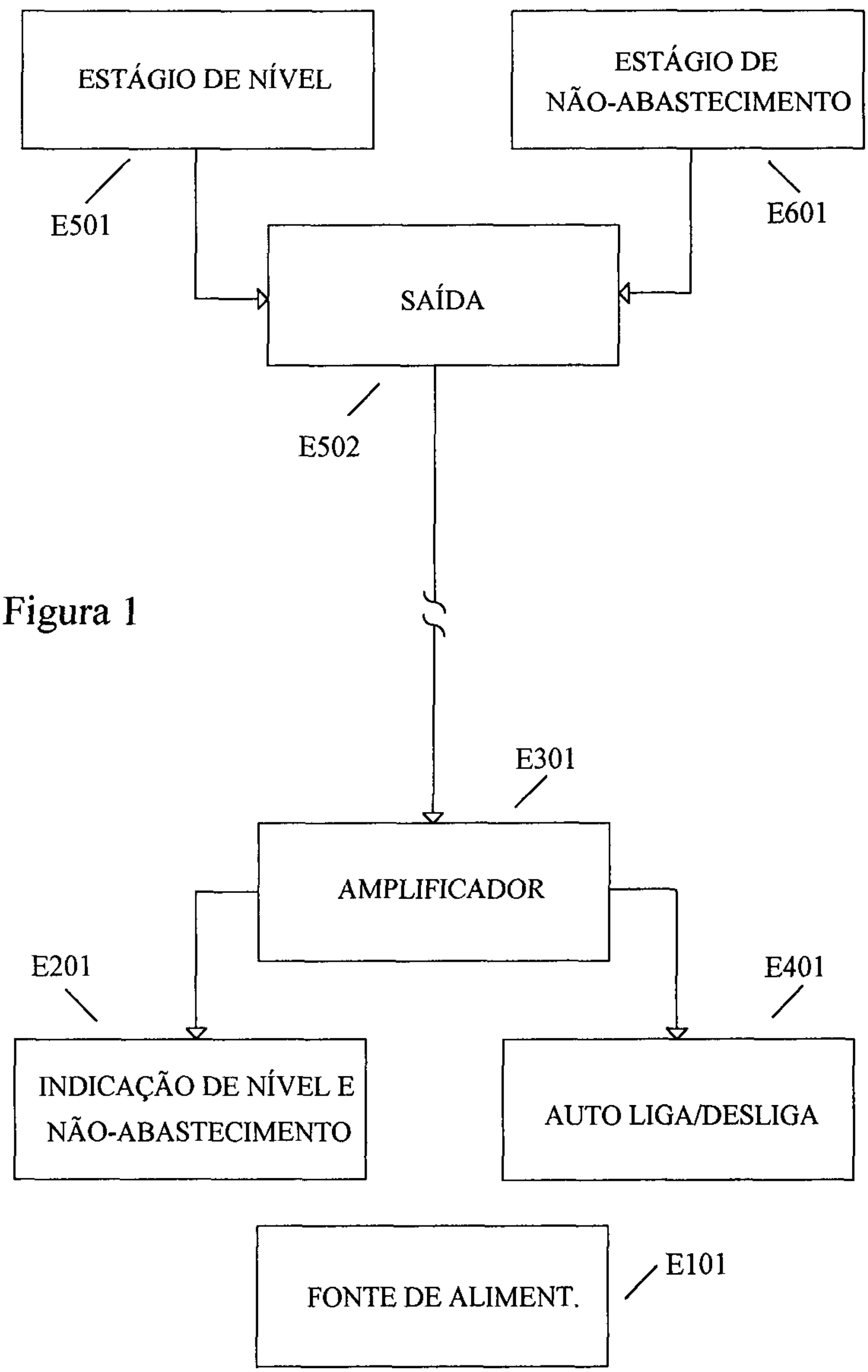
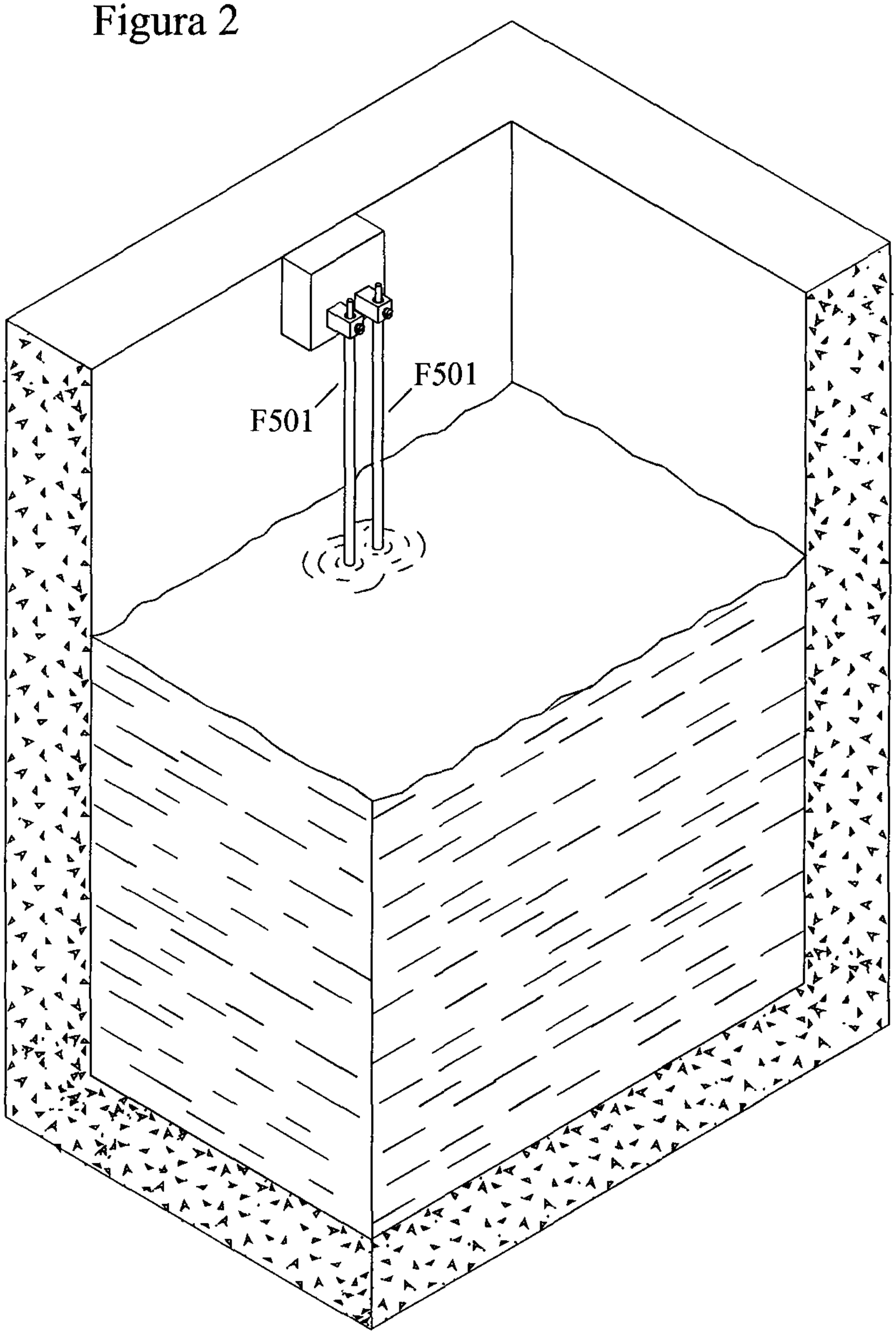

ESTÁGIO DE NÍVEL
ESTÁGIO DE NÃO-ABASTECIMENTO
E501
E601
SAÍDA
E502
E301
AMPLIFICADOR
E201
E401
INDICAÇÃO DE NÍVEL E NÃO-ABASTECIMENTO
AUTO LIGA/DESLIGA
FONTE DE ALIMENT.
E101

Figura 1

 PI980363

Figura 2



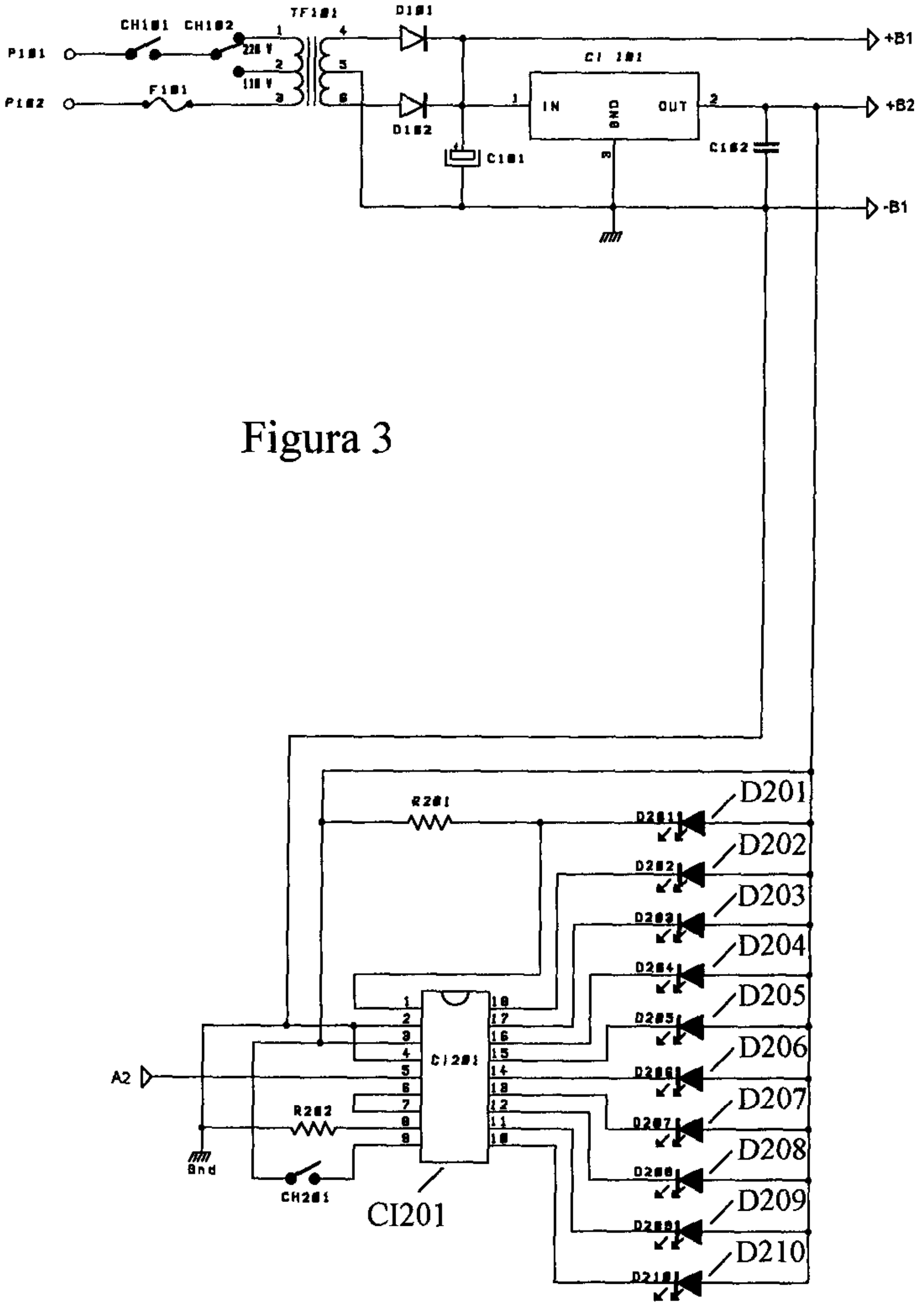
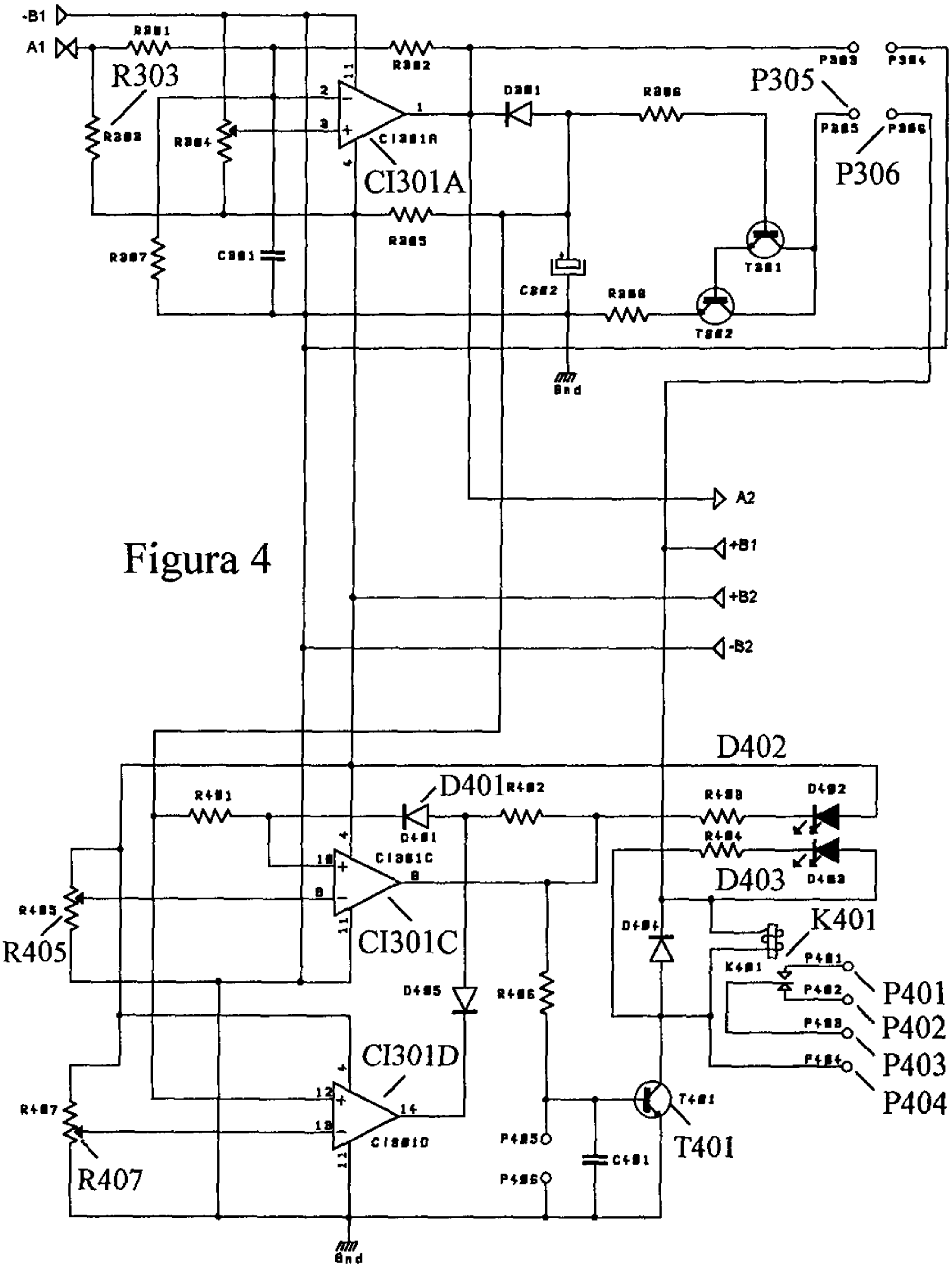

P101
P102
CH101
CH102
F101
220 V
110 V
TF101
D101
D102
C101
CI 101
IN
GND
OUT
C102
+B1
+B2
-B1
R201
R202
D201
D202
D203
D204
D205
D206
D207
D208
D209
D210
CI201
CH201
A2
Gnd

Figura 3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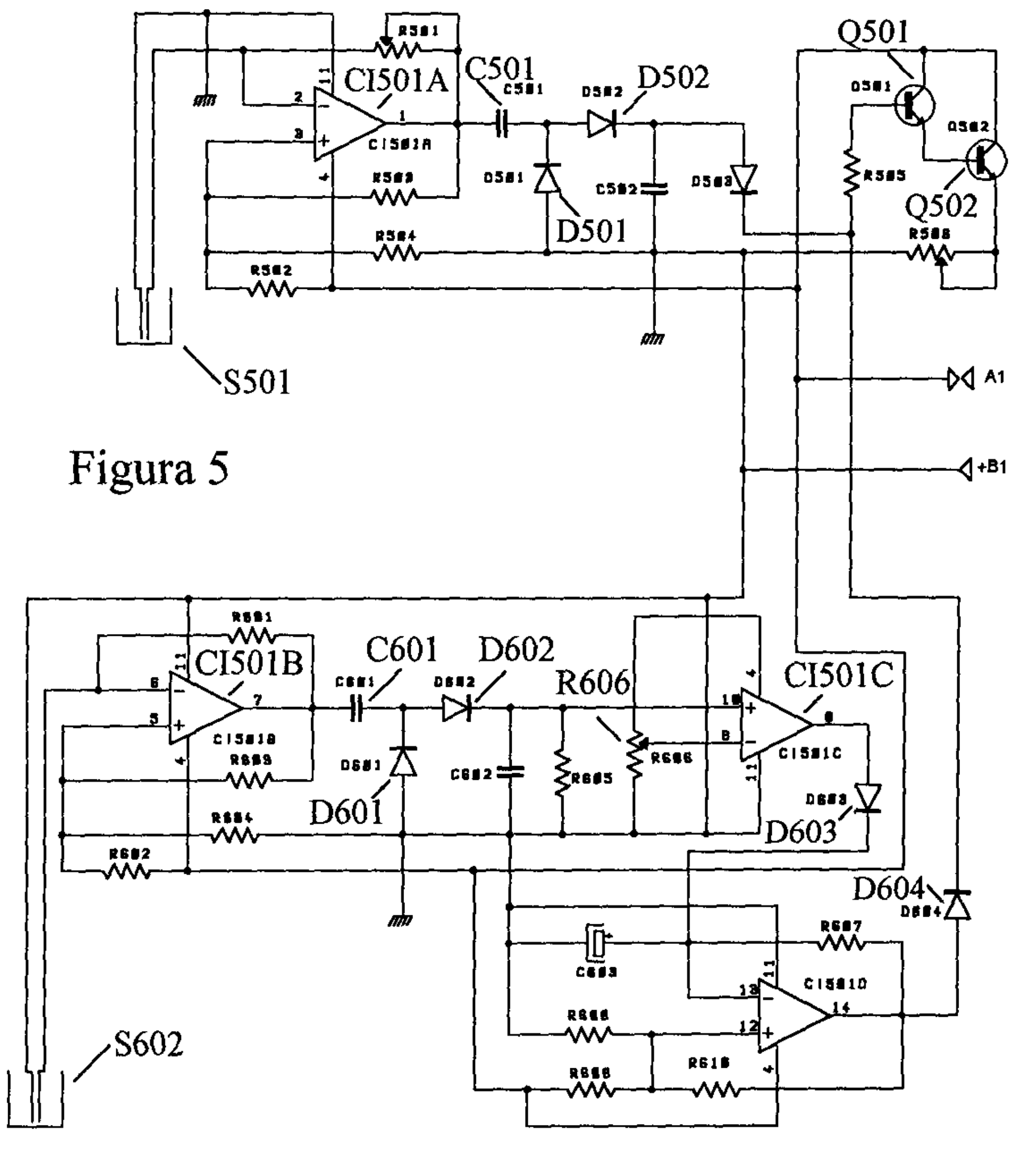
A1
R301
R302
R303
R304
R305
R306
R307
R308
C301
C302
D301
T301
T302
CI301A
P303
P304
P305
P306
A2
+B1
+B2
-B2
Gnd
D401
D402
D403
D404
D405
R401
R402
R403
R404
R405
R406
R407
CI301C
CI301D
K401
P401
P402
P403
P404
P405
P406
C401
T401

Figura 4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C501
D502
Q501
R501
C501
D502
D501
C502
D503
R503
R504
R502
R505
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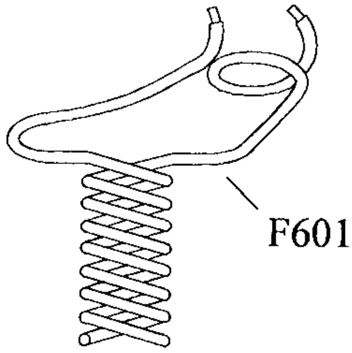
R508
S501
A1
+B1
CI501B
C601
D602
R606
CI501C
R601
R603
R604
R602
D601
C602
R605
D603
D604
C603
R607
R608
R610
S602

Figura 5



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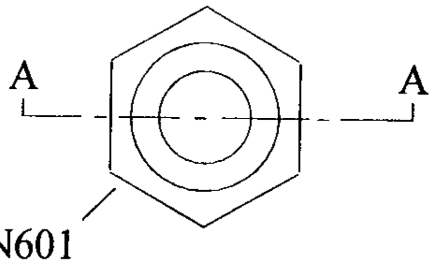

Figura 7

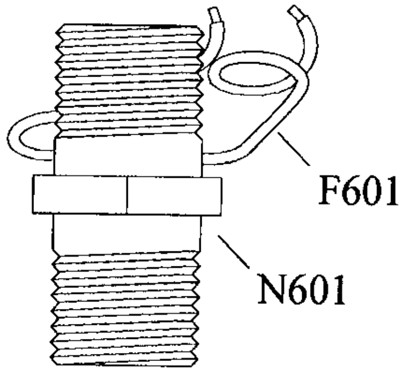

Figura 8

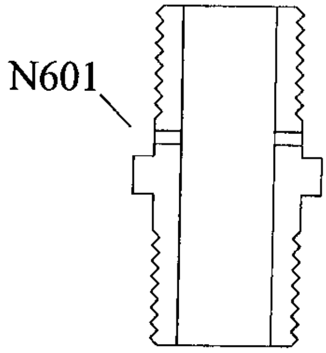

Figura 9

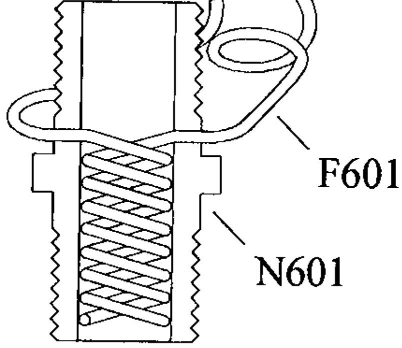

Figura 10

RESUMO

"TRANSMISSOR DE NÍVEL COM DETECTOR DE NÃO-ABASTECIMENTO E RECEPTOR INDICADOR DE NÍVEL E NÃO-ABASTECIMENTO, COM LIGA/DESLIGA AUTOMÁTICO PARA BOMBAS"

A presente invenção se refere a um novo aparelho eletrônico para medir e indicar o nível de reservatórios, bem como indicar se o referido nível está ou não sendo abastecido e, além disso, automaticamente, liga e desliga bombas, válvulas solenóides, etc.

O invento conjuga um transmissor (E501, E502 e E601) e um receptor (E101, E201, E301 e E401) Ressaltando que o transmissor, além do estágio de nível (E501), possui um estágio detector de não-abastecimento (E601) O sinal de nível, no receptor, serve para acionar os leds indicadores de nível (D201 a D210) bem como para fazer funcionar o auto liga/desliga (E401); já o sinal de não-abastecimento serve para fazer piscar os leds indicadores do nível (D201 a D210) E, desta forma (piscando), indicar ao usuário a falta de reposição de nível