NMC 23

Control Engineering Training

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Applicable Trainees: Engine Officers

Objectives of the Training

After completion of the training, the trainees should understand the followings:

1) Basic knowledge of control

2) Structure and principle of pneumatic and electrical controller

3) Adjustment of pneumatic and electrical controller

4) Maintenance of pneumatic and electrical controller

Duration of Training: 5 Days

Course schedule:

	Contents of the course		Contents of the course	
	AM	AM	PM	PM
1st day	Basic know ledge(Standard signals)	Basic knowledge (Types of Control theory)	Basic knowledge (Types of control action)	Basic knowledge (Principle and Structure of pneumatic control system components)
2nd day	Basic knowledge (Principle and Structure of pneumatic control system components)	Basic knowledge (PC based training)	Exercise for Pneumatic control system	Simulator training (Pneumatic control system)
3rd day	Simulator training (Pneumatic control system)			
4th day	Maintenance & Check points (Pneumatic control system)	Electronic control system	Electrical control system (Principle and Structure of components)	Exercise for Electrical control system
5th day	Simulator training (Electrical control system)		Simulator training (Electrical control system)	Troubleshooting Exercises & Examination

Contents and Syllabus

1.4.6 Valve Positioner

1.4.7 Pressure switch

1.4.8 Differential Pressure Transmitter for Pneumatic control system

1.4.9 Optimum control

2. Adjustment procedure

Training by the AMCO simulator unit

- Pneumatic Controller

- Pneumatic type Differential pressure transmitter

- Valve positioner

- Pressure switch

- Electrical type Differential pressure transmitter

- Smart Field communicator

- Electrical Controller

- I/P Converter

3. Maintenance and Check points

3.1 Pneumatic controller

3.1.1 Blockage of pneumatic line

3.1.2 Crater due to presence of oil and dust

3.1.3 Deterioration due to prolonged use and presence of oil or condensate water in control air

3.1.4 Eccentric abrasion due to vibration

3.2 Control valve

3.3 Valve positioner

5. Case Studies, Company's instructions, Maker's service information

6. Annex 1 – Definition of Terms used in Control system

7. Annex 2 – Layout of Various Control Systems

8. Annex 3 – Electrical Control System

8.1 Principle and Structure of control system components

8.1.1 Differential Pressure Transmitter (Electrical type)

8.1.2 Smart Field Communicator

8.1.3 Digital Indicating Controller

8.1.4 I/P Converter

8.2 Maintenance and Check Points (Electrical control system components)

9. Equipment, Materials, teaching Aids

PC software: PID – Master, AMCO Simulator and Hand outs

1. Basic Knowledge:
1.1 Standard signal:

There are many different types of controllers. These have different power source. However they must come up to a point of understanding each other signals.
In this regard, controllers utilize standard signals in order to understand each other.
Some times, it uses a signal converter to change a signal to another physical quantity.
In Table 1.1, the Pneumatic, Voltage, and Current Signals are shown.
The followings are standard signals used and their values:

Pneumatic Signal	20 kPa ~ 100kPa
Voltage Signal	DC 1 V ~ DC 5 V
Current Signal	DC 4 mA ~ DC 20mA

Table 1.1 Pneumatic, Voltage, and Current Signals

1.1.1 Pneumatic Signal:
The standard signal for Pneumatic system is adopted between 20 kPa and 100kPa because of the characteristics of linear variable and the starting point.
In table 1.2, the relationship between signal rate and air pressure is shown.

Signal Rate	Air Pressure
0%	20 k Pa
25%	40kPa
50%	60kPa
75%	80kPa
100%	100kPa

Table 1.2 Relationship between Signal rate and Pressure

Characteristics of linear variable:
Many Pneumatic control devices employ the Nozzle- Flapper system in order to convert the variable of distance between nozzle and flapper into that of pneumatic pressure.
Figure 1.1 shows a sketch for a standard Pneumatic Nozzle Flapper system.
In operating this device, the flapper is positioned against the nozzle opening.
When the constant air supply is given to nozzle, the nozzle back pressure “Pn” is controlled by the nozzle–flapper distance “x”. If the flapper moves away from the nozzle (i.e. if the distance “x” becomes larger), then the resistance to the air flow through the nozzle will decrease and subsequently the nozzle back pressure “Pn” will descend. On the other hand, if the flapper moves towards the nozzle (i.e. if the distance “x” becomes smaller), then the resistance to the air flow through the nozzle will increase and subsequently the nozzle back pressure “Pb” will increase.
Figure1.2 shows Characteristics curve of Nozzle and Flapper.

The nozzle back pressure “Pn” varies proportional to the variation in the movement of the flapper within some range. When the pneumatic pressure of 140 kPa is supplied to the Nozzle-Flapper system, the back pressure “Pn” changes linearly between 20kpa and 100 kPa.

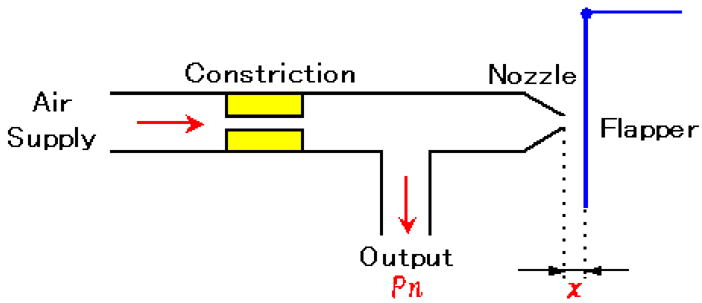


Fig. 1.1 Pneumatic Nozzle Flapper System

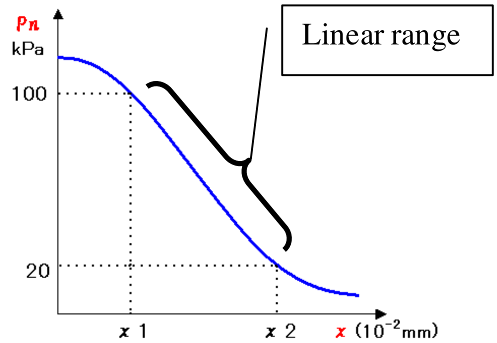


Fig. 1.2 Characteristics curve of Nozzle & Flapper

Starting point:
Let us consider the reason why the starting point of the standard signal is not 0Kpa.
If its starting point is 0kPa, it is impossible to distinguish between an actual 0% output signal and 0% output signal due to some fault with the controller system.

1.1.2 Electric Signal (Voltage and Current Signal):

The standard signal for Electric system is adopted between DC4mA as 0% and DC20mA as 100% and between DC1V as 0% and DC5V as 100%.

In table 1.3, the relationship between signal rate and pressure is shown.

Signal Rate	Current	Voltage
0%	DC 4 mA	DC 1 V
25%	DC 8 mA	DC 2 V
50%	DC 12 mA	DC 3 V
75%	DC 16 mA	DC 4 V
100%	DC 20 mA	DC 5 V

Table 1.3 Relationship between Signal rate and Current / Voltage

Linearization of voltage and current:
Figure 1.3 shows the relationship between Voltage and Current. Voltage and current signals have a linear relationship by virtue of Ohm’s law i.e. E=IR.
We only need to know the resistance to connect in order to have an output of standard voltage with a given current signal i.e. 250 ohms.

Minimum signal is 20% of the maximum signal level, which is similar to the standard signal for Pneumatic system.

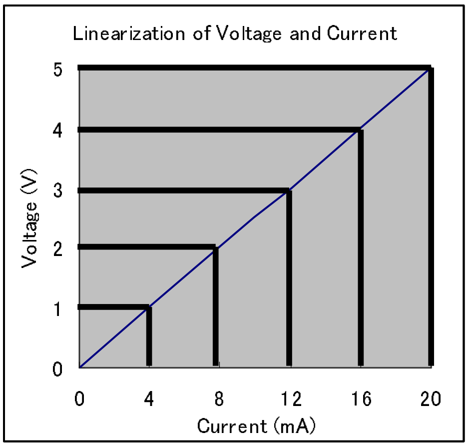


Fig. 1.3 Voltage and Current

Starting point:
Let us consider the reason why the starting point of the standard signals for Electric system is not DC 0mA or DC 0V. If its starting point is 0mA and 0V, it is impossible to distinguish between an actual DC 0mA / DC 0V output signal and DC 0mA / DC 0V output signal due to some fault with the controller system.

1.2. Types of Control Theory:

1.2.1 Feed Back Control (or Closed Loop Control System):

Feed Back Control or Closed Loop Control System is one in which the control action is dependent on the output. The system may be manually or automatically controlled. Figure 1.4 shows the bock diagram of basic elements in a closed loop control system.

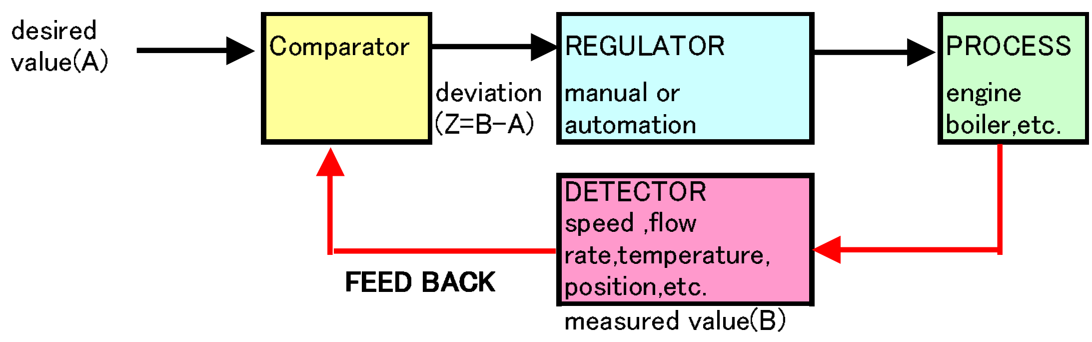


Fig. 1.4 Block diagram of Closed Loop Control System

Desired Value or Set Point: is the value of the controlled condition that the operator desires to obtain.
Measured Value or Process value: is actual value of the controlled condition which is desired to be obtained.
Deviation (or error): is the difference between measured and desired values.

In the feedback control process, the current process variable is compared with the desired value and the difference between the two values is used to reduce the difference by adjusting the control variable in the control system.
This series of operation can be shown through the signal flow of the closed loop that consists of detector, comparator, and regulator.

Example of Feedback control:
Figure 1.5 shows the arrangement of Feedback control. In automatic boiler water level control, the Level Controller (L.C.) has a set point (S.P.), which is set at Normal Water Level (0mm). The Level transmitter (L.T.) detects the drum water level. If the detected level is below N.W.L., the Feed Water Control (F.W.C.) Valve will open in order to supply Feed water to drum. Water level is therefore increased. When the drum water level increases above N.W.L., the F.W.C. Valve will be closed in order to stop feeding water. By repeating this cycle, the drum water level can be maintained at approximately N.W.L.

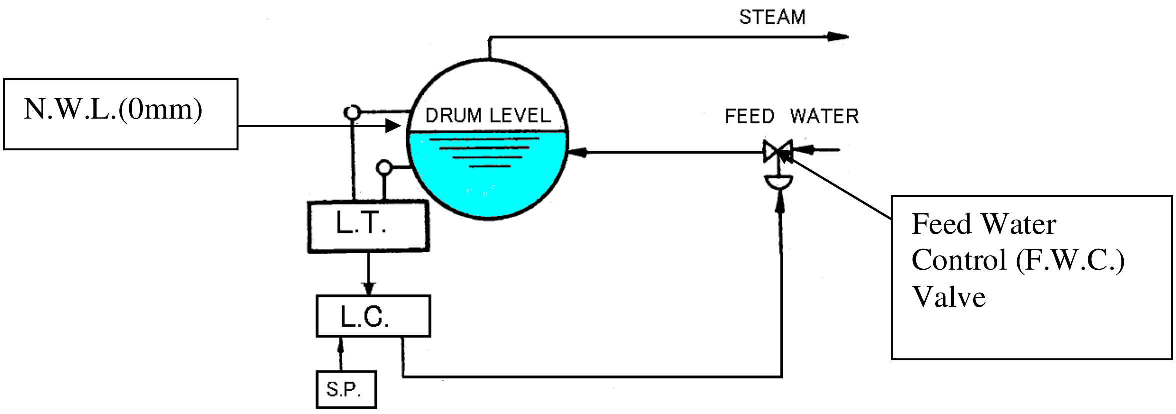


Fig. 1.5 Arrangement of Feedback control

Figure 1.6 shows block diagram of level control. The above control can be expressed in the block diagram like the one shown below, called a "feedback loop." This type of control is called "feedback control."

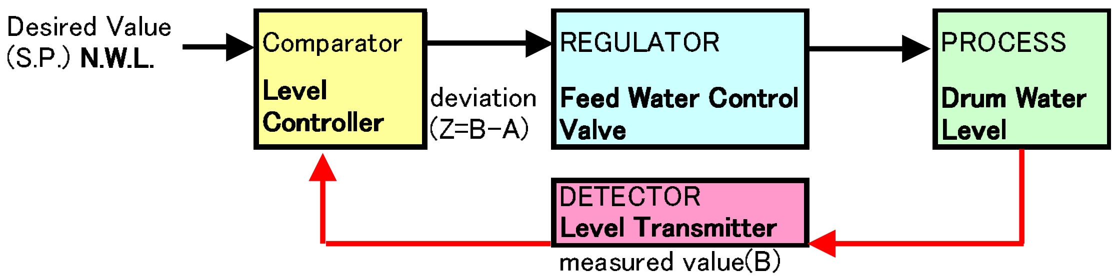


Fig. 1.6 Block diagram of Closed Loop Control System

1.2.2 Feed-forward control:

Feed-forward means that you let the controller act before there is a control error. This is only possible if you have a measurement of an external signal that affects (disturbs) your process.

Figure 1.7 shows the General arrangement of Feed-Forward Control System for maintaining Boiler water level. If there is disturbance, Feed-forward control gives corrective action by operating valve when the detected value is compared with the desired value before the disturbance affects the output of Process. So in other words, the necessary correction against the turbulence can be accomplished by the controlling element (Feed-forward) which calculates the input process if the relation between the input process and the output process can be expressed with calculating formula.

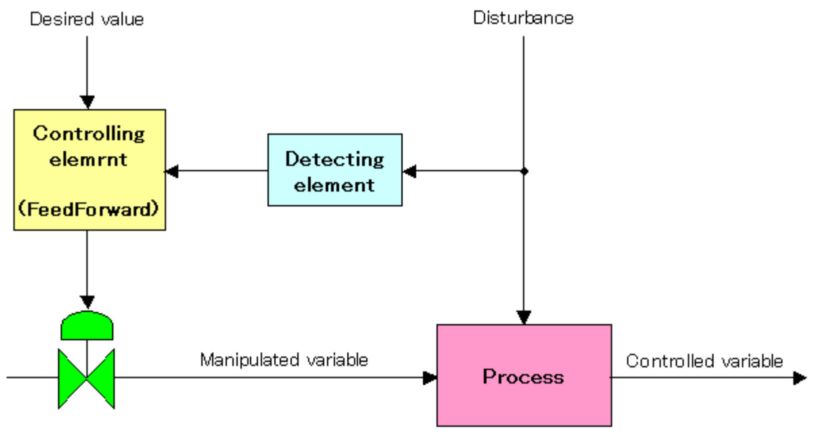


Fig. 1.7 General arrangement of Feed-forward Control System

Feed-forward control provides faster control than that of feedback by directly measuring disturbance and then reflecting the measurement in the control variable. It is not waiting for the compared difference between the operation result and the desired value to adjust the control variable.

Feedback control inevitably needs to spend certain amount of time to achieve this. Since if disturbance interrupts, first the sensor has to detect it and then provide feedback to minimize the difference. This time delay of feedback control sometimes causes a problem especially in the systems that require ultra-quick control operations.
Feed-forward control is usually combined with the feedback control process to allow quick response in the overall control process.

Example of Feed-forward control:
Figure 1.8 shows the arrangement of Feed-forward control for maintaining Boiler water level. In automatic boiler water level control, the Level Controller (L.C.) has a set point (S.P.), which is set at Normal Water Level (0mm). The Level transmitter (L.T.) detects the drum water level. The Flow transmitter (F.T.) detects the steam flow from drum. The Adder operates the signal both from L.C. and F.T.
If the steam flow increases, then the evaporation in drum water will be increased. It means the boiler load has increased. If the F.T. detects that the steam flow has increased, then the evaporation of water in drum will be increased, so the Feed Water Control (F.W.C.) Valve will open in order to increase feeding water to drum. Feed -forward signal is the estimated feed water demand based on the current steam flow. As a result, decrease in the water level is prevented. When the steam flow decreases, the F.W.C. Valve will be throttled in order to reduce feeding water. Thus, increase in the water level is prevented. By repeating this cycle, the drum water level can be maintained at approximately N.W.L. However, if the actual water level deviates from the S.P., NWL (0mm), then Feedback signal from Level controller corrects the deviation additionally.

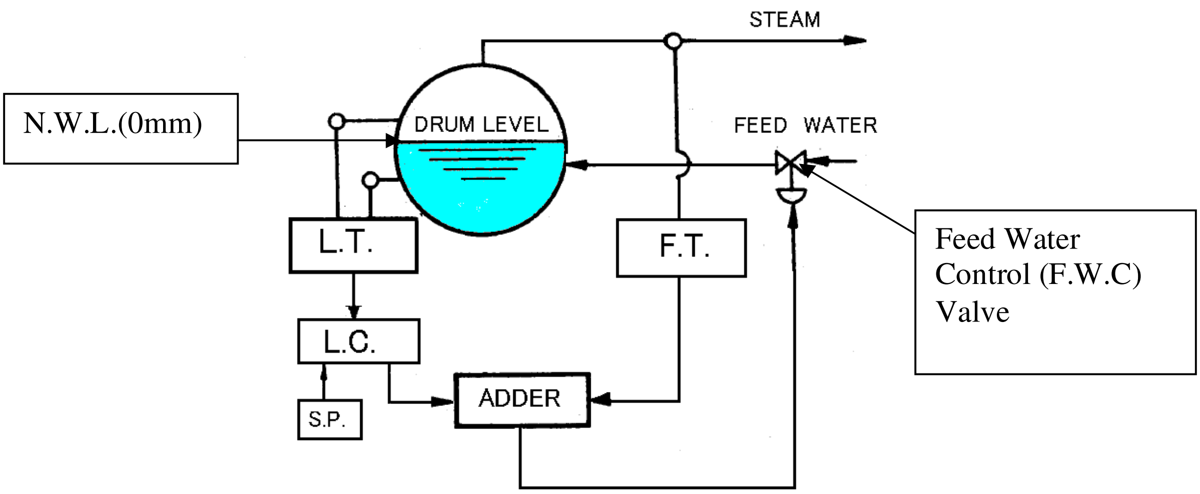


Fig. 1.8 Arrangement of Feed-Forward control

1.2.3 Cascade control:

Cascade control is used, where the output from a master controller is used to automatically adjust the desired value of a slave controller. Figure 1.9 shows General arrangement of Cascade Control System.

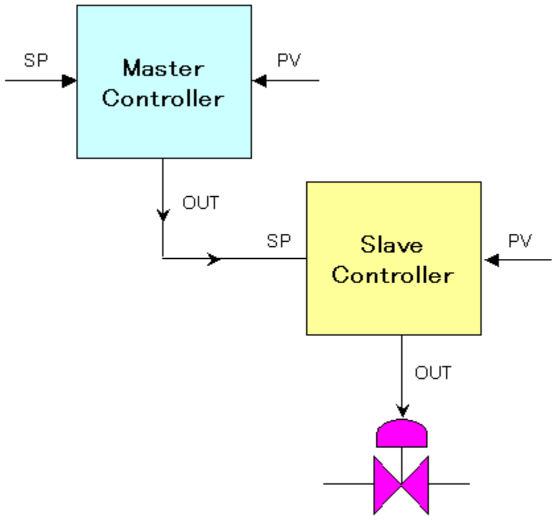


Fig. 1.9 General arrangement of Cascade Control System

Cascade control is the control system in which one controller provides the command signal to one or more other controllers.

Example of Cascade control:

Figure 1.10 shows the general arrangement of Cascade Control for maintaining Boiler water level. In automatic boiler water level control, the Level Controller (L.C.) has a set point (S.P.), which is set at Normal Water Level (0mm). The Level transmitter (L.T.) detects the drum water level. The Steam Flow transmitter (S.F.T.) detects the steam flow from drum. The Adder operates the signal both from L.C. and S.F.T.. The Feed Water Flow transmitter (F.W.F.T.) detects the Feed Water flow to drum.

The feed water pump and feed water pressure are always variable. Then, even if there is one valve position, feed water amount is not always same. Therefore, in order to accomplish more accurate water level control, the actual feed water flow after F.W.C. Valve is detected for feed water flow control.

The signal after the Adder is the master signal. The master signal turns into a set point (S.P.) for F.C., the slave controller. F.W.F.T. signal is input process of feed water Flow Control, as process variable (P.V.). By comparing both signals in F.C., F.W.C. Valve will be adjusted precisely to meet the master signal demand.

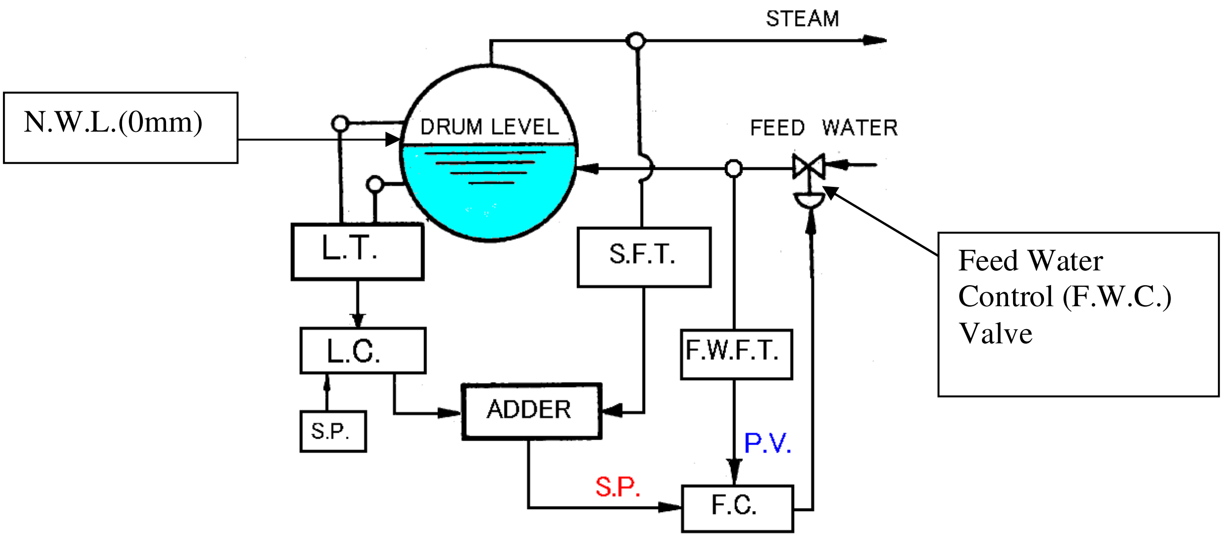


Fig. 1.10 Arrangement of Cascade Control System

1.2.4 Split Range Control:

In this control system arrangement, the output signal from the Controller is split into two or more to control two or more Regulating units.
Figure 1.11 shows arrangement of Split range control system for maintaining jacket water outlet temperature of Main engine.
The jacket cooling water outlet temperature sensor monitors the cooling water temperature at the outlet from the cylinder head and feeds a signal to the automatic controller. This signal is checked with the desired value for any deviation. The controller output ranges from 20kPa to 100kPa and it is fed to both the regulating units. These regulating units (Control valves) are adjusted in such a way that the low air signal range i.e. from 20kPa to 40kPa operates the steam supply valve to raise the water temperature, when the jacket cooling water temperature is below the desired value. When the output signal is above 40kPa, this valve is fully closed.
When the output signal is above 40kPa, the cooling water valve starts opening. Below 40kPa, this valve is fully shut so that only one valve is open at any time.
In some cases, where there would be problem with two valves open at the same time, a dead band is used i.e. one valve closing at 40kPa and other opening at 50kPa.

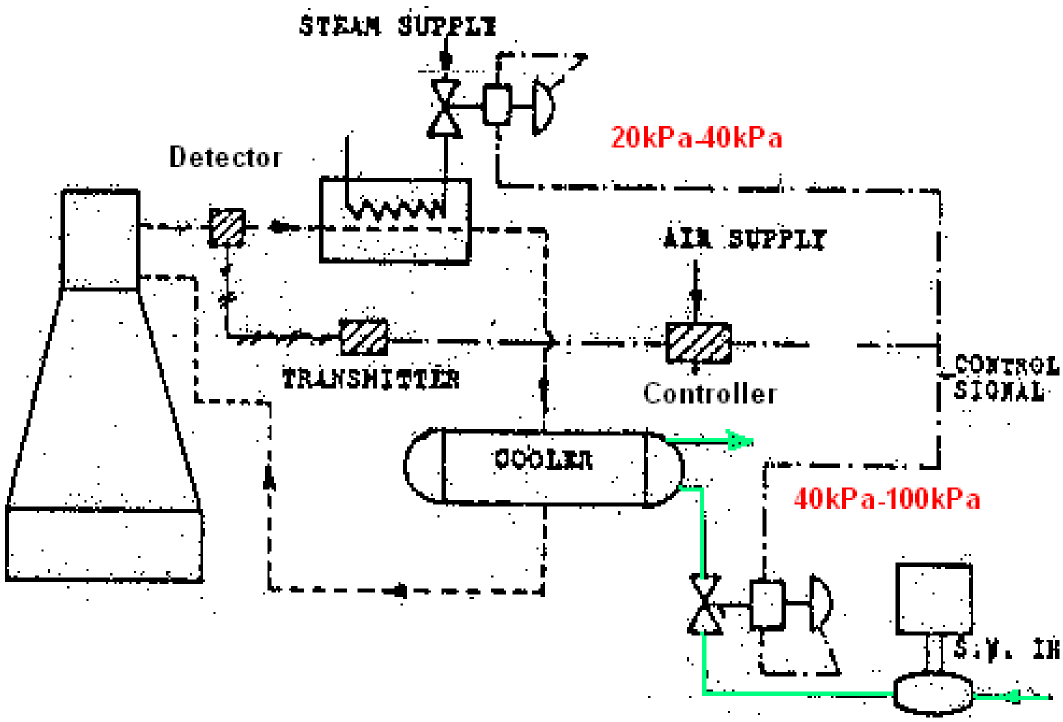


Fig. 1.11 Arrangement of Split range Control System

1.3 Types of Control Anction:

There are some common types of control: ON/OFF, PROPORTIONAL and PID etc.

1.3.1 Two Step Control or On/Off Control:

Two Step Control or ON/OFF control is the simplest and least expensive form of control available. The output signal from a controller is either FULL ON or FULL OFF depending on the polarity of the deviation from a set point.
Figure 1.12 shows Characteristics of On-Off Action.

With simple On/Off control, since the process value crosses the set point to change the output state, the process value will be cycling continually, going from below set point to above, and back below. In cases where this cycling occurs rapidly and to prevent damage to contactors and valves, an on-off differential or “hysteresis,” is added to the controller operations. This differential requires that the process value should exceed set point by a certain amount before the output will turn OFF or ON again. On-off differential prevents the output from “chattering” or fast and continual switching if the process value is cycling above and below set point very rapidly.
Figure 1.13 shows the Neutral Zone.

“On-Off” is the most commonly used form of control and for most applications it is perfectly adequate. It is used where a precise control is not necessary, in systems which cannot handle the energy being turned on and off frequently and where the mass of the system is so great that process value change extremely slowly.

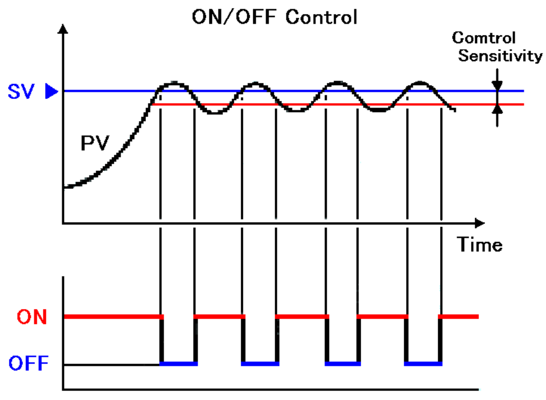


Fig. 1.12 Charasteristics of On-Off Control

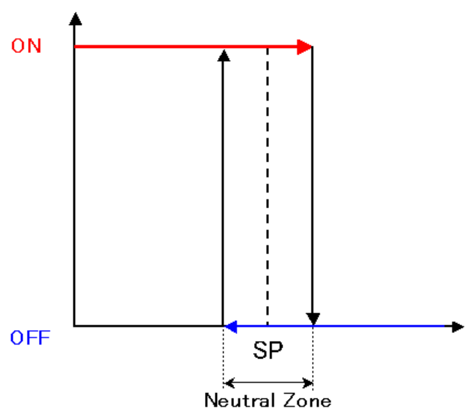


Fig. 1.13 Neutral Zone

1.3.2 Proportional Control:

Proportional control is designed to eliminate the cycling above and below the set points associated with On-Off control.
Figure 1.14 shows Characteristics of Proportional Control.

A proportional controller decreases the average signal being supplied to a control unit (control valve etc.). This has the effect of slowing down the control unit, so that it will not overshoot the set point, but will approach the set point and maintain a stable process value.

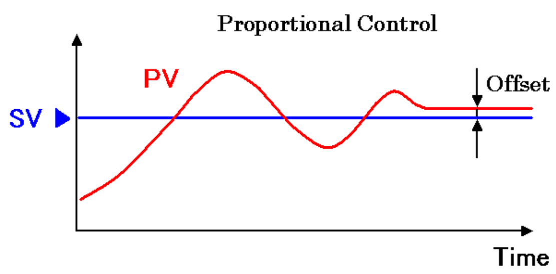


Fig. 1.14 Proportional Control

With proportional control, the proportioning action occurs within a "proportional band" around the set point. Outside this band, the controller functions as an on-off unit, with the output either fully ON (below the band) or fully OFF (above the band). However, within the band, the output is turned on and off in the ratio of the measurement difference from the set point. At the set point (i.e. the midpoint of the proportional band), the output ON:OFF ratio is 1:1 i.e. the ON-time and OFF-time are equal. If the process value is away from the set point, the ON- and OFF-times vary in proportion to the process value difference. If the process value is too low, the output will be ON for longer time and if the process value is too high, the output will be OFF for longer time.

Offset:
The difference between the set point and the actual value of the process variable is known as offset. Offset is an inherent characteristic of all proportional controllers only.

Gain:
When we talk about the proportional action of a controller, we generally refer to the proportional gain. The action means that the controller output varies in proportion to the deviation between the set point (SP) and the process output (PV).
controller output = K x (error) = K x (deviation)
= K x (SP - PV)
where the Gain is denoted by the parameter K.

For this Gain, many terms have been used by different manufacturers to designate this action. It has been called proportional gain, gain, throttling band, sensitivity and proportional band.

Proportional Band:
In practice, the controller output is limited, either by its own limitations or by the limitations of the corresponding actuator.
Now, let umax and umin denote the maximum and minimum output of the controller. The proportional band (P.B.)of the controller is then defined as:

$$PB = \frac{u_{max} - u_{min}}{K} \cdot 100\%$$

In the ideal case, a controller can have unlimited output. The proportional band (PB) is then defined as:

$$PB = \frac{1}{K} \cdot 100\%$$

This definition of proportional band is often used instead of the controller gain. The value is expressed in percent (%).

The proportional band is usually expressed as a percent of full scale, or degrees. It may also be referred to as gain, which is the reciprocal of the band.
Figure 1.15 shows Characteristics of Proportional Band.

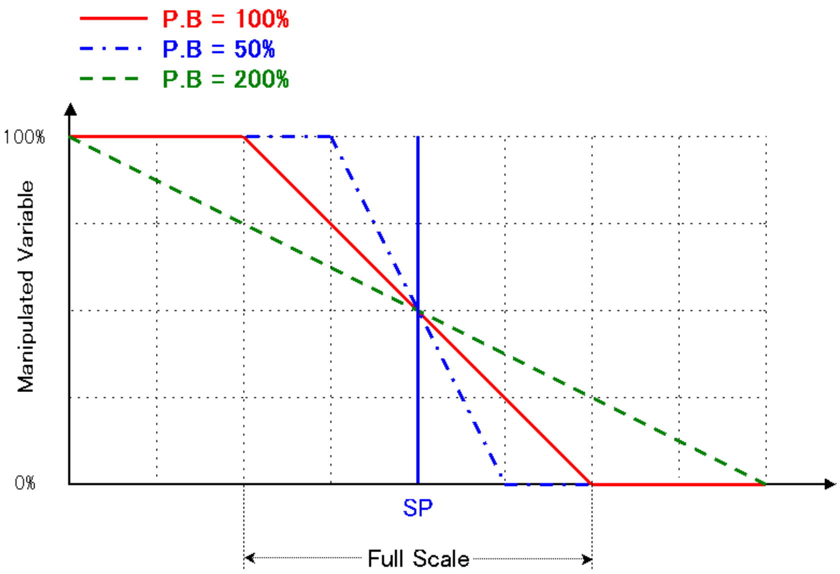


Fig. 1.15 Proportional Band

In other words, the proportion band [P.B.(%)] is a range of an input change (%) which is necessary to produce a range of output (MV) 0-100% change.

In the proportional control, there are Direct Acting or Reverse Acting controls.
Figure 1.16 shows Characteristics of Direct and Reverse Acting controls.
In the Direct Acting Proportional control, the Output signal (manipulated variable) increases if the Input signal (controlled variable) increases. The Direct Acting is often used for the cooling control system.
In the Reverse Acting Proportional control, the Output signal (manipulated variable) decreases if the Input signal (controlled variable) increases. The Reverse Acting is often used for the heating control system.

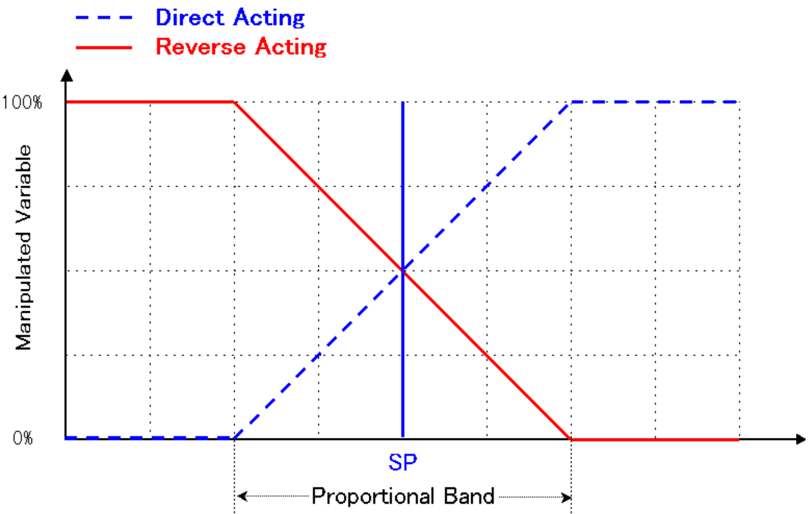


Fig. 1.16 Direct and Reverse Acting control

Proportional Action:
In Proportional action, Output signal (Y: manipulated variable) is proportional to the deviation (Z) between the Process Variable and the Set Point within Proportional band (PB).
Figure 1.17 shows Characteristics of Proportional Action.

Y = Kp x Z + b
Y: Output = 0% - 100%
Z: Deviation =SP - PV
Kp: Proportional sensitivity = 100 / PB
b: Manipulated Variable at no deviation
PB: Proportional band

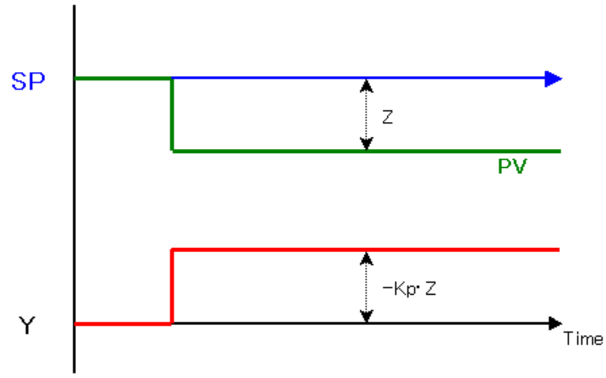


Fig. 1.17 Proportional Action

1.3.3 Integral Control:

With integral action, the controller output is proportional to the duration of time the error is present. Integral action eliminates offset which is inherent with proportional control.
Controller output = (1/Ti) x $\int$(error) = (1/Ti) x $\int$ (deviation)
= (1/Ti) x $\int$(SP - PV)
Where, the parameter Ti is called the integral time. Integral action is also known as reset control and the parameter Ti as reset time.
Some use reset rate, Tr, instead of reset time. These are simply the inverse of each other:
Tr = 1/Ti

Integral action gives the controller a large gain at low frequencies that results in eliminating offset. Integrals give information concerning the past. That is why integrals are always late. Integrals provide stability but have a tendency to get stuck in the past.

Integral action:

In Integral action, Output signal (Y: manipulated variable) can be denoted with following formula with Constant of integral control (Ki) and Deviation(Z).
Figure 1.18 shows Characteristics of Integral Action.

Y = - Ki $\int$ Z dt
Z: Deviation =SP - PV
Ki : Constant of integral control = Kp / Ti
Ti : Integral time

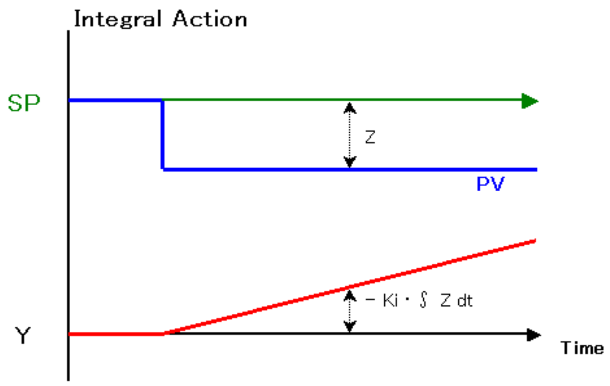


Fig. 1.18 Integral Action

Proportional and Integral Control Action:

In most controllers, the proportional and integral actions are combined.

Figure 1.19 shows Characteristics of Proportional and Integral Action.

In Figure 1.19, T1 is the time when the step input is added to the controller for P&I action and T2 is the time when the reset effect by the Integral action becomes equal to the gain effect by the Proportional action. The integral time is the duration between T1 and T2, T3=T2-T1.

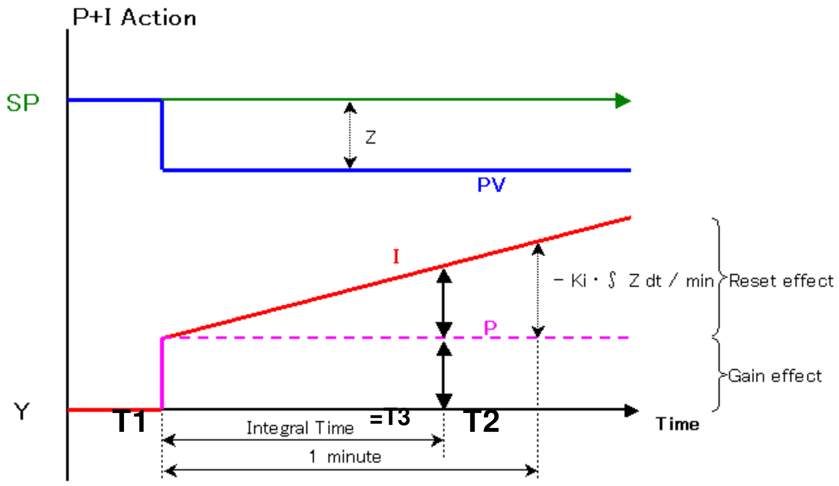


Fig. 1.19 Proportional and Integral action

Figure 1.20 shows Characteristics of Proportional & Integral Action (With same P action). If the gain effect by the Proportional action is steady, the reset effect by the Integral action will depend on the integral time.

Case1: If the integral time is set half, the reset effect by the Integral action becomes stronger.

Case2: If the integral time is set twice, the reset effect by the Integral action become weaker.

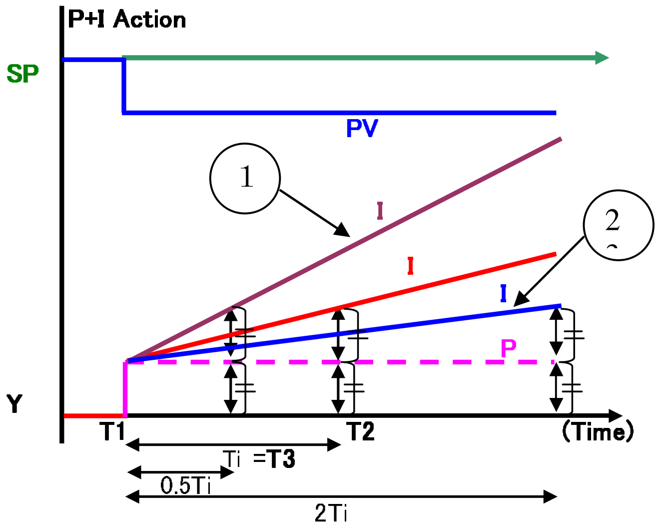


Fig. 1.20 Proportional & Integral Action (With same P action)

Figure 1.21 shows Characteristics of Proportional & Integral Action (With same Ti). If the integral time is steady, the reset effect by the Integral action will depend on the gain effect by the Proportional action.
Case3: If the gain effect by the Proportional action is set half, the reset effect by the Integral action become weaker.
Case4: If the gain effect by the Proportional action is set twice, the reset effect by the Integral action become stronger.

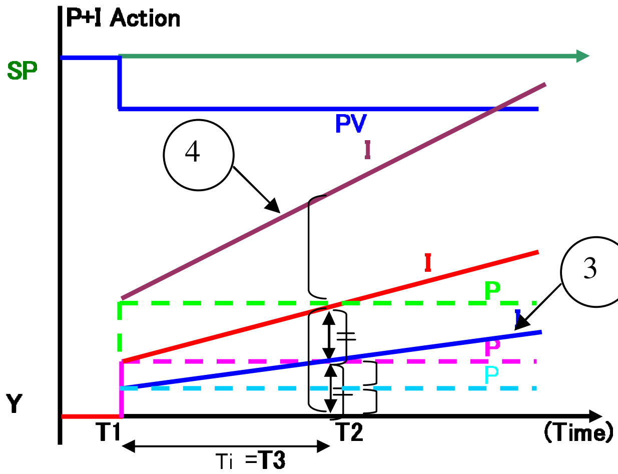


Fig. 1.21 Proportional & Integral Action (With same Ti)

1.3.4 Derivative Control:

With derivative action, the controller output is proportional to the rate of change of the measurement or error. Derivative, rate and pre-act are the same thing. The controller output is calculated by the rate of change of the error with time.

Controller output = Td x d(error)/dt = Td x d(deviation)/dt
= Td x d(SP - PV)/dt
Where, the parameter Td is called derivative action time.

Derivative action has the potential to improve performance when sudden changes in measured variable occur, but it should be used with care. It is mostly a matter of using enough, not too much.

Whereas proportional response responds to the size of the error and reset responds to the size and time duration of the error, the derivative mode responds to rate of change of the error. Figures 1.22 and 1.23 show two derivative control responses.

P+D Control Action:

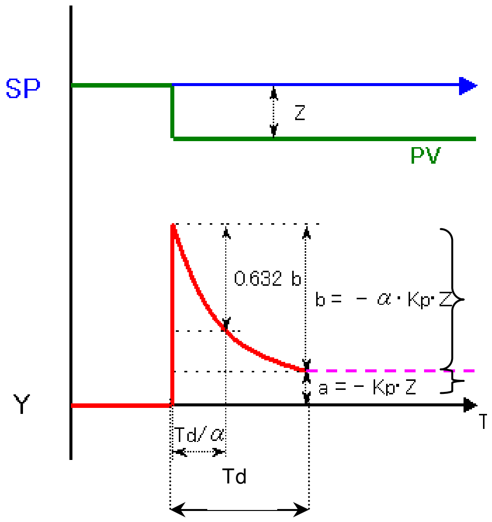


Fig. 1.22 Proportional & Derivative Action by Step input

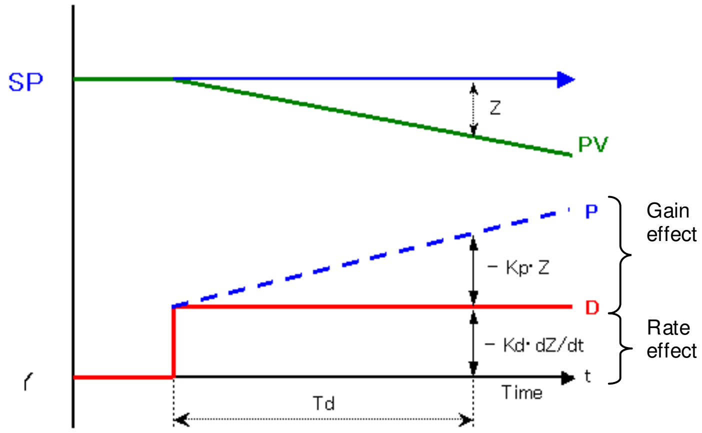


Fig. 1.23 Proportional & Derivative Action by Ramp input

In Derivative action, Output signal (Y: manipulated variable) can be denoted with following formula with Constant of Derivative control (Kd) and Deviation(Z).
Y = - Kd x dZ/dt
Z: Deviation =SP - PV
Kd : Constant of Derivative control = Kp x Td
Td : Derivative Time (Rate Time) in minutes

The first response is to stop change of the measurement away from the set point. Since the measurement is changing infinitely fast, the derivative mode in the controller causes a very large change in the output, which dies immediately because the measurement has stopped changing after this step. The Derivative Time (Td) is the time for the derivative component to become equal to the proportional component.

The second response shows the response of the derivative mode to a measurement which is changing at a constant rate. The derivative output is proportional to the rate of change of this error. The greater the rate of change, the greater will be the output due to derivative action. The derivative action holds this output as long as the measurement is changing. As soon as the measurement stops changing, even if measured value is below, above or at the set point, the response due to derivative action will cease. The Derivative Time (Td) is the time for the derivative component to become equal to the proportional component.
The derivative time (Td) in minutes is the time that the open loop proportional plus derivative response is ahead of the response due to proportional alone. Thus, the greater the derivative number, the greater will be the derivative response.

Figure 1.24 shows Characteristics of P + D Action by Ramp input (With same P action). If the gain effect by the Proportional action is steady, the rate effect by the Derivative action will depend on the derivative time.
Case 1: If the derivative time is set half, the rate effect by the Derivative action become weaker.
Case 2: If the derivative time is set twice, the rate effect by the Derivative action become stronger.

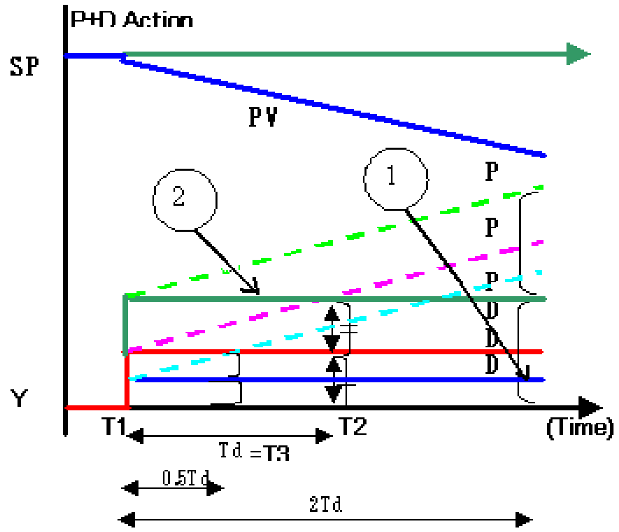


Fig. 1.24 P&D Action by Ramp input (With same P action)

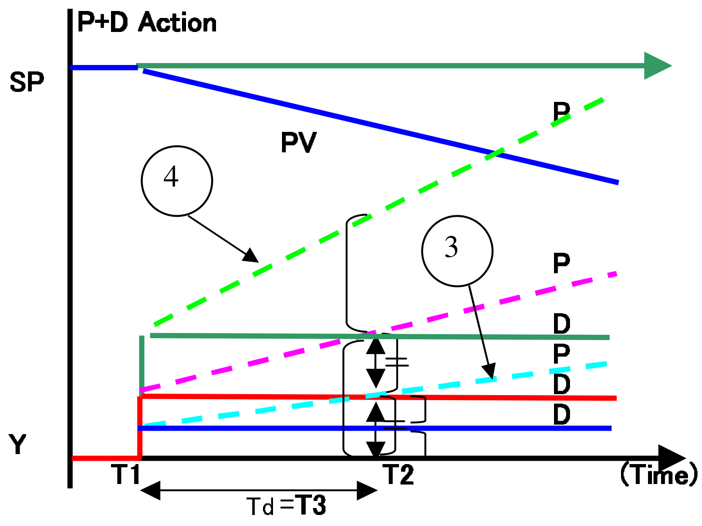


Fig. 1.25 P&D Action by Ramp input (With same Td)

Figure 1.25 shows Characteristics of P & D Action by Ramp input (With same Td). If the Derivative time is steady, the rate effect by the Derivative action will depend on the gain effect by the Proportional action.
Case 3: If the gain effect by the Proportional action is set half, the rate effect by the Derivative action become weaker.
Case 4: If the gain effect by the Proportional action is set twice, the rate effect by the Derivative action become stronger.

P+I+D Control:

Figure 1.26 shows the combined proportional, reset, and derivative response to a simulated heat exchanger temperature measurement which deviates from the set point due to a load change.
When the measurement begins to deviate from the set point, the first response from the controller is a derivative response proportional to the rate of change of measurement which opposes the movement of the measurement away from the set point. This action continues until the measurement stops changing, when derivative response ceases.
Since there is still an error, the measurement continues to change due to reset, until the measurement begins to move back towards the set point. The reset response continues because there is still error, although its contribution decreases with the error.
Thus, the measurement comes back towards the set point. With the measurement back at the set point, there is no longer any changing response due to reset.

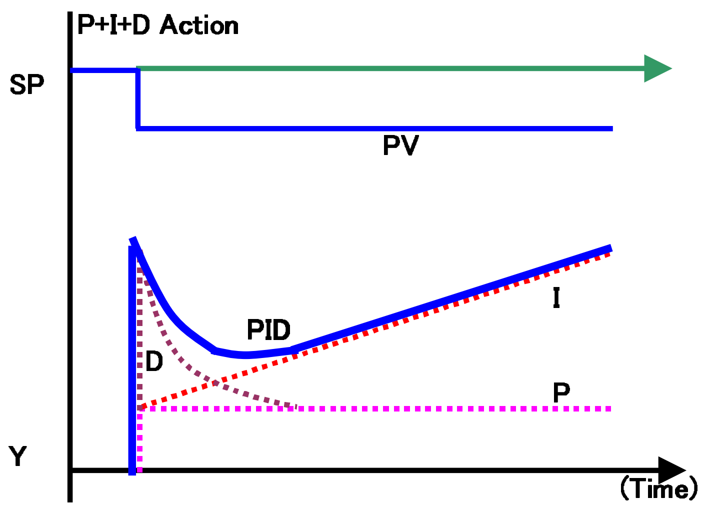


Fig. 1.26 PID Action by step input

As above explanation, PID controller can control more effectively the process whose dead time and transfer lag are large and load fluctuation is rapid and large.
PID is often used as a Temperature control for Main engine cooling fresh water controller or pressure control for high pressure boiler.

1.4 Principle and Structure of Control system equipments:

1.4.1 Pneumatic Controller:

The process temperature or pressure is converted into mechanical displacement by the sensor element. The mechanical displacement is fed through the over travel link (1) to the deviation detecting mechanism (2) which drives the red PV pointer (3) to indicate the process variable. At the same time, the process variable value (PV pointer) is compared with the set point value (SP pointer) to detect deviation (5).
The displacement, which is proportional to the deviation, is fed through the deviation link (6) to the proportional action unit (7) in order to drive the flapper (8). The back pressure of the nozzle varies in response to the flapper movement and amplified by the pilot relay (9) into a pneumatic control output signal.
Part of the output signal is returned as a feedback pressure signal via the derivative action unit (10). A reset pressure is provided by the integral action unit (11) and thus the control mechanism is balanced.
Figure 1.27 shows internal arrangement of YAMATAKE Controller.

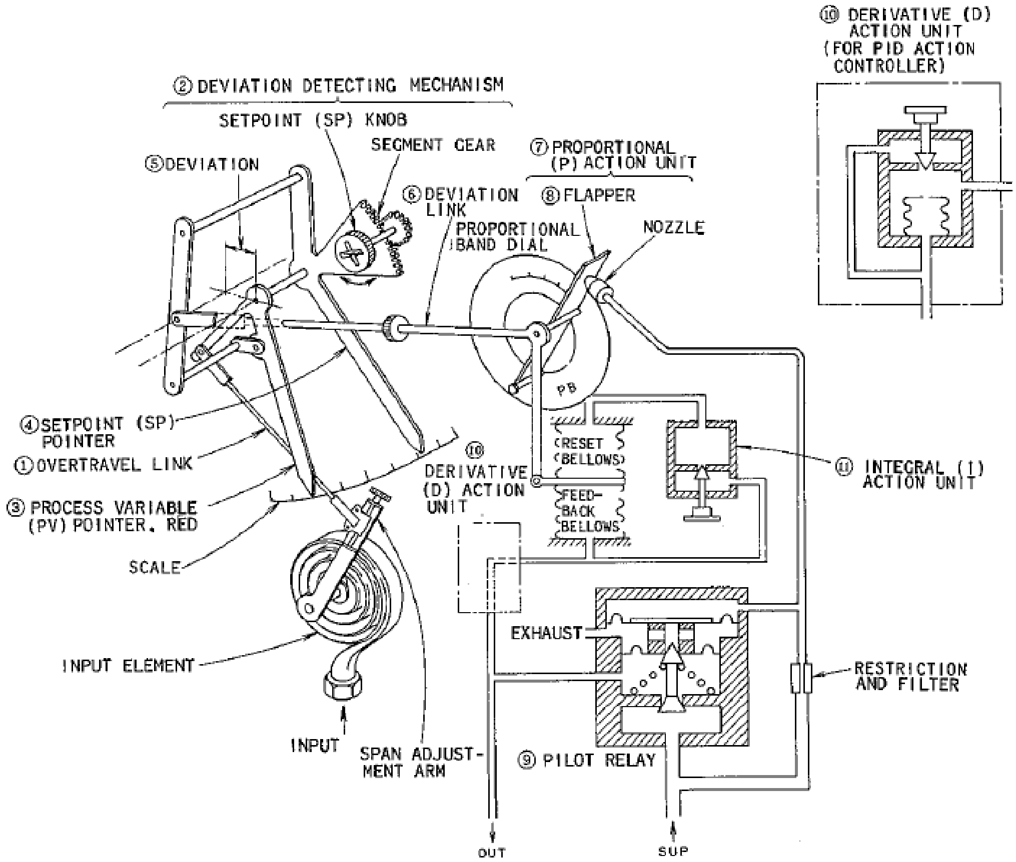
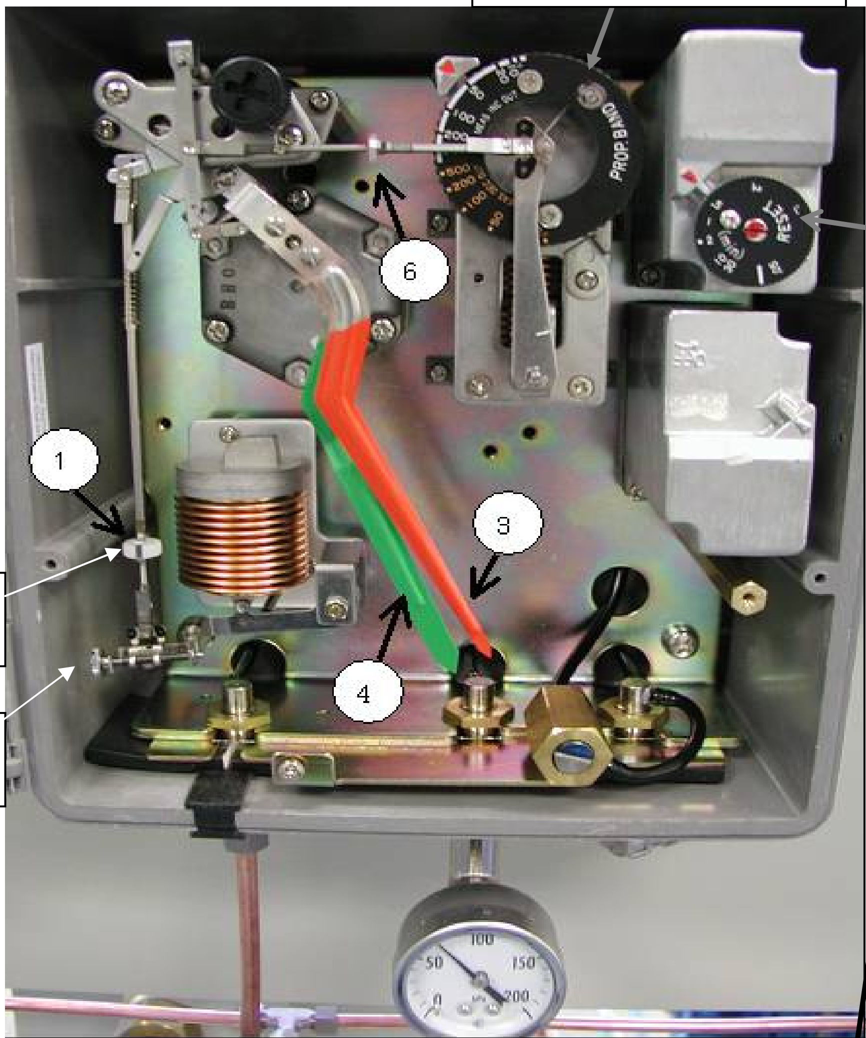
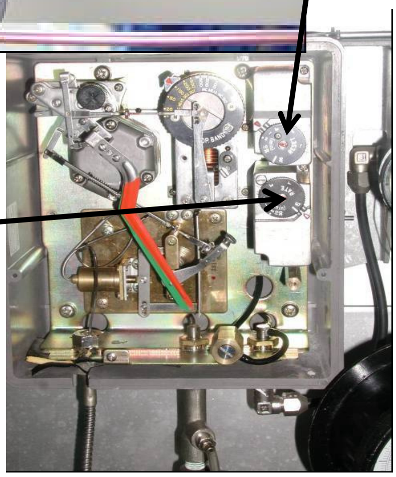


Fig. 1.27 Internal arrangement of Yamatake Controller

Pictures 1.1 and 1.2 show out view of YAMATAKE Pressure and Temperature Controllers.



Pic. 1.1 Yamatake Pressure Indicating controller MODEL:KGP



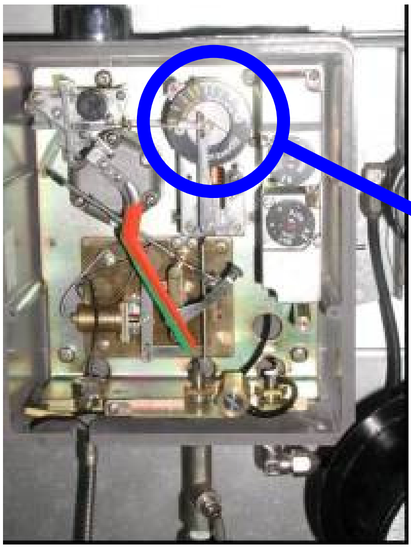
Pic. 1.2 Yamatake Temperature Indicating controller MODEL:KGT

1.4.2 Pneumatic Nozzle - Flapper system:

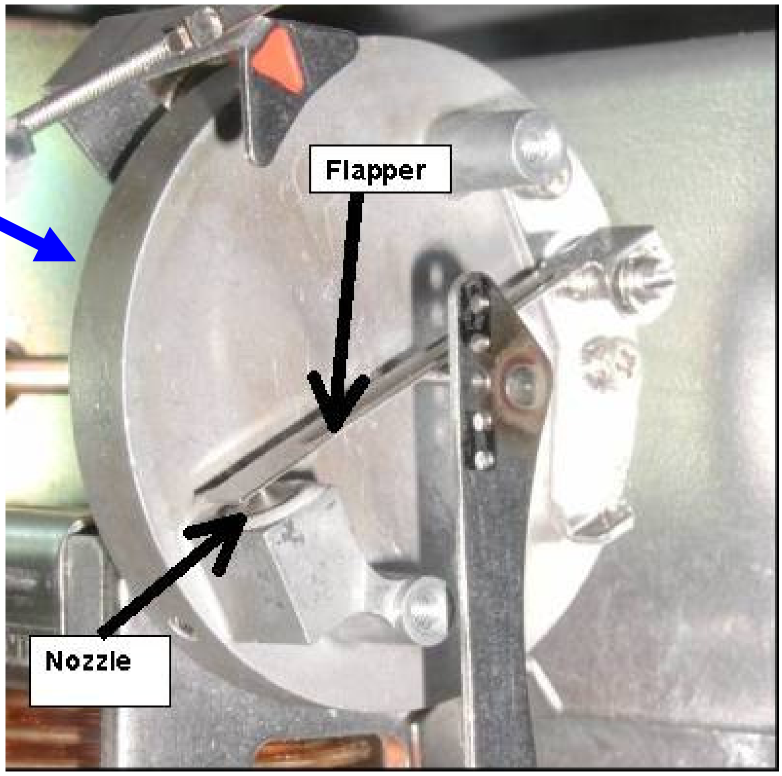
Details of Pneumatic Nozzle Flapper system are described under heading 1.1.1 Pneumatic Signal. In Figure 1.1, Pneumatic Nozzle Flapper system is shown. In Figure 1.2, Characteristics curve of Nozzle & Flapper is shown

There is a small distance between Nozzle and Flapper.

Pictures 1.3 and 1.4 show out view of Nozzle – Flapper arrangement.



Pic. 1.3 Yamatake Temperature Indicating controller MODEL:KGT



Pic. 1.4 Nozzle & Flapper

1.4.3 Pilot Relay (Relay Valve):

Most pneumatic controller has pilot relay fitted which magnify or amplify the output signals to reduce time lags in the system and permit for signal transmission over considerable distances.

In Fig 1.27, the principle of pilot relay, Yamatake Honey Well, is shown.

This valve consists of double-seated pilot valve where the nozzle flapper backpressure (P) operates from the top of the diaphragm and regulates the relay output pressure. This is a direct acting pilot relay valve where the increase in the nozzle back pressure causes increase in the relay output pressure. The air to the nozzle and flapper unit is routed via very fine restriction consisting of a filtering unit. This type of pilot relay valve is capable of giving amplification of 5 to 6 times.

Figure 1.28 shows Working Principle of Pilot Relay and Figure 1.29 shows Arrangement of Parts for a Pilot Relay.

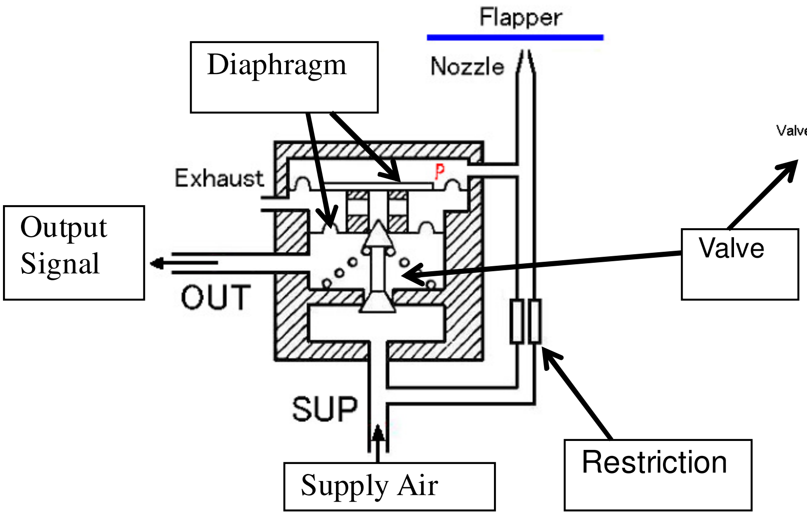


Fig. 1.28 Principle of pilot relay

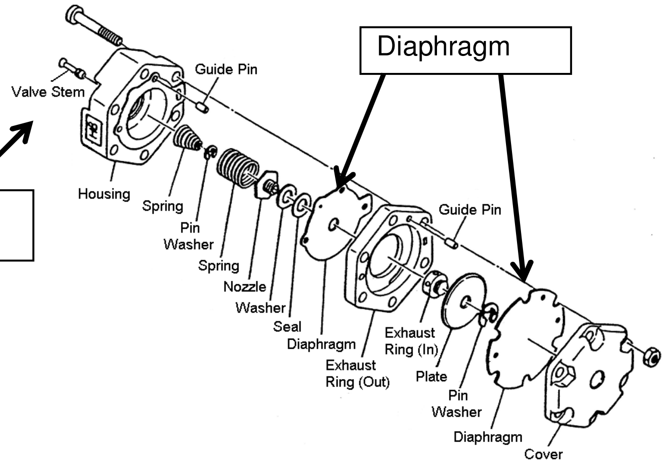
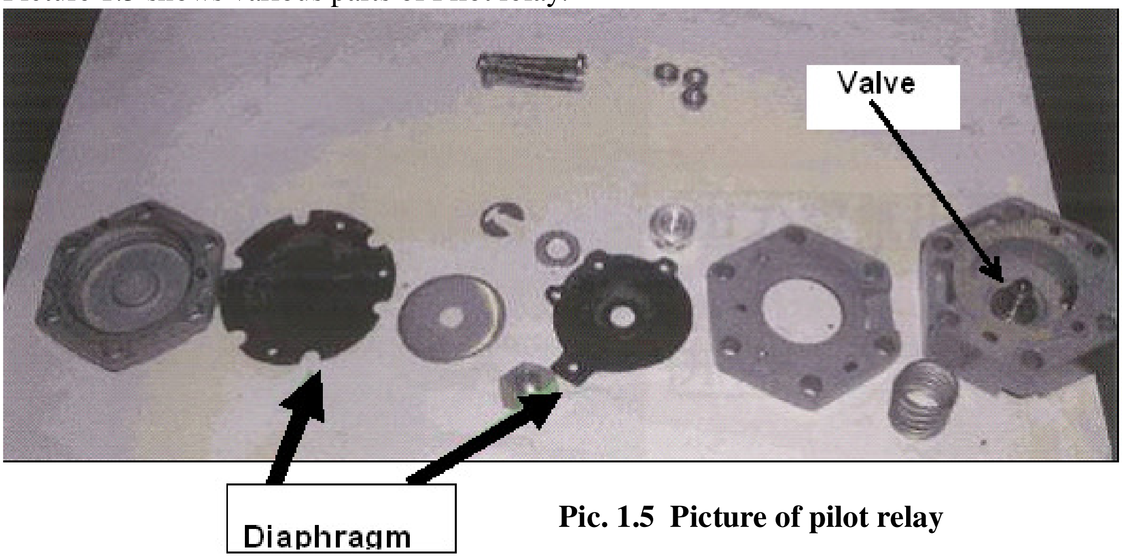


Fig. 1.29 Arrangement of Parts for Pilot relay

Picture 1.5 shows various parts of Pilot relay.



Pic. 1.5 Picture of pilot relay

Pilot relay valve unit is prone to malfunction, since it consists of diaphragm and Teflon valve seats. If air quality is not maintained, then it may hamper smooth functioning of pilot relay unit. So it is suggested that the air supplied to the pilot relay assembly should be clean and dry. The maximum number of problems with a controller system is usually associated with pilot valve assembly.

The pilot valve is not designed for the changes in the output for a given input.

1.4.4 Control Air Regulator:

Air regulator provides a constant pressure of supply air to pneumatic instruments and control valves.
Figure 1.30 shows Cross sectional view of Air Regulator. The outlet pressure is adjusted by the handle. The air, after reaching the area "A", applies force on the lower part of the diaphragm. This force is compared with the spring force on the diaphragm to maintain the outlet pressure either by releasing or restricting the air escape through Escape valve.

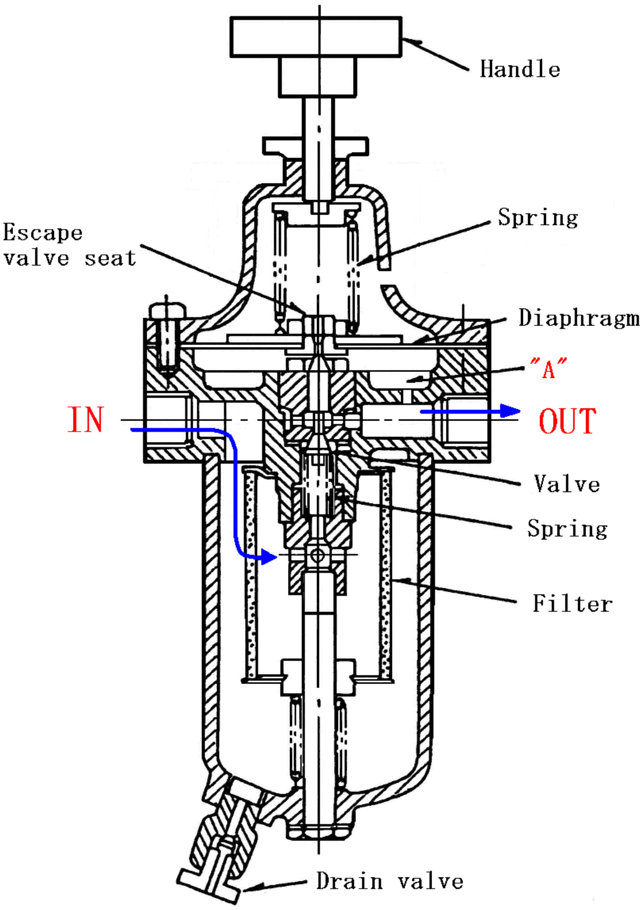


Fig. 1.30 Air Regulator

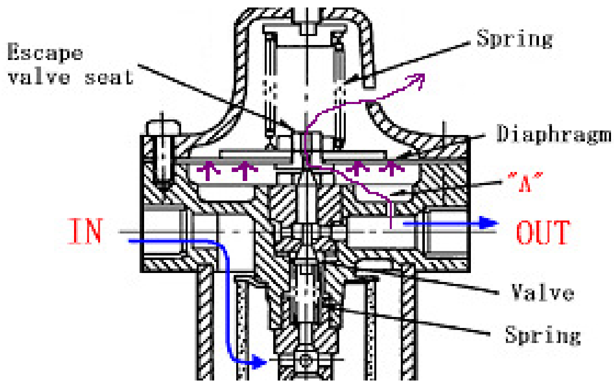


Fig. 1.31 Escaping route of Air

Figure 1.31 shows the Escaping route of Air through Air regulator.
If the outlet pressure increases, the force due to air pressure on the lower part of the diaphragm overcomes the spring force and then excess pressure is released to atmosphere passing through the opening of the escape valve seat.

1.4.5 Pneumatic Control Valve:

Figure 1.32 shows a Pneumatic Control Valve.

Pneumatic Control Valve can be considered to be made of two parts – the actuator and the valve. In the arrangement shown a flexible diaphragm forms a pressure tight chamber in one of the half of the actuator and the controller signal is fed in there. Movement of the diaphragm results in a movement of the valve spindle and the valve. The diaphragm movement is opposed by a spring and is usually arranged so that the variation of controller output corresponds to full travel of the valve.

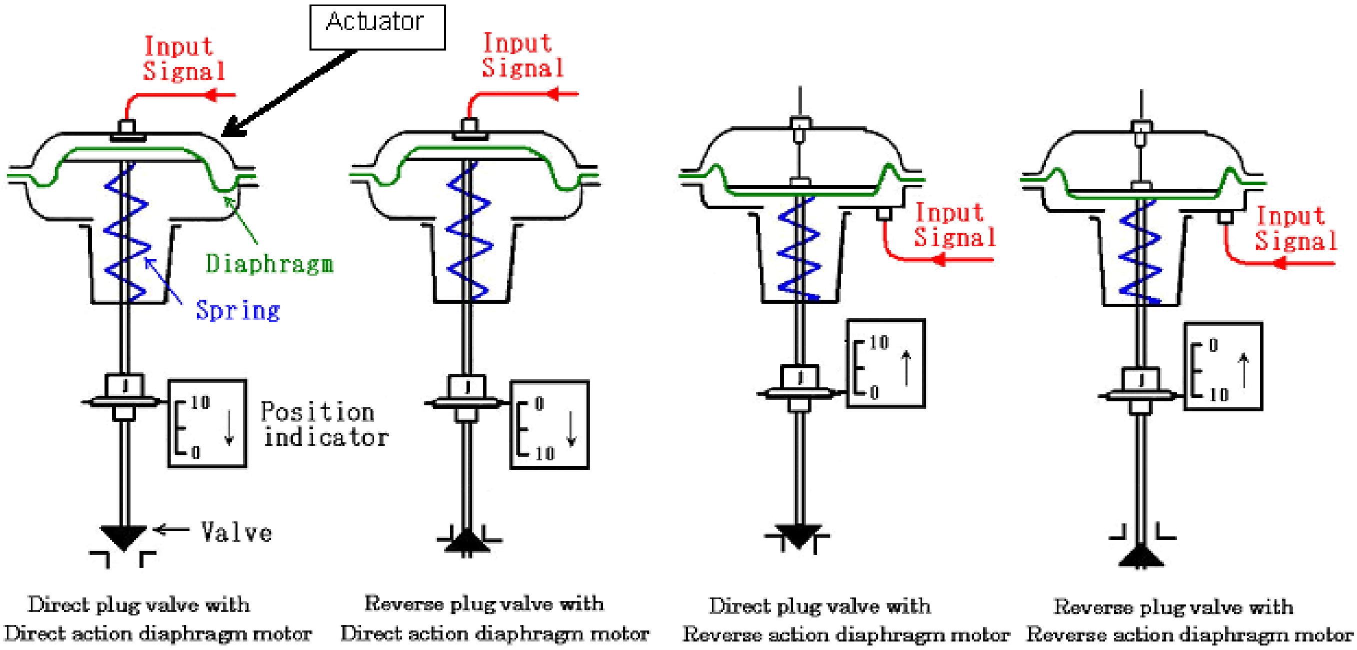


Fig. 1.32 Pneumatic Control Valve

Fig. 1.33 Direct Acting Valve

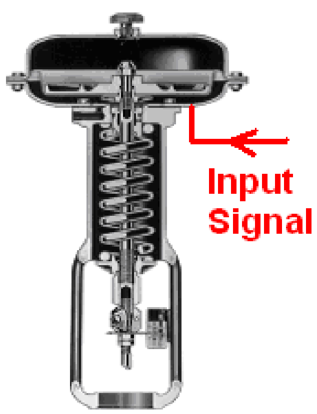


Fig. 1.34 Reverse Acting Valve

1.4.6 Valve Positioner:

In order to achieve accurate valve disc positioning and to overcome the effects of friction and unbalanced forces, a valve positioner may be used.

Such devices are necessary when:

(1) There is a high pressure drop across the valve or

(2) The valve is remote from the controller or

(3) The medium being controlled is viscous or

(4) High gland pressure is required.

Usually either of the above condition effectively increases friction, hysteresis or unbalanced forces acting on the valve spindle. The positioner provides extra power to position the valve accurately and quickly to offset these effects.

Figure 1.35 and Picture 1.6 show Out view of Yamatake HTP valve positioner.

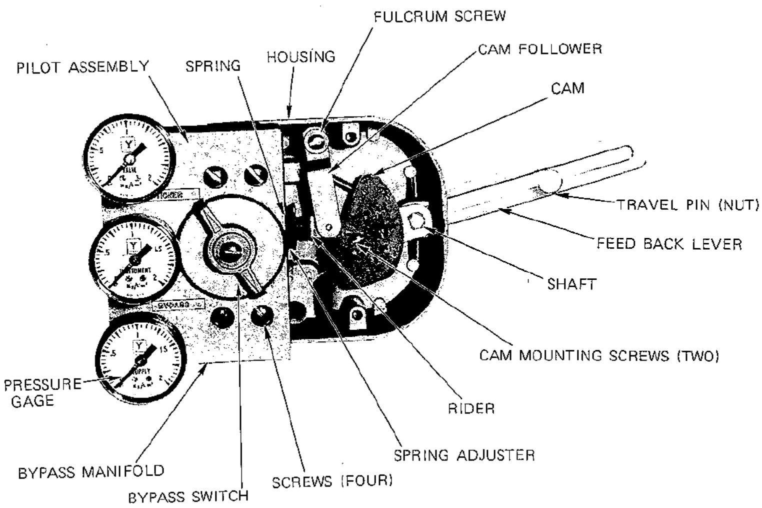


Fig. 1.35 Out view of Yamatake HTP valve positioner

Pic. 1.6 Out view of Yamatake HTP valve positioner

Valve positioner is principally a force - balance instrument. By the changes or effects of the air signal from a controller, the positioner feeds or bleeds air to the valve actuator until the force of the controller signal is in balance with the force created by valve stem movement.
To increase operational stability, the pilot is bleed type which balances between supply and exhaust air volume in normal condition. Positioner action is available in either direct or reverse action and is quickly changeable from direct to reverse or vice versa.

The operation principle of valve positioner is explained as an example of Yamatake HTP valve positioner.
Figures 1.36, 1.37 and 1.38 show working principle of Valve positioner.

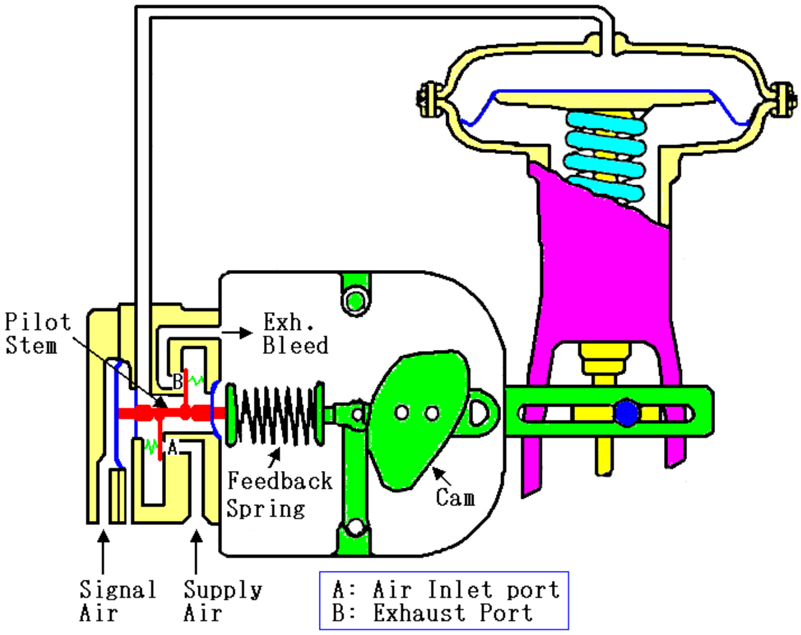


Fig. 1.36 Equilibrium condition

As the signal air is increased from Equilibrium condition in Figure 1.35, the pilot stem is moved down, closing the exhaust port and opening the Air Inlet port, which increases the pressure to actuator in Figure 1.36.

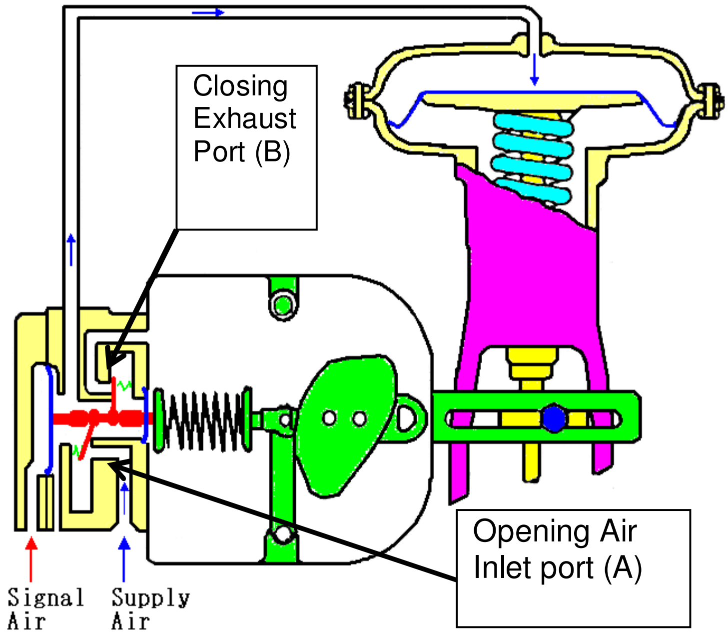


Fig. 1.37 Increasing signal

As a result, the valve stem movement compresses the feedback spring through the action of lever and cam, and applies a force to the pilot stem until the force created by the controller signal is in balance with the feedback spring in Figure 1.37.

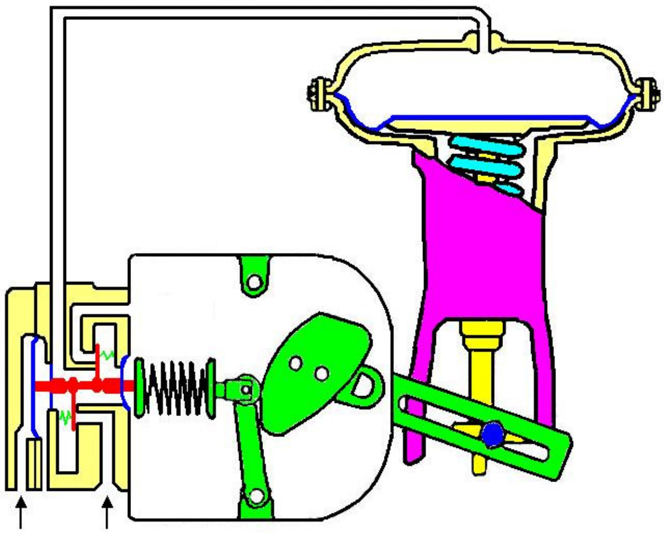


Fig. 1.38 Equilibrium condition

When the signal air decreases or process flow condition causes valve stem movement, the pilot feeds or bleeds air to actuator until the pilot stem balances in similar manner as described above.

1.4.7 Pressure switch:

Often when a measured pressure reaches a certain maximum or minimum value, it is desirable to have an alarm sounding a warning, a light to give a signal, or an auxiliary control system to energize or de-energize. A pressure switch is the device commonly used for this purpose. One of the simplest pressure switches is the single-pole, single-throw, quick-acting type, which is shown in Figure 1.39.

This switch is contained in a metal case that has a removable cover, an electrical connection, and a pressure-sensing connection. The switch contains a seamless metallic bellows located in its housing.

Changes, in the measured pressure, cause the bellows to work against an adjustable spring. This spring determines the pressure required to actuate the switch. Through suitable linkage, the spring moves the contacts to open or close the electrical circuit automatically, when the operating pressure falls below or rises above a specified value.

A permanent magnet in the switch mechanism provides a positive snap on both the opening and closing of the contacts. The switch is constantly energized. However, it is the closing of the contacts that energizes the entire electrical circuit.

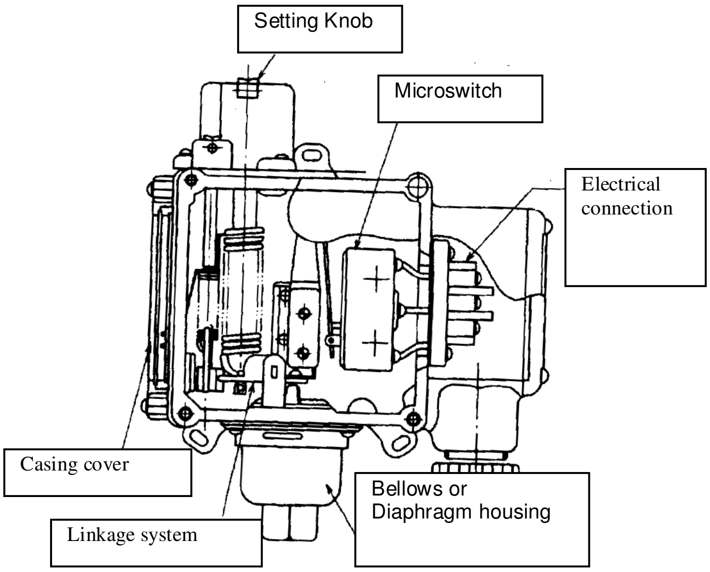
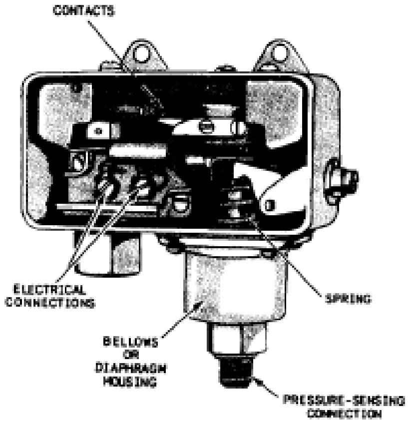
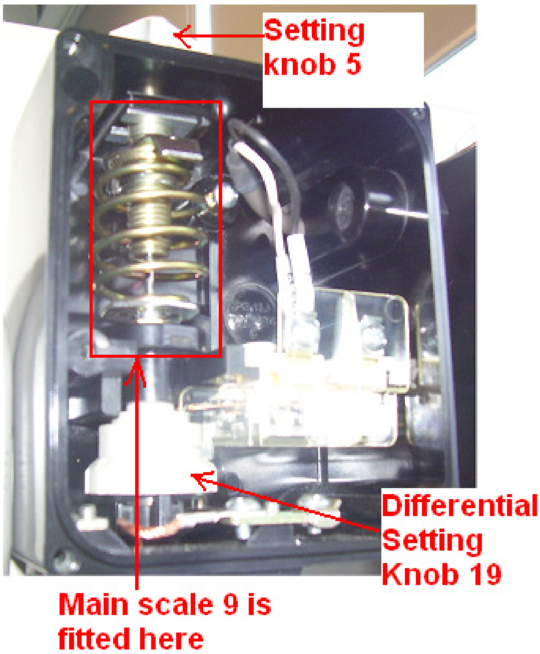


Fig. 1.39 Pressure switch



Picture 1.7 shows Danfoss Pressure switch RT. Type RT pressure switches incorporate a pressure controlled, single-pole changeover switch where the contact position depends on the pressure in the connection port and the set value. The RT series consists of pressure switches, differential pressure switches and pressure switches for neutral zone regulation. These units are for general use within the industrial and marine sectors.



Pic. 1.7 Danfoss Pressure switch RT

When the pressure falls to the set range value, contacts 1-2 make and contacts 1-4 break. The contacts changeover to their original position, when the pressure again rises to the set range plus the differential (see Figure 1.40).

I. Alarm for falling pressure given at the set range value.
II. Alarm for rising pressure given at the set range value plus the differential.
Units with min. reset can only be reset at a pressure corresponding to the set range value plus the differential.

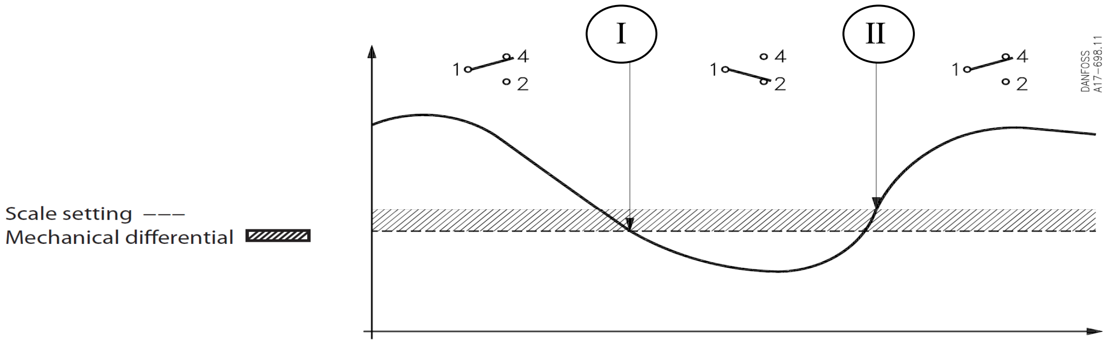


Fig. 1.40 Contact function and setting for falling pressure

(1)Setting:
Pressure:
The pressure controller is set by rotating the knob(5)., at the same time reading the main scale(9)
Pressure Differential:
The differential is set by rotating the differential adjusting nut(19) to the value indicated by the use of the nomogram in Figure 1.40 Obtainable differential disc scale.
The maximum operating pressure is thus the sum of the setting pressure and differential.

(2)Example:
It is desired to set alarm in a level controller by using a RT112.
Maximum pressure: 0.8 bar .
Minimum pressure: 0.7 bar.
Differential 0.8－0.7=0.1 bar

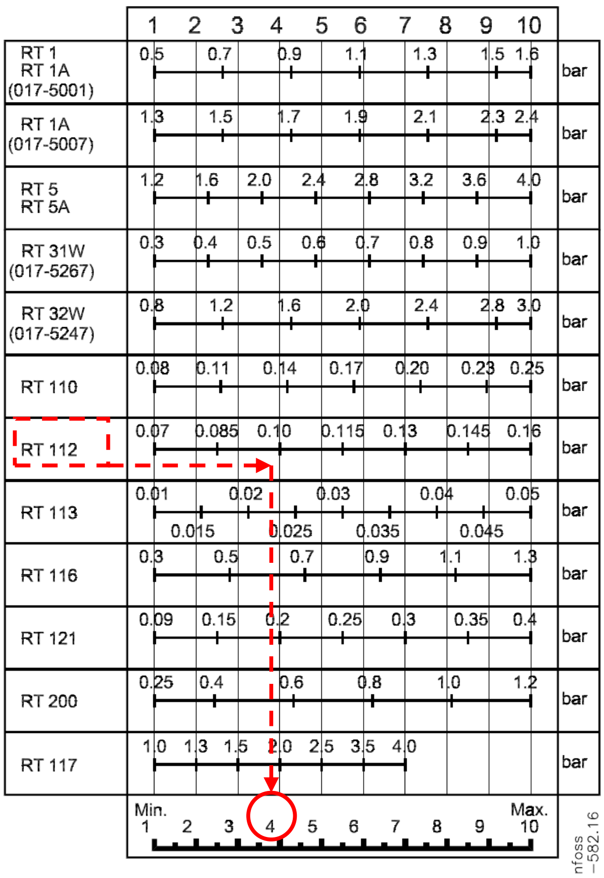


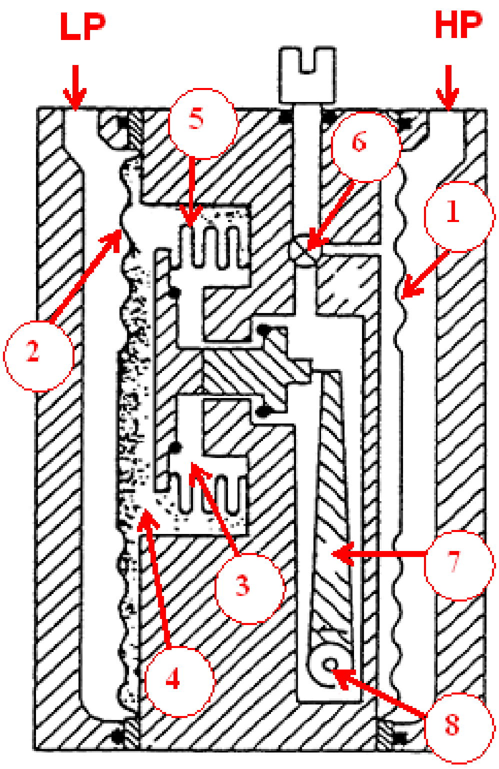
Fig. 1.41 Obtainable differential disc scale

1. Connect the Alarm Buzzer to terminals (1)-(4) of the pressure controller.
2. Set the pressure controller for 0.7 bar by rotating the knob (5).
3. Set the differential adjusting nut (19) at the figure (4), which is found by reading the nomogram in Figure 1.41.
4. Referring to Figure 1.40, the alarm is activated at above 0.8bar and reset at below 0.7bar.

1.4.8 Differential Pressure Transmitter (Pneumatic Type):

(1) Differential pressure cell:

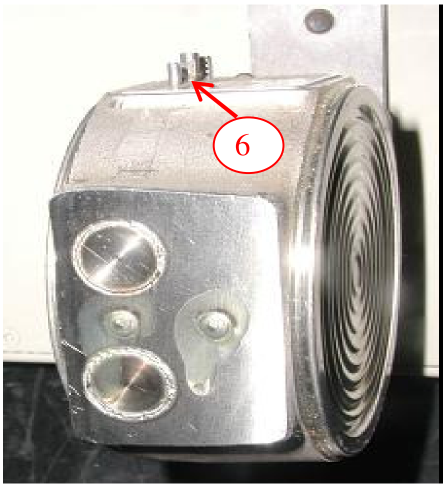
Differential pressure cell is used for flow and level measurements.
The detecting element of the cell is a bellows (5) and diaphragms (1) and(2), whose mechanical movement is used to indicate or transduced to electrical or pneumatic signal output.
Inside of the cell is filled with a constant viscosity fluid (silicone) in spaces (3) and (4), which also damps oscillation.
Pressure increase on the high-pressure side displaces liquid and expands the bellows. This bellows is connected to the torque arm(7).
Figure 1.42 shows Operating principle of Meter body.



(1) Seal diaphragm (HP)
(2) Seal diaphragm (LP)
(3) Fluid (HP)
(4) Fluid (LP)
(5) Bellows
(6) Damping
(7) Torque arm
(8) Torque tube

Fig. 1.42 Operating principle of Meter Body

The purpose of the Damping (6) is to prevent the mechanical failure due to the pressure fluctuation from HP side.
There is a mechanical part fitted after torque tube.
Moreover, after pneumatic type Differential Pressure Transmitter, the pneumatic signal is distributed to controllers, pressure switches, indicators, and etc. which also have mechanical components.
However, this Damping is optional item.
Picture 1.8 shows the Outview of Meter Body.



Pic. 1.8 Out view of Meter body

(2) Suppressed Zero Range and Elevated Zero Range:

Figure 1.43 shows Graph of suppression and Elevation range.

(a) Elevated Zero Range (Suppression)
A Range, in which the zero value of the measured variable, measured signal etc. is LESS than the Lower Range Limit (As the zero value does not appear on the scale shown above it is a suppressed zero range).
For example, a range of -20kPa to 0kPa.

(b) Suppressed Zero Range (Elevation)
A Range, in which the zero value of the measured variable, measured signal etc. is GREATER than the Lower Range Limit.
For example, a range of 20kPa to 100kPa.

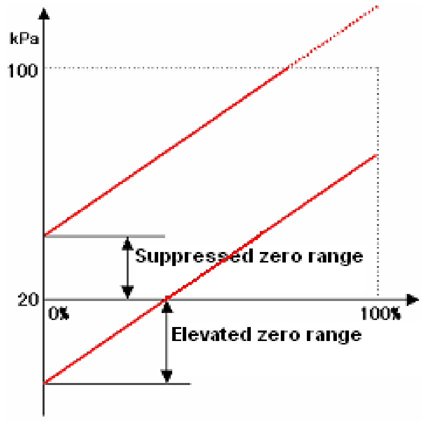


Fig. 1.43 Suppression and Elevation

(3) Open tank and Closed tank:

(a) Open tank and Closed tank (Dry Leg):

The following symbols are used to express density and distance.
It is assumed that the density is fixed during liquid level measurement.
γ: Specific gravity of liquid in tank
P0: Atmospheric pressure
P1: Tank pressure
h: Distance between 0% liquid level and liquid level in tank
h2: Distance between 0% liquid level and high-pressure outlet port

(1) Open Tank (Dry Leg):

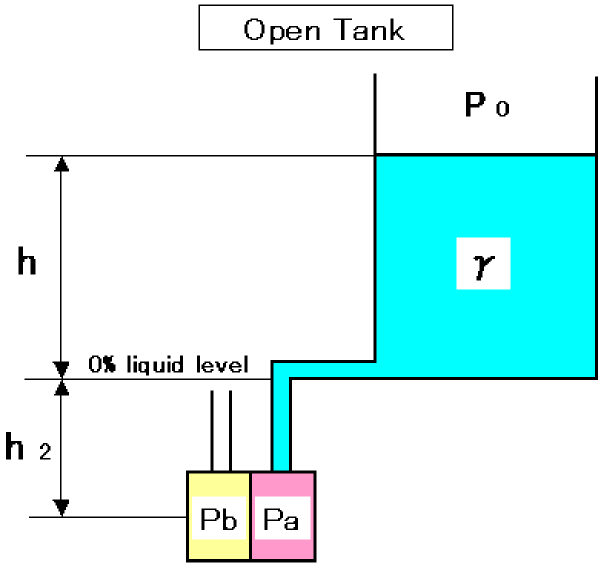


Fig. 1.44 Open Tank(Dry Leg)

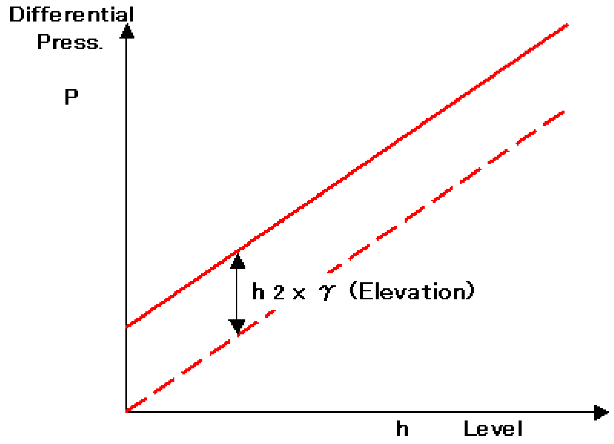


Fig. 1.45 Elevation at Open Tank (Dry Leg)

Following calculation is to estimate the elevation.
Pb side = P0
Pa side = h x γ + h2 x γ + P0
Differential pressure (P) = Pa – Pb
= h x γ + h2 x γ
It is necessary to correct the Head (h2 x γ) for measuring liquid level (h).

(2) Closed Tank (Dry Leg):

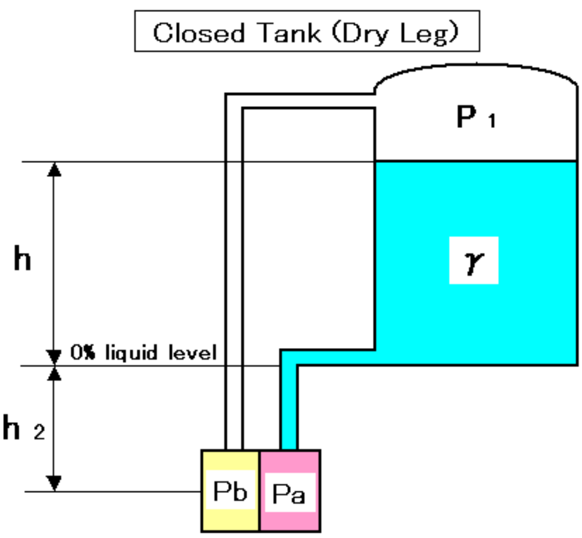


Fig. 1.46 Closed Tank (Dry Leg)

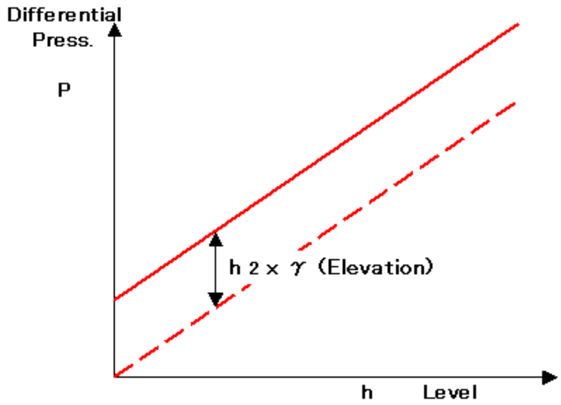


Fig. 1.47 Elevation at Closed Tank (Dry Leg)

In Figure 1.46, the low pressure side is air space in Closed Tank (Dry Leg).
Figure 1.47 shows Elevation at Closed Tank (Dry Leg).
Following calculation is to estimate the elevation.
Pb side = P1
Pa side = h x γ + h2 x γ + P1
Differential pressure (P) = Pa – Pb
= h x γ + h2 x γ
It is necessary to correct the Head (h2 x γ) for measuring liquid level (h).

(3) Closed tank (Wet Leg):

In Figure 1.48, the low pressure side is connected to the seal pot in Close Tank (Wet Leg)
Figure 1.49 shows Suppression at Closed Tank(Wet Leg).

The following symbols are used to express density and distance.
It is assumed that the density is fixed, during liquid level measurement.
γ: Specific gravity of liquid in tank
P1: Tank pressure
h: Distance between 0% liquid level and liquid level in tank
h2: Distance between 0% liquid level and high-pressure outlet port
h3: Distance between 0% liquid level and Seal pot level
h4: Distance between liquid level in tank and Seal pot level

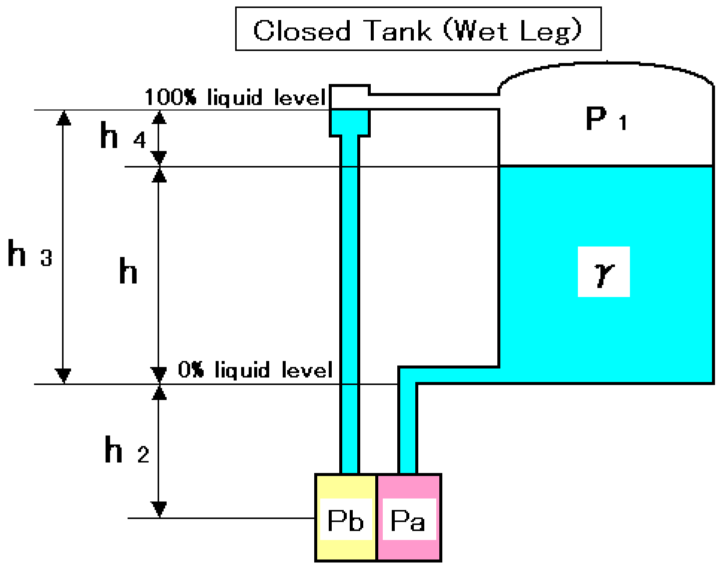


Fig. 1.48 Closed Tank (Wet Leg)

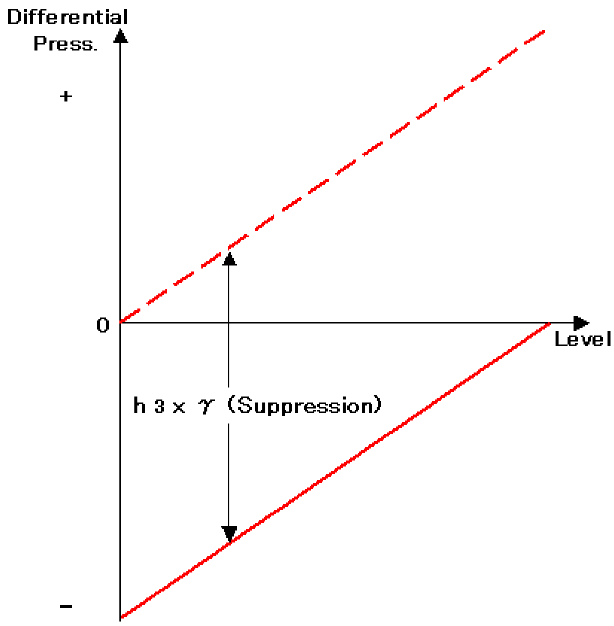


Fig. 1.49 Suppression at Closed Tank (Wet Leg)

Following calculation is to estimate the elevation.
Pb side = h3 x γ + h2 x γ + P1
Pa side = h x γ + h2 x γ + P1
Differential pressure (P) = Pa – Pb
= h x γ – h3 x γ
= –h4 x γ
Therefore, 0% liquid level = Differential pressure is maximum
100% liquid level = Differential pressure is 0
It is necessary to correct "0% liquid level = Differential pressure is 0".

1.4.9 Optimum control:

The ideal Optimal or optimum control is as follows,
(1) The Process variable meets the Set point constantly.
(2) The process of system is steady at any time.
However there are disturbance, response delay of the controller, etc.
In accordance with above actual difficulties, Optimal or optimum control is;
(1) to minimize the deviation between the Set point and the Process variable as small as possible and
(2) to stabilize the rapid fluctuation of controlled object in the shortest period of time
For the accurate response of the process condition, it is very important to understand the dynamic characteristics.
There are some methods like Ziegler Nichols, Ultimate Sensitivity Method and Reaction-Curve Method.

(1) Ziegler Nichols Method:

Note: This valve action is specialized for PID master. It means that the control valve of manipulated variable increases, when the output signal increases.

a) First, to operate it with proportional band, Time of integral (Ti, Reset time) should be adjusted to the maximum and Time of derivative (Td, Rate time) to the minimum to the full openness.
b) PB should be gradually adjusted down (to the direction of sensitivity increase) until Process variable pulsates. After confirming the start of the pulsatory motion, the value of PB0 should be secured.
c) PB should be readjusted to 2~4 times value of **PB0** (the value secured when the pulsatory motion started, to get out of pulsatory motion. (to get out of pulsatory motion and keep stable, sensitivity should be set a little below the pulsatory motion limit.
d) After adjusting PB dial, time of integral (Ti) should be adjusted. Ti, set to the maximum, should be gradually adjusted down until Process variable starts pulsating. In this process, after confirming the spot, where pulsatory motion starts and designating the Ti as **T0**, adjust Ti up to two times of **T0**.
e) After gradually adjusting up the Td, set to the full openness, to confirm the spot where pulsatory motion starts, adjust Td a little down to a lower value. It is empirically proper to adjust **Td to a quarter of Ti.**

(2) Ultimate Sensitivity Method:

This method permits calculating the controller settings (PID) from data obtained in close loop characteristic.

(1) Ultimate Sensitivity (Kc) – is the maximum value of gain (for a controller with only proportional mode) for which the system is stable.

(2)Ultimate Period (Pu) - period of the response with gain set at its ultimate value as shown on Figure 1.50 below.

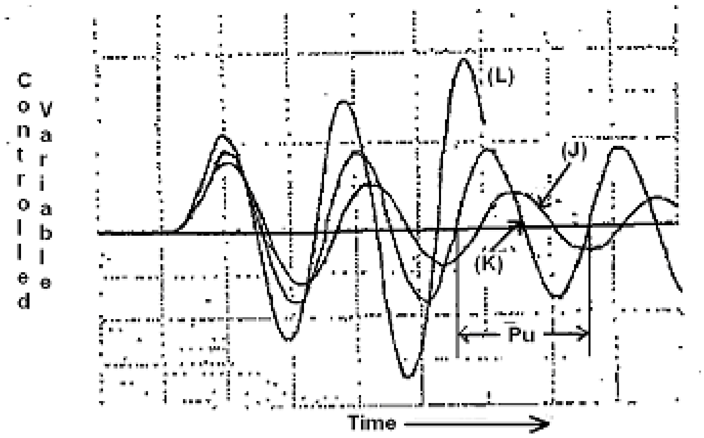


Fig. 1.50 Typical Responses Obtained When Determining Ultimate Gain and Ultimate Period

To obtain the required curve, proceed as follows:

(a)Be sure that:

Set Point at 60%

Derivative time at Minimum

Reset time at maximum

Set Point same as PV

Transfer Switch shift to Auto Position

(b)Turn on the switch for chart drive

(c)First with wide PB, impose an upset (disturbance) on the process.

One easy method is to move the set point to 10% difference for a few seconds and then return it to its original value.

(d)If the response curve in step (c) damps out (as in curve J in Fig 1.50) the gain is too low (PB is too wide).

Narrow the PB setting to 1/2 of previous setting and repeat step (c) until a response curve is similar to curve K in figure is obtained.

(e)Note the values of the PB setting (PBu) at the period (Pu) of the response.

(f) Using the equation in Table 1.4, calculate controller settings 1/4 decay ratio curves will be obtained.

Mode	Proportional Band(%)	Reset Time Ti (Min)	Derivative Time Td (min)
Proportional (P)	2P Bu (Kp=100/200=0.5Kc)	Maximum	Minimum
Proportional (P) + Reset (PI)	2.2P Bu (Kp=100/220=0.45Kc)	0.85Pu	Minimum
Proportional (P)+ Derivative (PID)	1.7P Bu (Kp=100/170=0.6Kc)	0.5Pu	0.125 Pu

Table 1.4 Setting value of Ultimate Sensitivity Method

(2) Reaction-Curve Method:
This method is to determine controller settings (PID) from the reaction curve response of the system i.e., with controller in manual position, a sudden step change is imposed to the process, and then the parameters used to characterize the process are obtained.
From the parameters, 1/4 decay ratio response curves will be obtained.
To do this, proceed as follows:
(a)With the transfer switch in manual position, adjust manual output so that measurement pen (PV) reaches 10% and level does not change for 5 minutes.
(b) turn on switch for chart drive.
(c)Impose a 5% step up set in the controller output.
(d)The response curve will be obtained as shown in Figure 1.51 below.
The real system is usually approximated by a system with a pure time delay plus first order lag.
Approximate the process reaction curve as follows:
(1) Draw a straight line tangent to the process reaction curve at its point of maximum rate of ascent, i.e., point of inflection.
(2) Calculate the equivalent time delay or dead time L (the time in minutes between the step change and the point when this tangent straight line crosses the initial value of the controlled variable) the equivalent time constant T, and the process gain Kp.

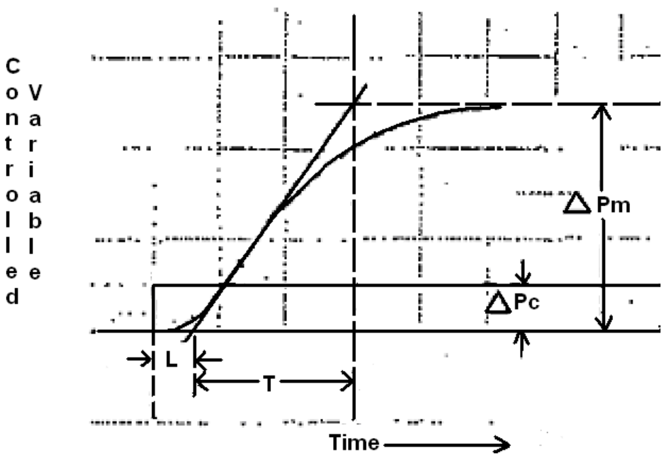


Fig. 1.50 Typical Reaction Curve for Step Change in Manual Output

The process gain Kp is determined as follows:

$$Kp = \frac{\text{Final Steady-state change in Controlled Variable}}{\text{Change in Manual Output}}$$

$$Kp = \frac{\Delta Pm}{\Delta Pc}$$

(3)With the values, L, T, and Kp, calculate controller settings using the equations in Table 1.5.
1/4 decay ratio response curves will be obtained.

Mode	Proportional Band(%)	Reset Time Ti (Min)	Derivative Time Td (min)
Proportional (P)	100Kp L/T	Maximum	Minimum
Proportional (P) + Reset (PI)	110Kp L/T	3.3L	Minimum
Proportional (P)+ Derivative (PID)	83Kp L/T	2L	0.5 L

Table 1.5 Setting value of Reaction Curve Method

2. Adjustment procedure:

Training by the AMCO simulator unit

- Pneumatic Controller

- Pneumatic type Differential pressure transmitter

- Valve positioner

- Pressure switch

- Electrical type Differential pressure transmitter

- Smart Field communicator

- Electrical Controller

- I/P Converter

3.0 Maintenance and Check points:
3.1 Pneumatic controller:

Causes of trouble:
The following items are considered as the key trouble factors for the pneumatic control equipment.
(1) Blockage of pneumatic line
(2) Crater due to presence of oil and dust
(3) Deterioration due to prolonged use and presence of oil or condensate water in control air
(4) Eccentric abrasion due to vibration
(5) Parts failure and so forth

3.1.1 Blockage of pneumatic line:

Principal location of failure:
Nozzle Flapper, Restriction and each filter, etc.
Cause:
Presence of Oil, Condensate water and dust/dirt in control air
Countermeasures:
The quality of the control air must be improved and maintained in good condition.
Confirm whether the oil in the control air is separated and removed by the equipments like oil mist separator etc. provided for the purpose of preventing the oil/water contamination in the control air.
Moreover, on the filter regulator, carry out the drain-off and the inspection periodically in order to maintain the filter in good condition.

3.1.2 Crater due to presence of oil and dust:

Principal location of failure:
Nozzle Flapper
Cause:
Oil contamination and dust/dirt in control air
Countermeasures:
Remove Crater on flapper by some very thin, non-metallic object e.g. business card

3.1.3 Deterioration due to prolonged use and presence of oil or condensate water in control air:
Principal location of failure:
Pilot relay, pneumatic pressure regulator and internal rubber tube, where parts are made of rubber as a material
Cause:
Deterioration due to prolonged use and presence of oil or condensate water in control air.
Countermeasures: Same as the countermeasures for Blockage of pneumatic line

3.1.4 Eccentric abrasion due to vibration:
Principal location of failure:
Fulcrum of segment gear or link in deviation detecting mechanism (indicating and setting mechanism)
Cause:
Vibrations from hull and machineries
Countermeasures:
To reduce level of vibrations by reinforcing the support structures for pneumatic control devices.

The following figures and pictures show the Principal location of failures regarding pneumatic controller and associated components, in order to understand the check points.

(1) Pneumatic pressure regulator:

No.	Parts name	Material
1	Bonnet	
2	Body	
3	Filter case	
10	Handle	
12	**Diaphragm assembly**	**Acrylo-nitrile-Butadiene Rubber (NBR)**
13	**Packing**	**NBR**
14	**Packing**	**NBR**
15	Spring	
16	Spring	
19	Pilot valve	
21	Drain cock	
25	**Metaric filter**	**BC**
33	**Packing**	**NBR**

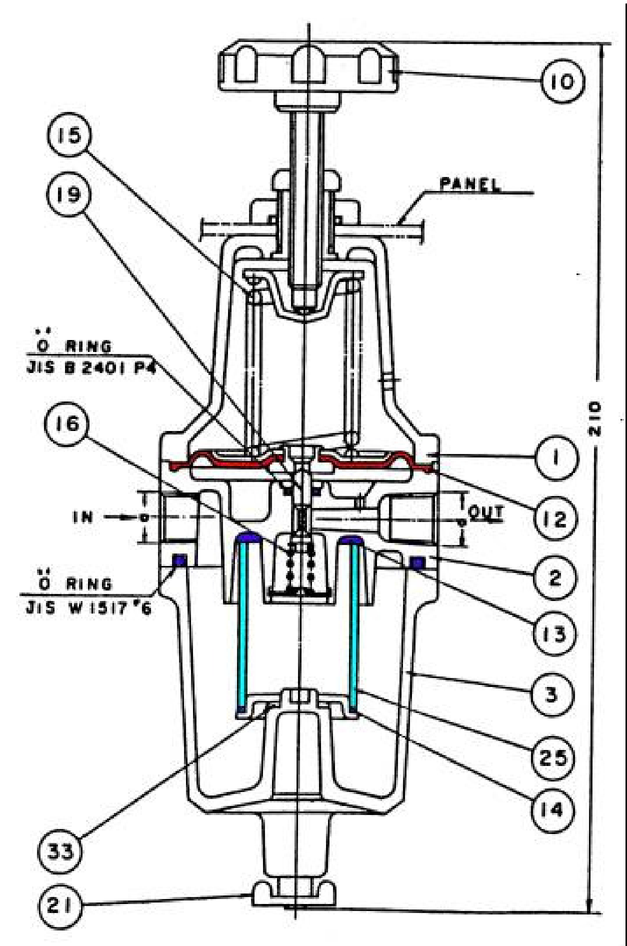
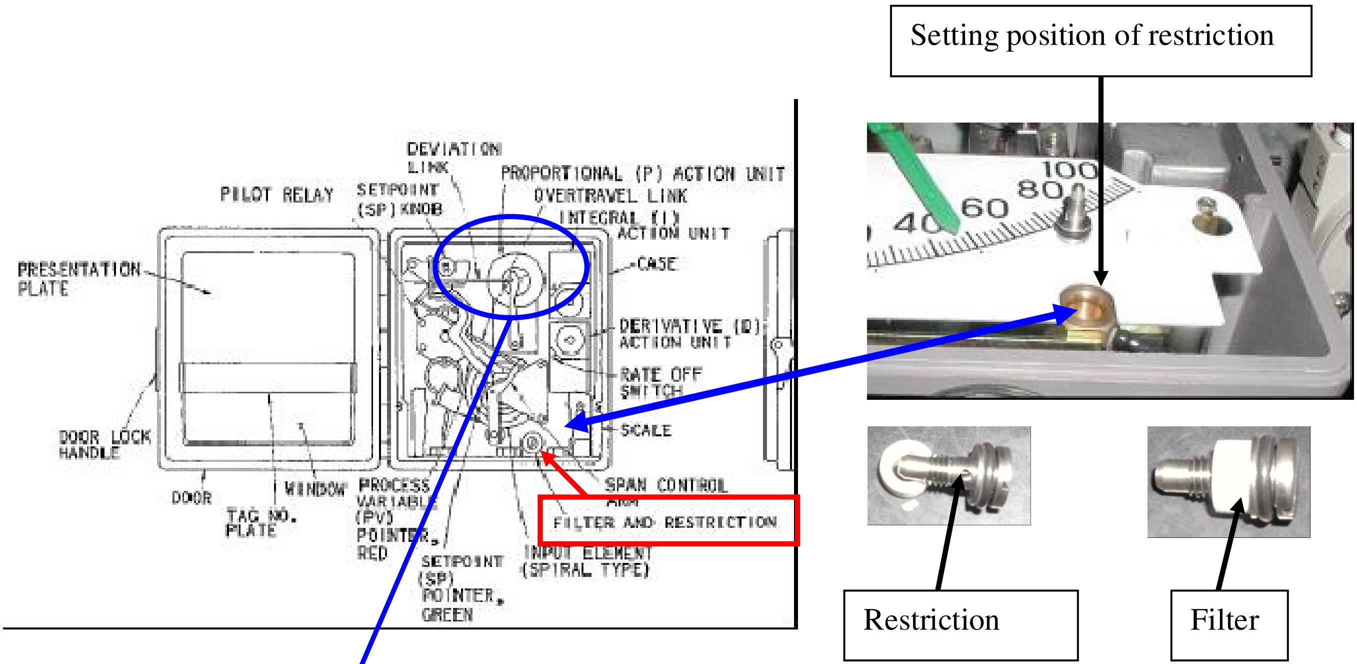
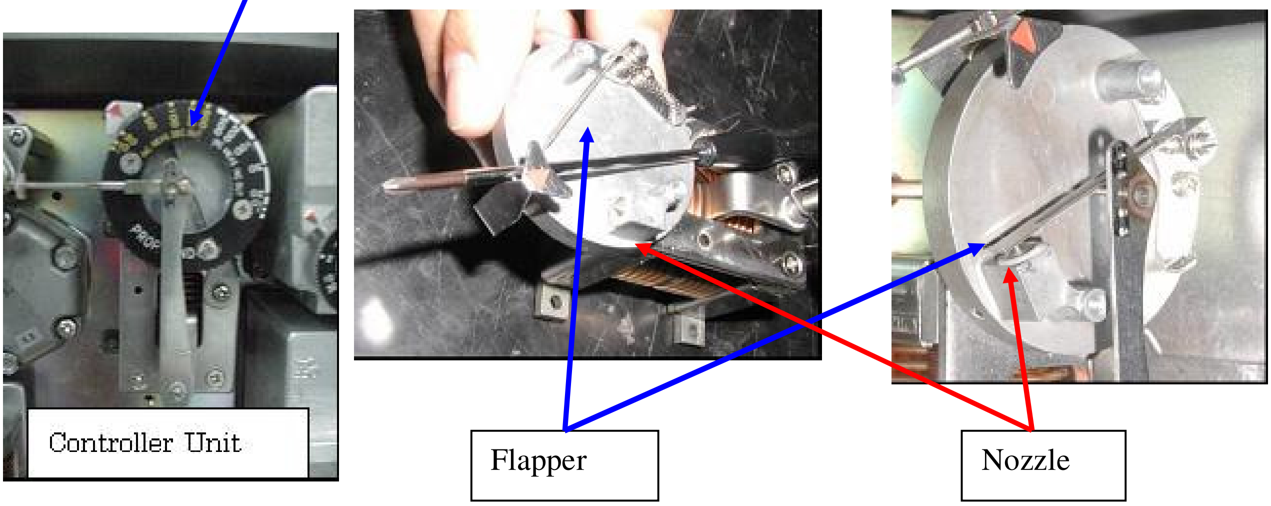


Fig. 3.1 Pneumatic pressure regulator

(2) Filter and Restriction:

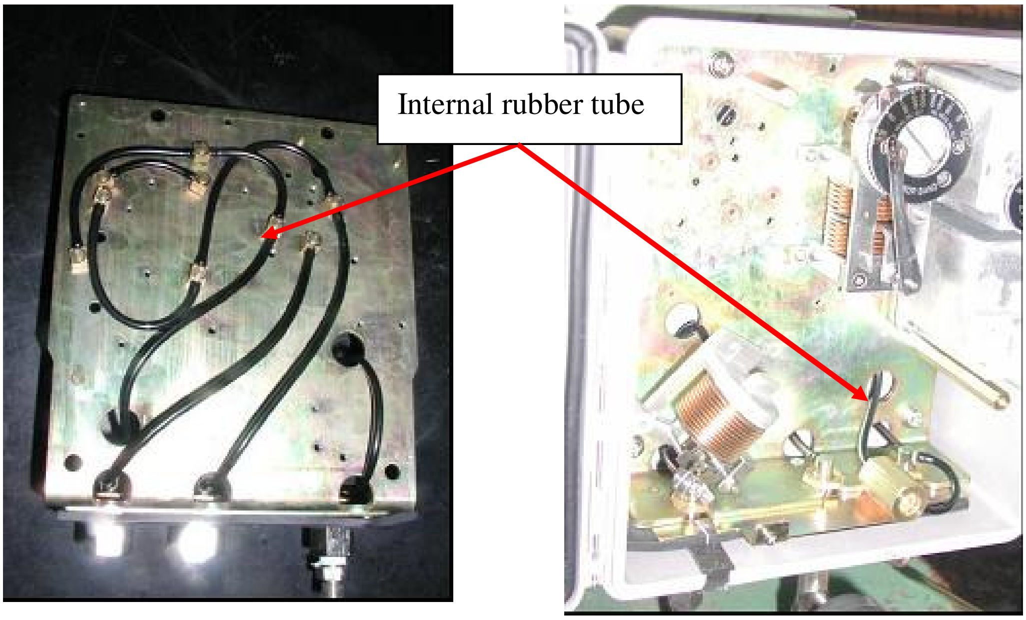


(3)Nozzle and Flapper:



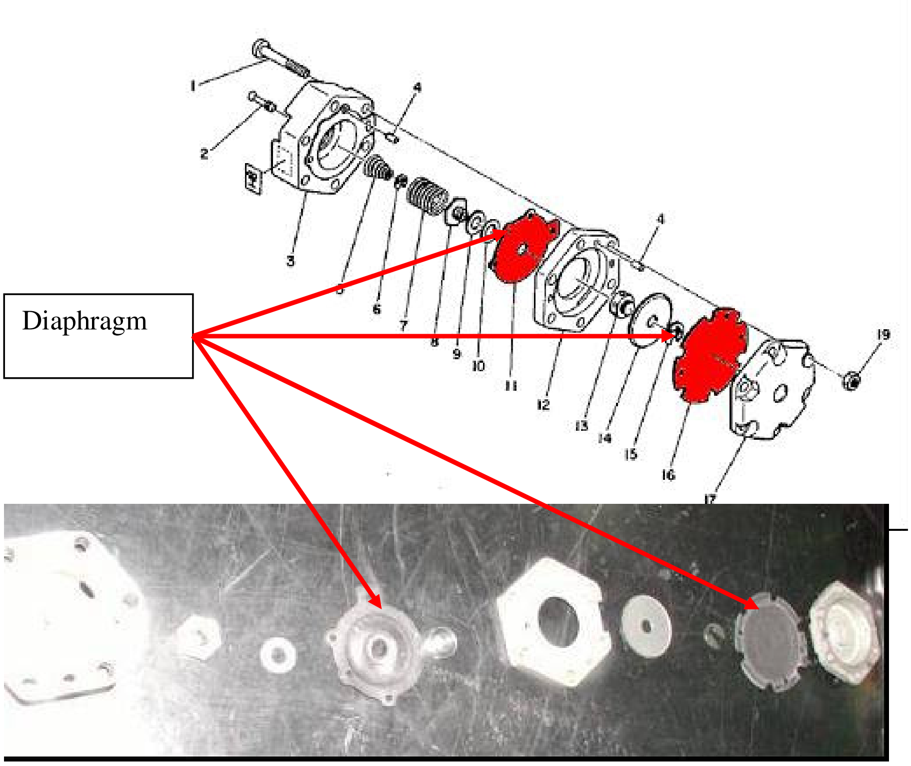
Pic. 3.1 Filter/Restriction and Nozzle/Flapper

(4) Internal tube:

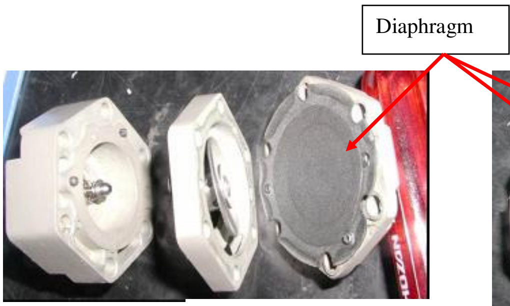


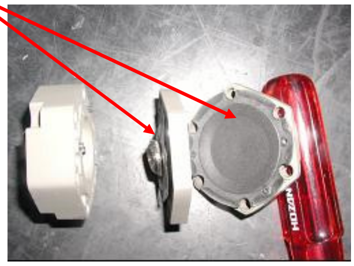
Pic. 3.2 Internal tube

(5) Pilot relay:



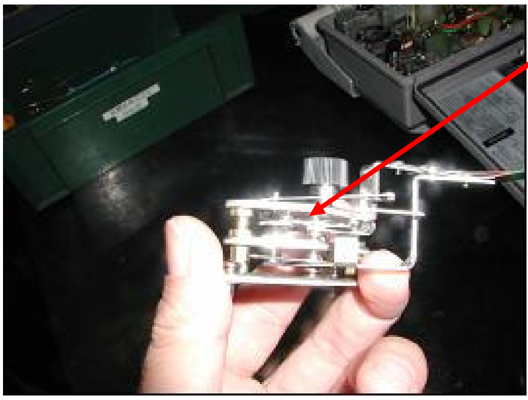
Pic. 3.3 Pilot relay

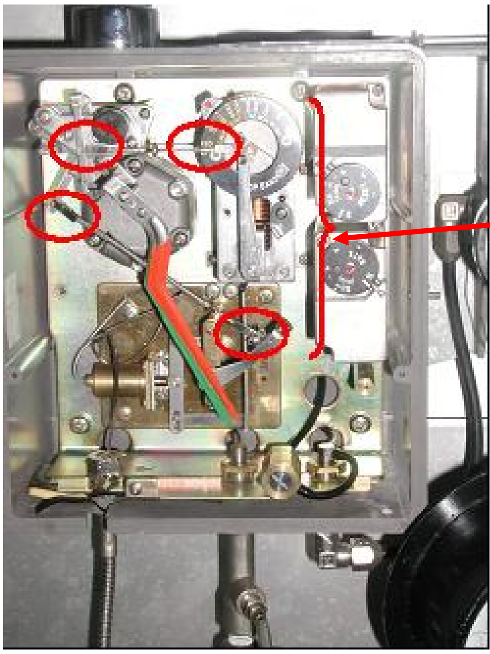


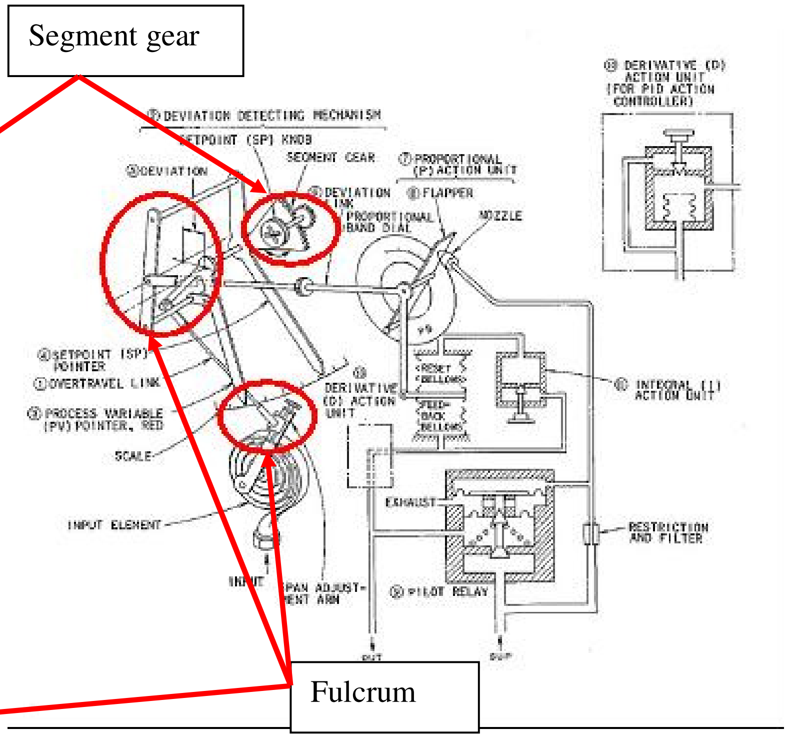


Pic. 3.4 Pilot relay

(6) Fulcrum of segment gear or link in deviation detecting mechanism (indicating and setting mechanism:)







Pic. 3.5 Fulcrum of segment gear

3.2 Control valve:

Phenomenon:
Air leakage
Cause of trouble:
Damaged or Cracked diaphragm due to prolonged use
Countermeasures:
Replace the diaphragm.
During storing spare diaphragms, keep them at cool and dark environment.

3.3 Valve positioner:

Cause of trouble:
The following items are considered as the key trouble factors for the pneumatic control equipment.
(1) Blockage of pneumatic line
(2) Deterioration due to prolonged use and presence of oil or condensate water in control air
(3) Eccentric abrasion caused by vibrations
(4) Parts failure and so forth

3.3.1 Blockage of pneumatic line:

Principal location of failure:
Pilot assembly and air way, etc.
Cause:
Presence of Oil, Condensate water and dust/dirt in control air
Countermeasures:
The quality of the control air must be improved and maintained in good condition.
Confirm whether the oil in the control air is separated and removed by the equipments like oil mist separator etc. provided for the purpose of preventing the oil/water contamination in the control air.
Moreover, on the filter regulator, carry out the drain-off and the inspection periodically in order to maintain the filter in good condition.

3.3.2 Deterioration due to prolonged use and presence of oil or condensate water in control air

Principal location of failure:
Pilot assembly, air ways, etc.
Cause:
Deterioration due to prolonged use and presence of oil or condensate water in control air.
Countermeasures:
Same as the countermeasures for Blockage of pneumatic line

3.3.3 Eccentric abrasion caused by vibrations:

Principal location of failure:
Fulcrum, Link, Cam, etc.
Cause:

Vibrations from hull and machineries

Countermeasures:

To reduce level of vibrations by reinforcing the support structures for pneumatic control devices

The following figures show the Principal location of failure in order to help you know where to check.

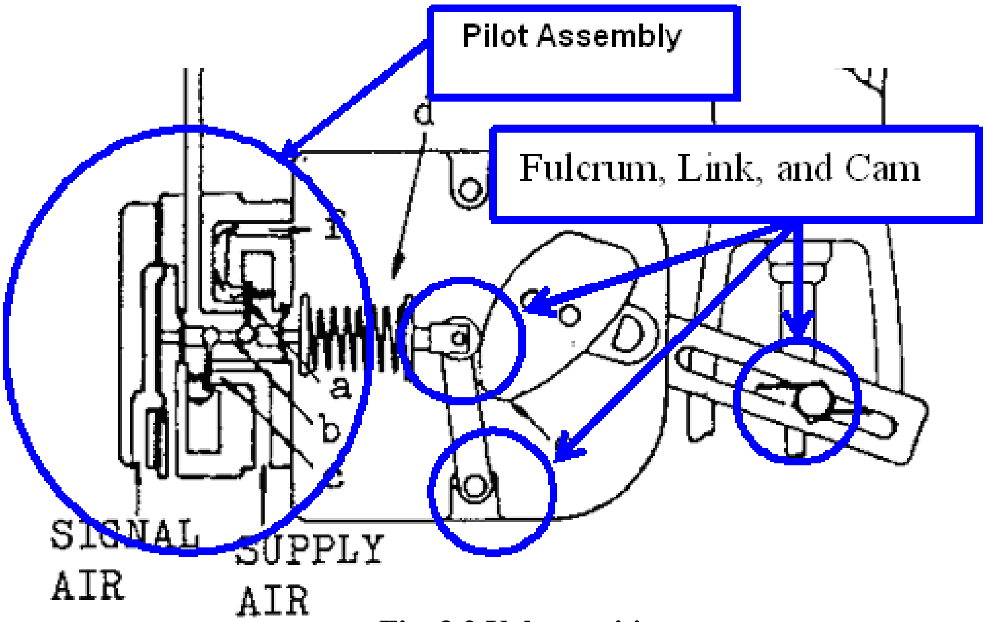


Fig. 3.2 Valve positioner

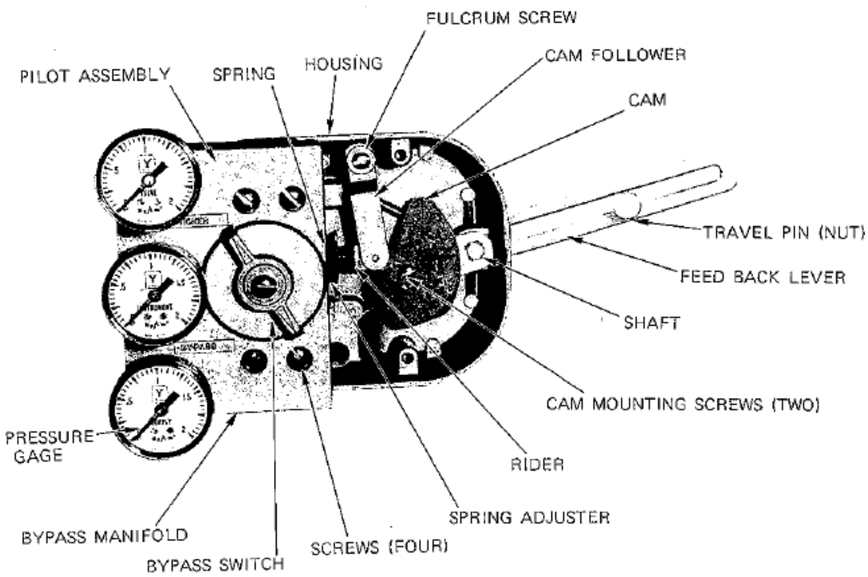


Fig. 3.3 Valve positioner

3.4 Differential transmitter (Pneumatic Type):

Causes of trouble:

The following items are considered as the key trouble factors for the pneumatic control equipment.

(1) Blockage of pneumatic line
(2) Deterioration due to prolonged use and presence of oil or condensate water in control air.
(3) Crater due to presence of oil and dust
(4) Eccentric abrasion caused by vibrations
(5) Blockage of pressure line

3.4.1 Blockage of pneumatic line:

Principal location of failure:

Nozzle Flapper, Restriction, filters, etc.

Cause:

Presence of Oil, Condensate water and dust/dirt in control air

Countermeasures:

The quality of the control air must be improved and maintained in good condition.
Confirm whether the oil in the control air is separated and removed by the equipments like oil mist separator etc. provided for the purpose of preventing the oil contamination in the control air.
Moreover, on the filter regulator, carry out the drain-off and the inspection periodically in order to maintain the filter in good condition.

3.4.2 Crater due to presence of oil and dust:

Principal location of failure:

Nozzle Flapper

Cause:

Oil contamination and dust/dirt in control air

Countermeasures:

Remove Crater on flapper by some very thin, non-metallic object e.g. business card

3.4.3 Deterioration due to prolonged use and presence of oil or condensate water in control air

Principal location of failure:

Pilot relay and Pneumatic pressure regulator

Cause:

Deterioration due to prolonged use and presence of oil or condensate water in control air.

Countermeasures:

Same as the countermeasures for Blockage of pneumatic line

3.4.4 Eccentric abrasion caused by vibrations:

Principal location of failure:

Fulcrum

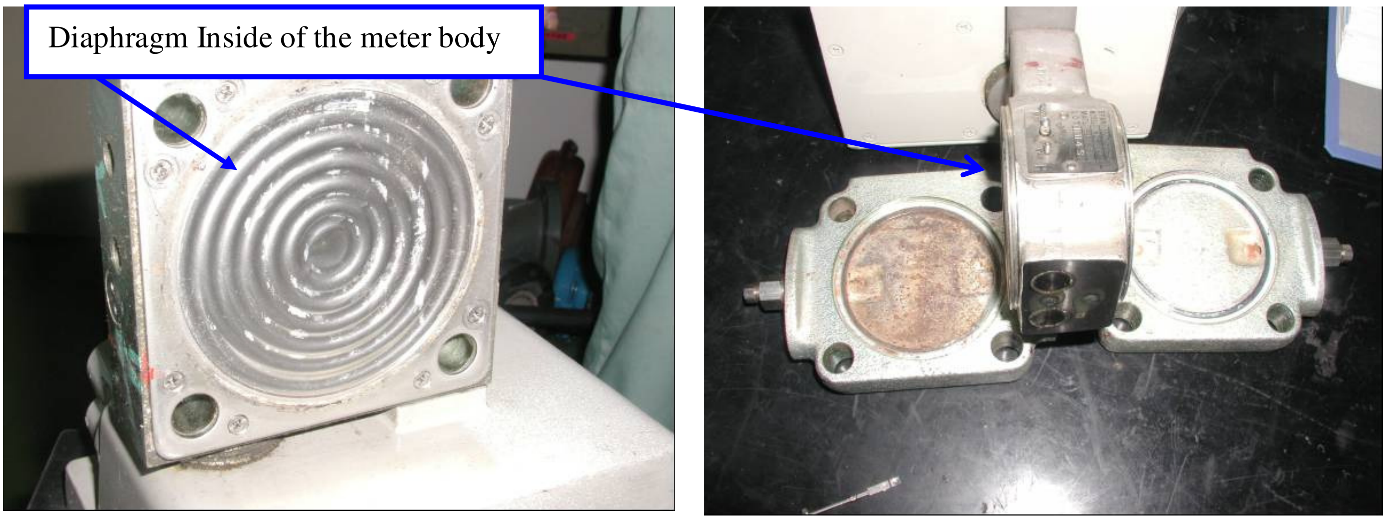
Cause:

Vibrations from hull and machineries

Countermeasures:
To reduce level of vibrations by reinforcing the support structures for pneumatic control devices

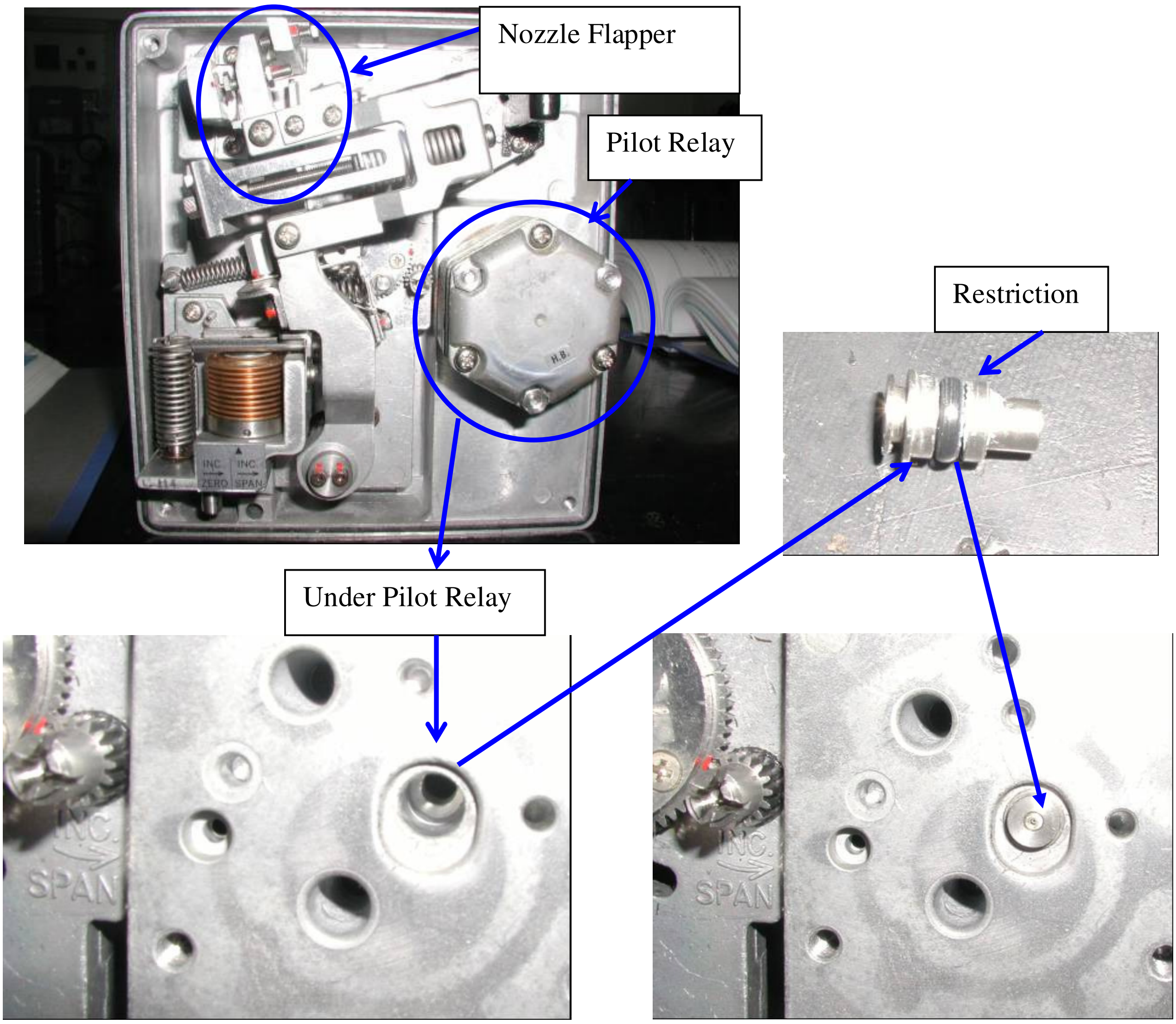
3.4.5 Blockage of Pressure line:
Principal location of failure:
Meter body and Pressure pipe, etc.
Cause:
Water mud, water stain and components of hard water
Countermeasures:
Blow off water mud, water stain and components of hard water from meter body.
It is quite likely for the diaphragm, fitted inside of the meter body, to get damaged.
So, do not open meter body because the meter body doesn't work properly if the diaphragm gets damage. The water blowing off is enough for cleaning.

The following pictures show the Principal location of failure in order to help you know where to check.
(1) Diaphragm, fitted inside of the meter body



Pic. 3.6 Diaphragm

(2) Pressure transmitter:



Pic. 3.7 Pressure transmitter

3.4.6 Blow Procedure When No Blow Pipes are provided:

The check procedure, when no blow pipes are provided, is as follows;

WITHOUT BLOW PIPE

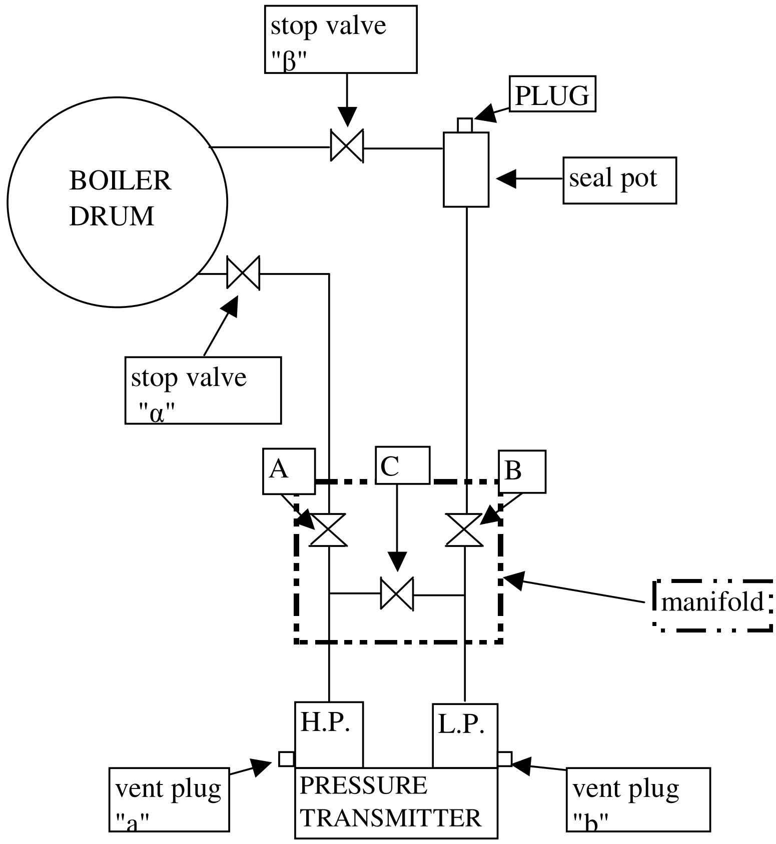


Fig. 3.4 Piping arrangement when no blow pipes are provided

- Objective of "CHECK PROCEDURE WHEN NO BLOW PIPES ARE PROVIDED" is to check the condition in the pipes attached on the pressure transmitter.
- Then, if the dirty water was observed from the drain plugs during the above check, carry out the following maintenance work;

1) Remove the transmitter from the pipes.
2) Blow pipes.
3) Clean inside of the transmitter by the non pressure water.
4) Install the pressure transmitter on the pipes again and resume the transmitter.

Remarks:
Mounting valve: stop valve[α], and stop valve[β]
Manifold valve: high pressure side valve [A], low pressure side valve [B] and equalizer valve[C].
Vent plug : vent plug [a] and vent plug [b]

Check method:
The following procedure is the check operation.
1) Close the stop valve of the high pressure side[α] and the high pressure side valve [A].
2) Close the stop valve of the low pressure side[β] and the low pressure side valve [B].
3) Open the equalizer valve [C].
4) Slowly open the both side vent plugs[a]and [b] to release the pressure carefully.

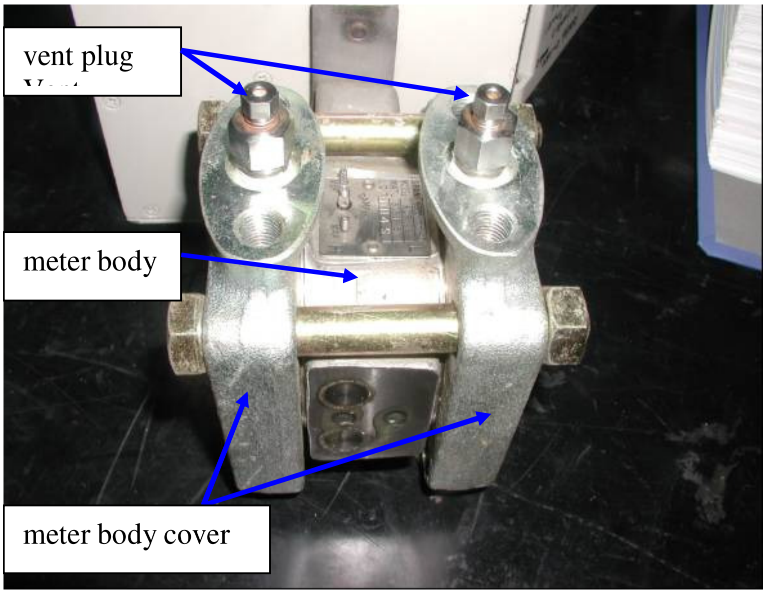
Check that there is no leakage from the mounting valves i.e. stop valve[α] and stop valve[β].
a) Slightly open the high pressure side valve [A], **and then confirm that drain water does not splash from the vent plugs. It means that the valve [α] does not leak.**
Close valve [A] and valve [α] .
b) **Also, check the low pressure side by the same procedure** as described above in 'point a' for the low pressure side valve [B] and close low pressure side valve [B] and valve [β].
c) Then close the both side vent plugs[a]and [b] and the equalizer valve [C].

5) If **the [α] and /or [β] valves are leaking, go to <Operation method>** because the further work cannot be carried out.

6) If there is no leakage, check the water condition by the following procedure.
a) Open the equalizer valve [C].
b) Slightly open the both side vent plugs[a]and [b].
c) Slightly open the high pressure side valve [A], then slightly open the stop valve of the high pressure side[α].
d) After checking the water condition, close the stop valve of the high pressure side[α] and the high pressure side valve [A].
e) Slightly open the low pressure side valve [B], then slightly open the stop valve of the low pressure side[β].
f) After checking the water condition, close the stop valve of the low pressure side[β] and the low pressure side valve [B].
g) Close the both side vent plugs[a]and [b] and the equalizer valve [C].

7) Then, if the dirty water was observed from the drain plugs during above procedure in point 6, carryout the following maintenance work;
a) Remove the transmitter from the pipes.
b) Blow pipes.
c) Clean inside of the transmitter by the non pressure water.
d) Install the pressure transmitter on the pipes again and resume the transmitter.

Remarks: When cleaning inside of the transmitter, don't open the meter body cover because the damage to diaphragms for the meter body should be prevented. Refer to the Picture 3.8 below.



Pic. 3.8 Attached fittings on meter body

Operation method:

The following procedure is for commencing the operation.

1) Fill water into the seal pot.

2) Open the low pressure side valve [B] and vent air from the low pressure side vent plug [b] and afterwards close plug [b].

3) Close the low pressure side valve [B]

4) Slowly open the stop valve of the high pressure side[α].

5) First open the equalizer valve[C] and then the high pressure side valve [A]so as to equalize the pressure between the high pressure side and the low pressure side carefully. Then, open the vent plugs on both the high pressure side[a] and the low pressure side[b], and purge the air there carefully and close them

6) Close the high pressure side valve [A] and the equalizer valve[C].

7) Slowly open the stop valve of low pressure side[β].

8) Slowly open both the low pressure side valve [B] and the high pressure side valve [A].

3.4.7 Blow Procedure When Blow Pipes are provided:

WITH BLOW PIPE

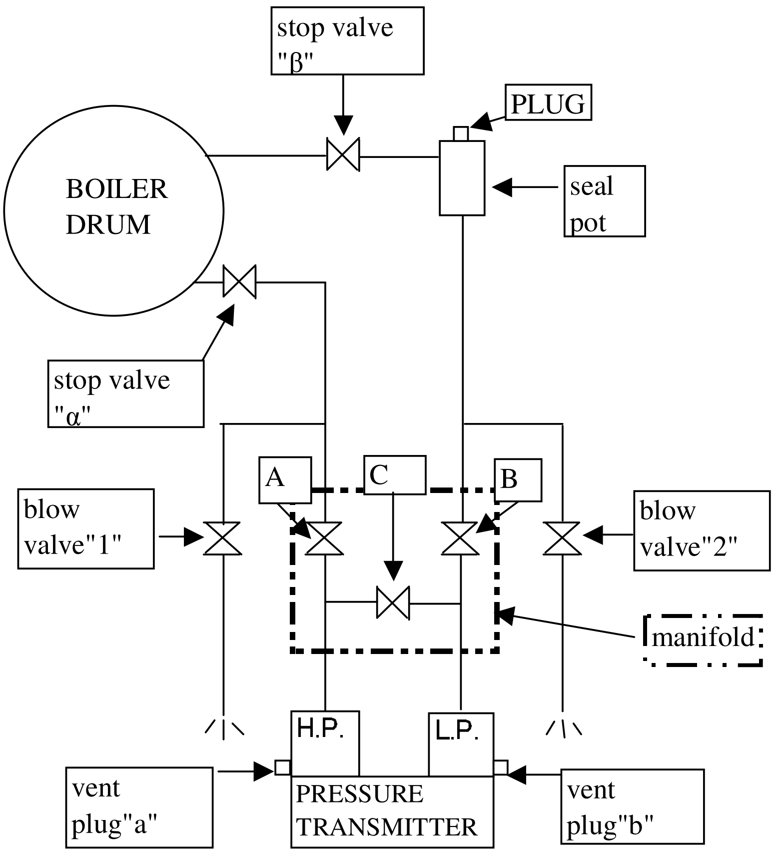


Fig. 3.5 Piping arrangement when blow pipes are provided

The blow procedure, when blow pipes are provided, is as follows;

Remarks:

Mounting valve: stop valve[α], and stop valve[β]

Manifold valve : high pressure side valve[A], low pressure side valve[B] and equalizer valve[C].

Vent plugs: vent plug [a] and vent plug [b]

Blow valves: blow valve"1"and blow valve"2"

Maintenance method:

The following procedure is the blow pipe operation.

1) Close both the high pressure side valve [A] and the low pressure side valve[B].

2) Open the blow valves of both the high pressure side[1] and the low pressure side[2] slowly.

Then, blow the tube carefully.
3) After the completion of the blow pipes, close the blow valves of both the high pressure side [1] and the low pressure side [2]
4) Close the stop valves of both the high pressure side[α]and the low pressure side[β].

Operation method:
The following procedure is for commencing the operation.
1) Fill water into the seal pot.
2) Open the low pressure side valve [B] and vent air from the low pressure side vent plug [b] and afterwards close plug [b].
3) Close the low pressure side valve [B]
4) Slowly open the stop valve of the high pressure side[α].
5) First open the equalizer valve[C] and then high pressure side valve [A]so as to equalize the pressure between the high pressure side and the low pressure side carefully. Then, open the vent plugs on both the high pressure side[a] and the low pressure side[b] and purge the air there carefully and afterwards close them
6) Close the high pressure side valve [A] and the equalizer valve[C].
7) Slowly open the stop valve of low pressure side[β].
8) Slowly open both the low pressure side valve [B] and the high pressure side valve [A].

4. Electronic control system:

Many control systems use the semiconductor or computer. This section explains outline of semiconductor and computer control system, especially regarding basic knowledge, maintenance, check points and handling methods.
At present, almost all semiconductor print cards and modules are black box and instruction manuals do not explain about their operating procedure clearly. Therefore engineers may find it difficult to understand. But it is also necessary to have some basic knowledge, which has been explained below.

4.1 Working Voltage for Semiconductor:

Almost all semiconductors have a working voltage.
LED i.e. Light Emitting Diode is one of the semiconductor. One of the LED's working voltage is 3.6V. 3.6V LED starts lighting at 2.8V to 3.0V and if supply voltage goes below the minimum working voltage for example 2.8V, LED goes OFF.
Filament type light bulb only decreases the splendor according to the reduction in the voltage, but it does not put out the light.
If the source of voltage is dropped below the minimum working voltage instantly, it means that the semiconductor remains in OFF condition. So, a stable electrical source is very important for semiconductor.

Case study 1: NYK LODESTAR BLACK OUT
Cause of Trouble:
Power Management System (GAC21) Communication link (PE link) module power source (DC3.3V) is unstable and source voltage is fluctuating between 3.0V ~ 3.5V. The processor bus control LSI working voltage is 3.0 ~ 3.6V and the power source is instantly below the 3.0V. Therefore, processor bus control LSI fails and stops the control.
Finally, black out occurs.
Defective Parts:
Soldering of Capacitor for smoothing out the voltage is not good and so the capacitor is not carrying its function properly.

4.2 DC Power Source:

Fig. 4.1 shows the step of rectifier
Typical DC power source circuit has been shown in Fig.4.2 and 4.3.

All Wave Rectifier:

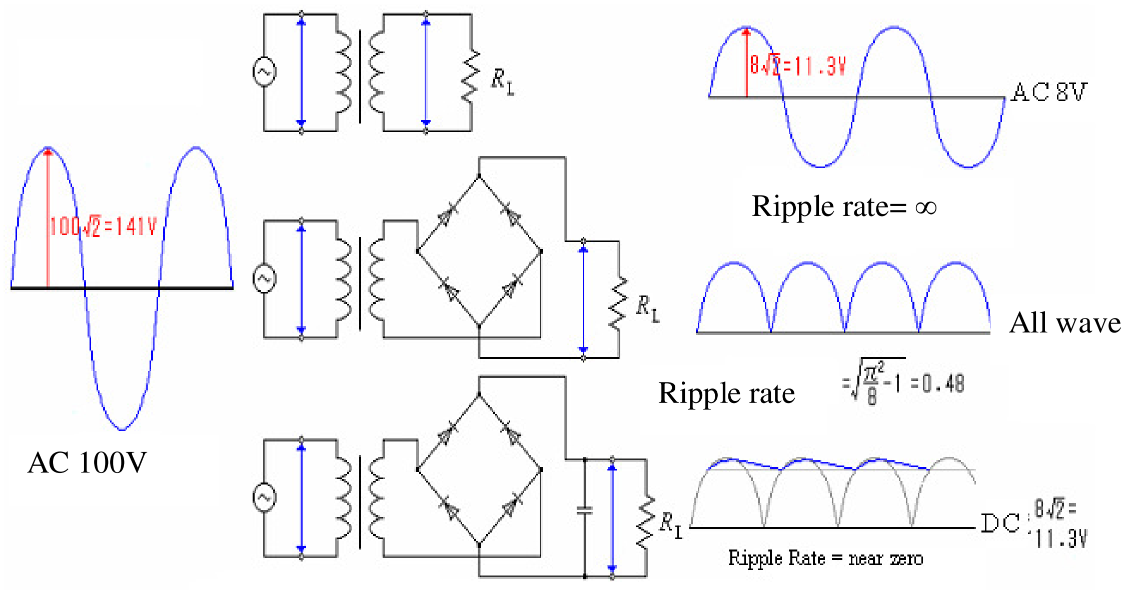


Fig.4.1 step of All Wave Rectifier (Diodes Bridge type)

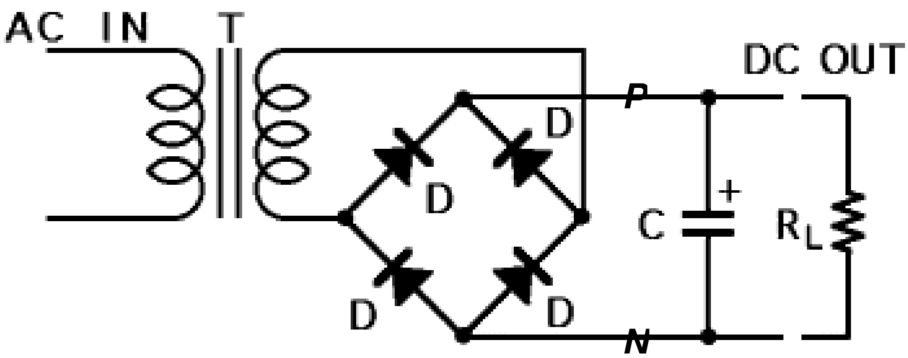


Fig.2 All Wave Rectifier (Diodes Bridge type, Capacitor Input)

Fig. 4.2

AC IN:	Alternating Current for Input (Source)
T:	Transformer
D:	Diodes
P:	Positive (+)
N:	Negative (-)
C:	Capacitor (Chemical Condenser); for voltage smoother
RL	DC (Direct Current) Load (Resistance)

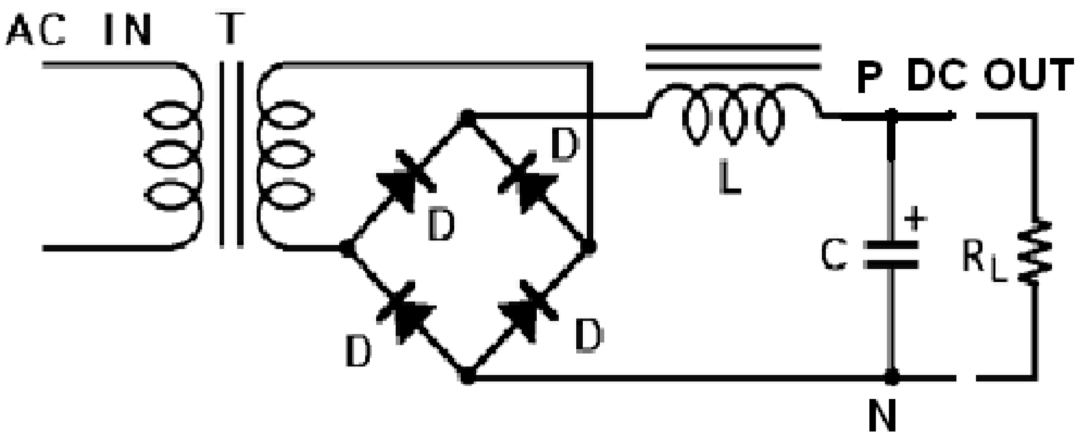


Fig. 4.3 All Wave Rectifier (Diodes Bridge type, Choke-coil Input)

L: Reactance (DCL); for current smoother

4.2.1 Capacitor (Condenser):

Capacitor stores electrons at increasing voltage until saturation and discharges electrons at decreasing voltage. It accumulates the electrons.

The capacitor, used in the rectifier DC circuit, should have the large capacity so as to accumulate the large number of electrons for saturation. If a small capacity capacitor is used in the rectifier DC side, it will get saturated soon, when there is an increase voltage. It means when DC voltage is increasing, there will be an increase in the line voltage because the capacitor will get saturated soon. Therefore it’s necessary to have a large capacity capacitor, which is normally a chemical capacitor (chemical condenser).

The chemical capacitor (chemical condenser) is of special structure, in which, an electrolyte is kept between aluminum foils.

The capacity of condenser is depended upon the surface area of conductor (aluminum foil) and the gap between the conductors. Large surface area and small gap makes large capacity. The surface of chemical condenser is etched and makes large surface area.

Fig. 4.5 is an overview and Fig. 4.5 is the structure.

The quality of chemical condenser declines over the period whether used or not.

Normally ship has no spare chemical condenser.

Fig. 4.4 Overview of Chemical condenser

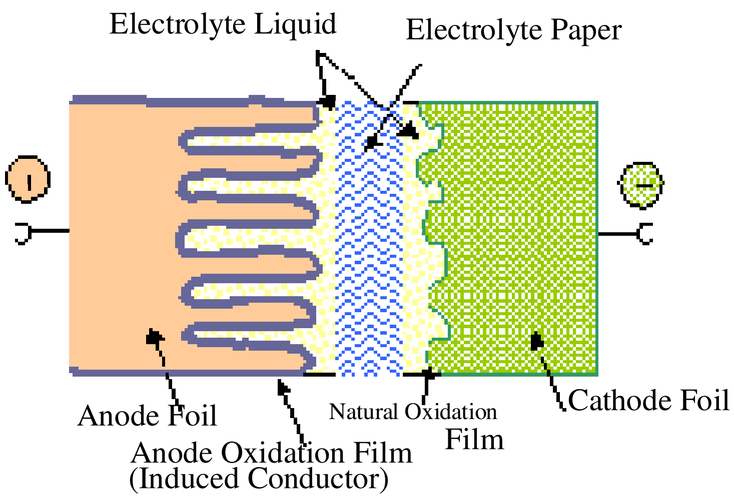


Fig.4.5 Outline of Structure (Chemical Capacitor)

4.2.2 Reactance:

"DCL" means the Direct Current Reactance. It uses the "self induction effect" for smoother the direct current.

"Self induction effect"

When the electric current flow in the coil changes, the magnetic flux is also changed. In this time, the electromotive force is occurred in the coil by the electromagnetic induction. This electromotive force makes a counter current for changing current in the coil. Therefore DC current changing is small. It means smoother current.

4.2.3 Symbol mark:

Fig.4.6 is one of the symbol marks of all wave rectifiers (Diodes Bridge). It deletes each diodes, smoother condenser and smoother DC reactance.

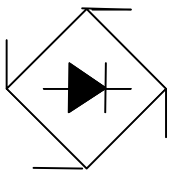


Fig.6 Symbol mark of
All Wave Rectifier
(Diodes Bridge)

4.3 Trouble Response:

Engineer should refer and understand the instruction manual when there is trouble with semiconductor equipments. Following items are useful to deal with general semiconductor equipment's troubles.

4.3.1 Check the Source Voltage:
Semiconductors work on low voltage i.e. DC3.3V, DC5V, DC9V, etc. Generally DC/DC converter is used to make stable voltage supplies to semiconductor equipments.
The semiconductor has a minimum working voltage. If the supply voltage has dropped below the minimum working voltage instantly, it means that the semiconductor is rested condition. If there is an instant drop in the supply voltage, the semiconductor systems will result in error action and/or failure.

First of all, check the source voltage by Digital type voltage meter. Analogue Multi meter is insufficient to measure for feeble voltage and slow response, because indicator of analogue meter is driven by electromagnetisms. Therefore, Analogue Multi meter can not check the ripple voltage. Since, Digital type's impedance is high, so it has high precision. The oscilloscope is an ideal match for measuring the supply voltage.

Normally supply voltage is stable, if measuring voltage is fluctuating (including the voltage ripple), engineer should doubt the bad condition of the source device.

* Refer above trouble of NYK LODESTAR

4.3.2 Cleaning of the Connector:
A card connector joins the print card and rack, whereas a cable connector joins the communication cable and unit interface.
If a point of contact is in bad condition, it suffocates electrical flow. A bad point of contact increases resistance and thus causes voltage to drop. And then, it causes troubles, which are drop in source voltage and/or abnormal communication signals.
Connector parts are one of the weak points to system using semiconductors. If contact surface is dirty and/or bad fitting, it means systems can not receive and/or output the sufficient electric source and/or accurate signals. Therefore, the system fails and/or provides bad control. There can be many troubles for bad contact.
The resistance of a point of contact is increased by dusts, vibrations, nitrification, etc., if no care is taken for a long time. Periodically cleaning the connector part is very important. But some control devices can not be stopped for servicing. In this case, there is a possibility of troubles in the connector parts.

During investigation of the trouble card, one of the methods is to replace the card with spare one by one. In this process, when the trouble card is replaced with spare card, the system returns to normal. It seems that the card is bad. But many cards do not have damaged semiconductors. It is the problem of connector. Therefore it returns to normal, when a cleaned connector is in contact.

It is recommended that trouble card is investigated and the card connectors are cleaned. After cleaning, it should be reinstalled again and then check the functions.
If the system is still in bad condition, the card should be replaced with spare.

4.3.3 How to replace the card:

Basically, the following steps should be taken when replacing the cards.
1) To prepare the spare card
2) To confirm that shut down system does not affect the related systems and/or equipments
3) To switch off the source
4) To draw out the card
5) To compare the spare card and the existing card
* Card number, position of dipswitches, etc.
6) To set the position of dipswitches as same as that of the existing card
7) To clean the connector of the existing card
8) To put the cleaned existing card in to the same position (existing card is used again)
9) To switch on the source
* First Main Source, 2nd Back-up
10) To check the condition and function test
***** If still bad condition *****
11) To carry out above 3) & 4)
12) To put the checked spare card
13) To carry out above 9) & 10)

4.3.4 How to check the Computer Control System:

The computer control system is separated input part, computer part and output part.
1) Check Input side devices
The system has interface for input side. Generally the interface has indication LED that indicates the digital input signal condition. When the input digital signal comes from the input data side for example the limit switch signal, the LED is lit on. We can possibly understand that the signal is coming. Therefore, we can confirm that the input side digital signal condition.
If LED is not lit on at the normal condition, it may be the trouble of input side.
But the analogue signal cannot be monitored generally. The analogue signal is 4-20mA current signals or 1-5V voltage signals.
If input signal is in good condition, the input equipments are in good condition.
If input signal is not corresponding with the condition of input equipments, this means trouble in input side equipments.
2) Check Output side devices
The system has interface for output side. Generally, the interface has indication LED that indicates the digital output signal condition. But generally the analogue signal cannot be monitored. Also analogue signal uses 4-20mA current signals or 1-5V voltage signals.
If output signal is in good condition, the computer control system is also in good condition.
If output signal is not corresponding with the required control result, it means problem in the computer control system.
3) Reset the computer
4) Re-load the program

5. Case Studies, Company's instructions, Maker's service information

5.1 Case Studies:

Case 1:

Subject: Auxiliary boiler differential pressure water level indicator defective

Reference: Trouble report (KAT-13/2004)
Date of failure: 11/05/2004

Description of event:

During sailing, vessel encountered problem with differential pressure level indicator. On inspection, the following damages on the controller were observed.
1) Top diaphragm was found cracked. Same was temporarily repaired with "Loctite" glue.
2) The mating surfaces of the Pilot relay housing were found worn out. Same were lapped.
3) One spring was found not to be original.
4) Receiving mechanism bellows were found welded at the place of leakage. The same leakage was stopped by welding again.
5) The threads of Span adjusting knob were found worn out.
6) Feed back bellows were also found cracked and welded.
It was evident that the controller was overhauled somewhere in the past.

Direct cause of Failure: Worn out and damaged parts due to prolong use.

1) Leaks due to initial expansion /shrinkage of lines.
2) Overstressing of pipe sections during initial fitting.
The ship staff was extra careful regarding this and extra precautions were taken to monitor the same. Actually the mentioned leak was too minor to be noticed, but it was noticed due to extra precautions taken by the ship staff.

Countermeasures:

The controller was temporarily overhauled and settings were adjusted. Afterwards, the controller was renewed.

Estimated cost: USD 5000/-

Loss of time: Nil

Case 2:

Subject: Damage of Auxiliary boiler due to malfunction of safety device

Reference: Marine engineering information (503E-010-2000)
Date of failure: 12/07/2000

Description of event:

During port stay, the duty oiler informed the chief engineer that the auxiliary boiler misfired occasionally and the boiler water level dropped rapidly. The chief engineer informed the company about the water leakage. The company informed the service engineers to inspect the boiler. The inspection revealed the followings:
1) Most of the smoke tubes of the boiler were burnt out.
2) The furnace side of the boiler drum was melted down and bent.

Direct cause of Failure: The auxiliary boiler was equipped with two safety devices for low water level i.e. Float type level switch and Water level transmitter. However, malfunction of safety devices happened simultaneously and led to shortage of water in the boiler, which resulted in serious damage to the smoke tubes and the boiler drum of the boiler. The malfunction of the float type level switch was caused due to adherence of the scale to the hinge of the level switch, thereby restricting its movement.
On the other hand, the malfunction of the water level transmitter was caused due to damage of its diaphragm, which kept on sending the wrong signal of high water level to the feed water controller of the boiler.
Consequently, the output signal from the feed water controller caused the feed water control valve to keep fully shut, thereby decreasing the water level in the boiler.

Countermeasures:
1) To check the local water level gauges regularly.
2) To check the local water level gauges for proper operation by blow-off operation regularly.
3) The safety and protection devices should be tested as per the maker's schedule or the shipboard PMS.
4) The inside of the float type level switch should be cleaned regularly.
5) The blow-off operation of water level transmitter should be carried out regularly as per maker's schedule or the shipboard PMS schedule. This should be carried out as per maker's instructions.
6) The level condensers for the water level transmitters should be filled up with water at all times.
Estimated cost: Unknown
Loss of time: 20 days

5.2 Company's instructions:

Subject: Operation of water level gauges for Auxiliary boiler

Reference: Marine engineering information (500E-007-2000)
Date: 09/03/2000

Summary: For the prevention of accidents of the auxiliary boilers during steam raising operation, special attention to the indication of boiler water level gauges should be paid.
The followings are the precautions to be observed during steam raising operation of the auxiliary boilers and handling procedures of water level gauges. The operators are requested to use these precautions as a reference onboard.

1) Precautions for steam raising operations:

a) Boiler mounting valves should be operated in accordance with the check list for auxiliary boiler steaming up procedures (cold start).
b) On the first water filling, while taking the boiler water expansion by heating into consideration, the water level should be properly adjusted a bit lower than the normal water level.
c) Water in the local water level gauge should be checked for accurate indication by carrying out blowing –off operation of the gauge before firing and during combustion.
d) Blow down of the boiler water is prohibited during firing.
e) When it is necessary to blow-off the boiler water to lower the water level during steam raising operation, this should be done by means of surface lowdown.
f) As countermeasures against a back fire, the pre-purge and post-purge operation should be included in the procedures.
g) Prepare the boiler start-up sequence program and then the steam raising operation should be carried out in accordance with the program.
In case, the stem raising curve is not provided in the instructional manual, request it from the makers.

2) Handling of the remote water level gauge:

a) During steam raising operation of the boiler, the remote water level gauge and the attached safety device for low water level should be kept in good working condition. It should be kept in mind that there is a difference in indication between the remote water level gauge and the local water level gauge.
The level condensers foe the water level transmitters should be filled up with water before steam raising operation.
When the auxiliary boiler is in cold condition, the remote water level gauge generally indicates the water level 10 to 15% higher than the local water level gauge due to a difference in the specific gravity of the boiler water in cold and warm up condition.

Example:

Manufacture	Type of boiler	Total range	Difference in indication
Osaka boiler	OEV-130	About 1000mm	+100 to 150mm
MHI	MAC-70, 80	About 800mm	+80 to 120mm
MHI	MC-110, 140	About 600mm	+60 to 90mm

b) Since large amount of condensed water or oil may enter the control air lines, when the plant is started up, a thorough draining out of the lines should be carried out before start using the remote level gauge.
c) A blowing in pipes for the water level transmitters should be carried out at an interval of six months to drain out the accumulated dirt. The blowing procedures should be done in accordance with the maker's instructions.

3) Handling procedures of the water level gauge with the safety device:
(Maker: Osaka boiler Mfg. Co., Ltd.)
a) Method of blowing:
For the boiler equipped with the safety device for low water level as shown in the figure, the blowing of the water level gauge should be carried out in the following manners (with two steps), because the common passage between the water side and the steam side is made from the water column.

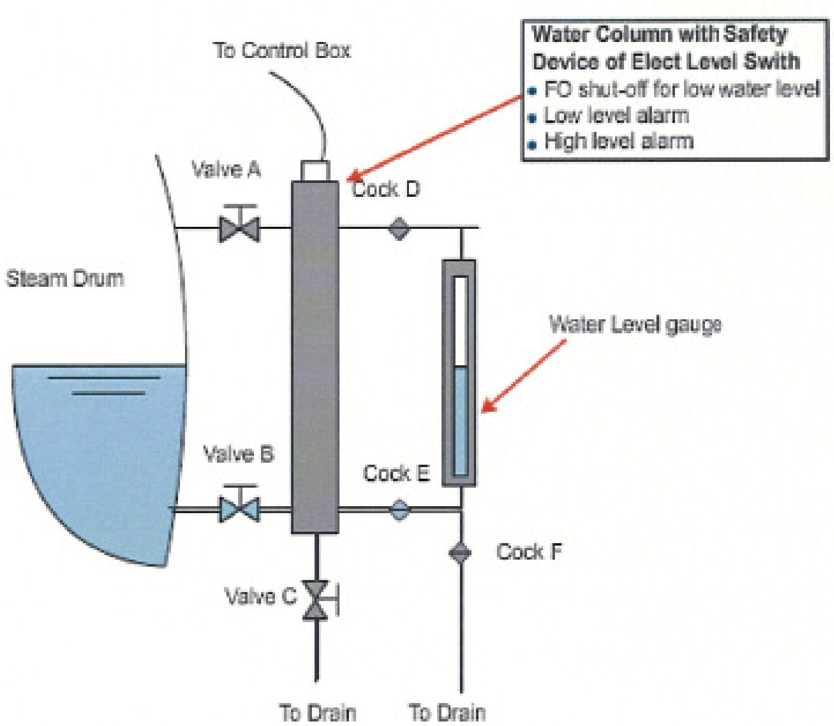


Fig. 4.1 Water level gauge with safety device of Elec. Level switch

Status of valves during blowing procedures of the water column

- Before start blow operation

Cock D and Cock E: Open.

- For Cleaning and checking of the water passage through Valve B

Valve A: Close, Valve B and Valve C: Open.

- For cleaning and checking of the steam passage through Valve A

Valve B: Close, Valve A and Valve C: Open.

- For normal operation

Valve A and Valve B: Open, Valve C: close

Status of valves during blowing procedures of the local water level gauge

- For Cleaning and checking of the water passage through Cock E

Cock D: Close, Cock E and Cock F: Open

- For cleaning and checking of the steam passage through Cock D

Cock E: Close, Cock D and Cock F: Open

- For normal operation

Cock f: Close, Cock D and Cock E: Open

b) Cleaning of the electric level switch for the safety device:

The electric level switch should be cleaned up at regular intervals as dirt may cause malfunction.

Conceivable abnormalities caused by dirt can be

- The fuel oil shut-off for the low water level and the low water level alarm will be actuated.
- The high water level alarm will not be actuated.

Annex 3
Electrical Control System

8.1 Principle and Structure of Control system equipments:

8.1.1 Differential Pressure Transmitter (Electrical type):

In order to learn Differential Pressure Transmitter for electric type, we use JTD ST3000 ACE from Yamatake.

1) Introduction:

A differential pressure transmitter is a highly-engineered instrument that is specifically designed to measure liquid or gas flow rate, Pressure data and liquid level data, and transmit the data to another location.

Combined with a contracting mechanism (such as an orifice and a flow nozzle), because the transmitter detects the pressure difference between two points in a process (differential pressure), the differential pressure transmitter can be used for measuring flow rate.

The transmitter can also be employed to measure multiple process variables such as pressure and liquid level.

Electrical differential pressure transmitters enjoy widespread use. Such instruments offer significant benefits to end-users and construction engineering companies. The instruments have a unified structure that consists of a pressure receiving unit which senses high pressure and low pressure and a transmitting unit which transmits the differential pressure. Before transmission, the instrument converts a differential pressure value into an electrical signal (DC 4-20mA).

2) Operating principle:

A typical electrical differential pressure transmitter has a composite semi-conductor sensor.

High pressure and low pressure in the process are transmitted to the diaphragm, mounted on the both sides of the pressure receiving unit. These diaphragms are in contact with the liquid, and transmit the pressure via a special fluid, to the composite semiconductor sensor inside.

This sensor is strained according to the difference between high pressure and low pressure (differential pressure). For transmission, another unit sends out a signal corresponding to the strain.

At the same time, two auxiliary sensors, a temperature sensor and a static pressure sensor, come into action. These sensors are formed on the sensor chip. They sense the ambient temperature and the static pressure, whose values are also digitalized and sent to the transmitting unit.

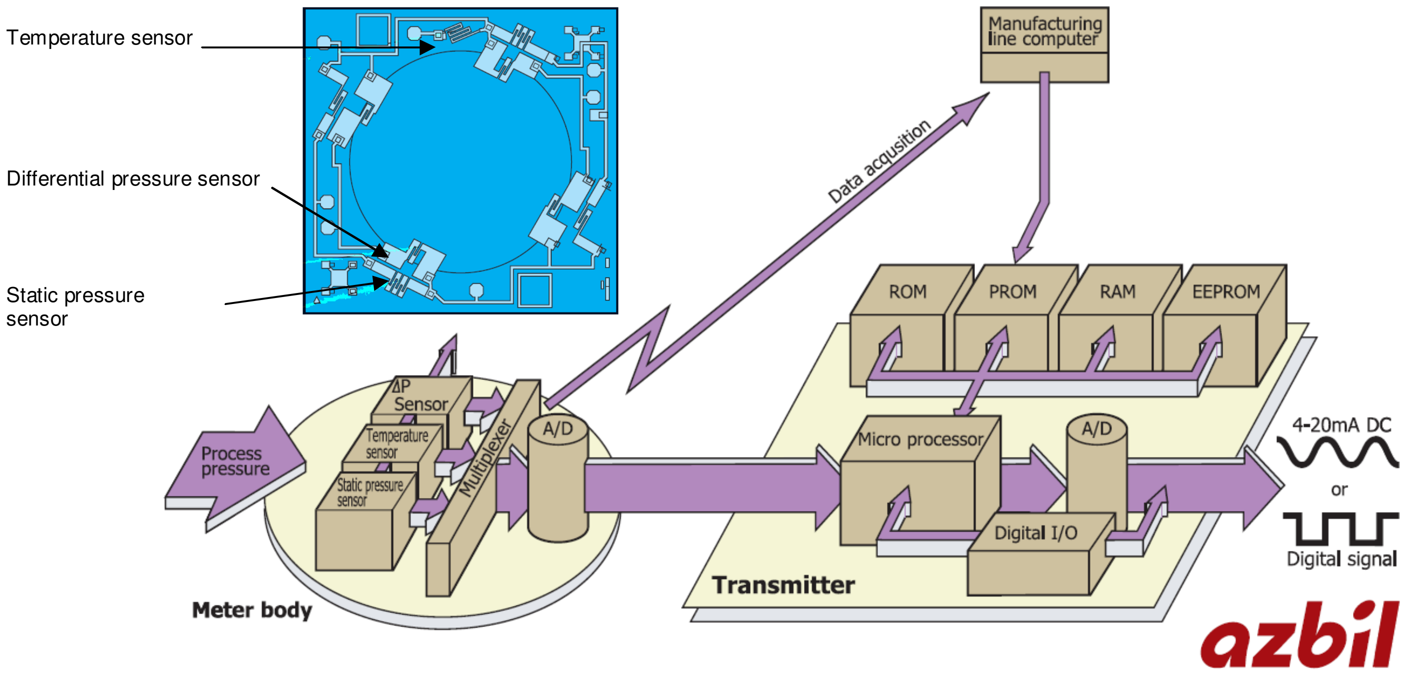


Fig. 8.1 Block diagram for Operating principle of the transmitter

3) Function:

The function of each part is as given below:

(a) Center body: It consists of a composite semiconductor sensor, a pressure diaphragm and excessive pressure protection mechanism, etc.

(b) Center body Cover: Two Center body covers sandwich the Center body and connect a connection pipe to this part.

(c) Bolts and nuts: They fix the Center body between covers and are a series of bolts and nuts.

(d) Sensors: It consists of a composite semiconductor sensor, a pressure receiving diaphragm, a flange, a capillary tube, etc.

(e) Electronics module: It consists of electronic circuits having functions for processing differential pressure and other signals, and transmitting them.

(f) Transmitter unit case: It houses the electronics module and the terminal board.

(g) Case cover: It encloses the transmitter unit case.

(h) Terminal board with integrated indicator: It derives electric signals form within the instrument. It connects an SFC to this terminal board. An optional digital indicator, integrated with the terminal board, displays an analogue output.

Refer to Fig. 8.2 "Structure of the DPT".

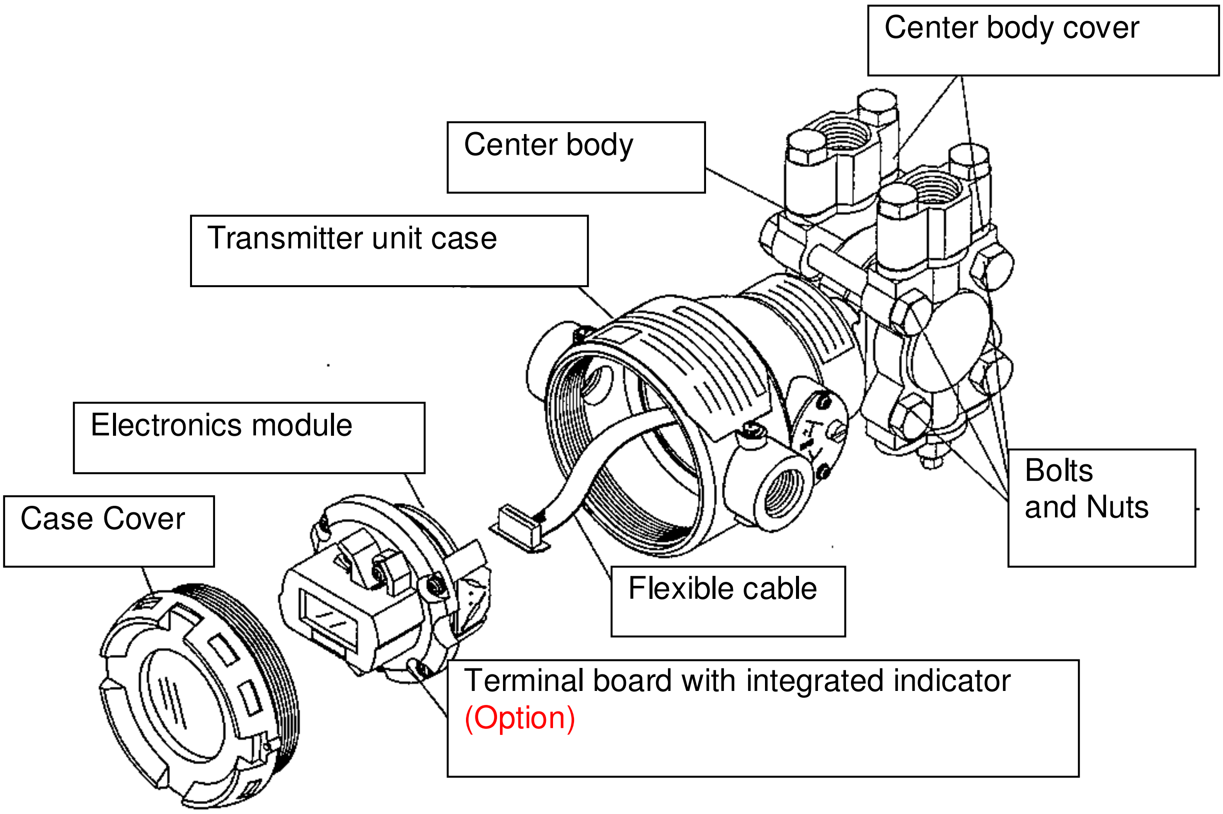


Fig. 8.2(a) Structure of the DPT

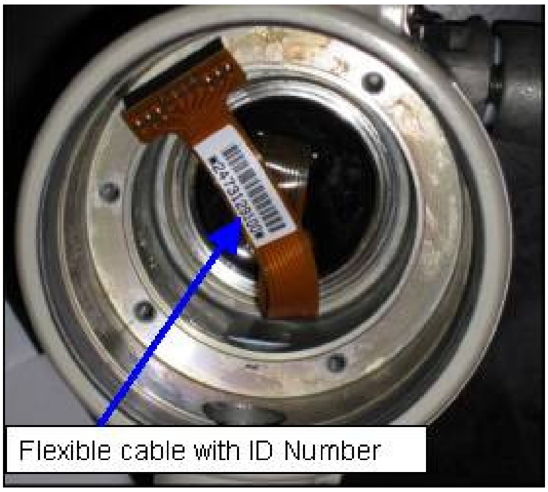


Fig. 8.2(b) Structure of the DPT

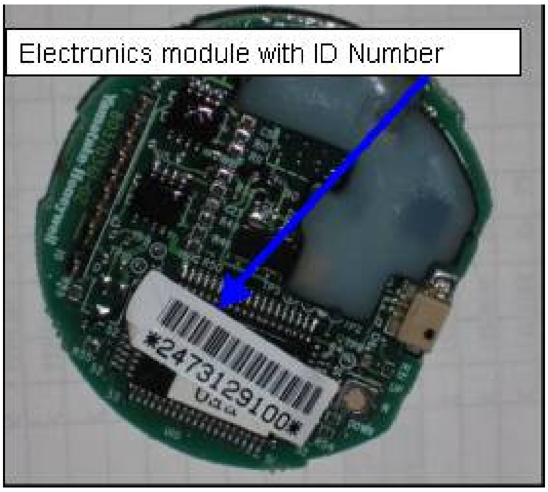


Fig. 8.2(c) Structure of the DPT

4) ID number on both the center body and the electronics module:

Every center body (meter body) is not same because the manufacturer can't assemble it completely the same. The electronics module must be installed with EEPROM, which has specific and particular information and characteristic of each center body. So, both the center body and the electronics module must have ID number to identify each other.

5) Steps for operation:

In order to operate the Differential Pressure Transmitter for electrical type (smart field instrument), we have to take 4 steps i.e. Connecting cable & pipe, Configuring data by SFC (Smart Field Communicator), Save data into DPT, and Run as shown in **Fig. 8.3.**

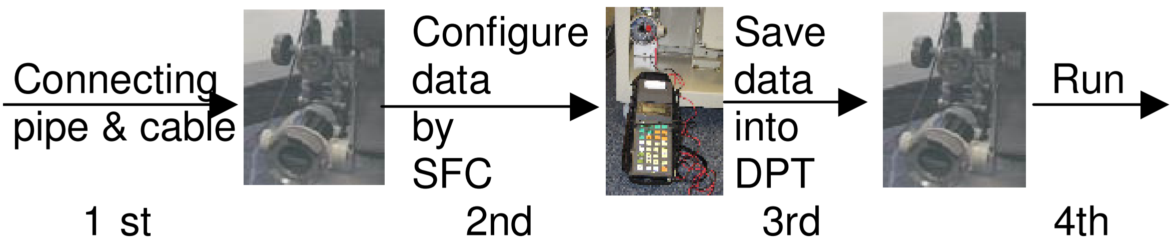


Fig. 8.3 Steps for operation of Differential Pressure Transmitter of electrical type

6) DPT connection depending on Tank Condition:

There are some connection methods between tank and differential pressure transmitter (DPT). The suppression, elevation, and some corrections must be taken into consideration for Open tank and Closed tank arrangement.

The detail explanation of suppression and elevation is given in "Ch. 1.4 (1.4.8.2) Suppressed Zero Range and Elevated Zero Range".

6)-1 Summary for piping:

The summary of connection on DPT is shown in Fig. 8.4**.**

		Pneumatic Type	Electrical Type
Open Tank	HP side	Liquid Outlet port	Same as Pneumatic
	LP side	Open to Atomsphere	Same as Pneumatic
Closed Tank (Dry Leg)	HP side	Liquid Outlet port	Same as Pneumatic
	LP side	Vapor Outlet port	Same as Pneumatic
Open Tank (Wet Leg)	HP side	Liquid Outlet port (Drum Water side)	-
Normal	LP side	Seal water Outlet port (Level condenser side)	-
Open Tank (Wet Leg)	HP side	-	Seal water Outlet port (Level condenser side)
Normal Design (LP:Left HP:Right) (Direct Action Assemble)	LP side	-	Liquid Outlet port (Drum Water side)

Fig. 8.4 Table for connection on DPT

a) DPT of Pneumatic type
In principle, the pipe from water drum or a tank is connected to HP side of DPT.
b) DPT of Electrical type:
In principle, the pipe from Level condenser (Seal pot) is connected to HP side of DPT.

Figure 8.5 below shows example of piping for DPT (Pneumatic type).

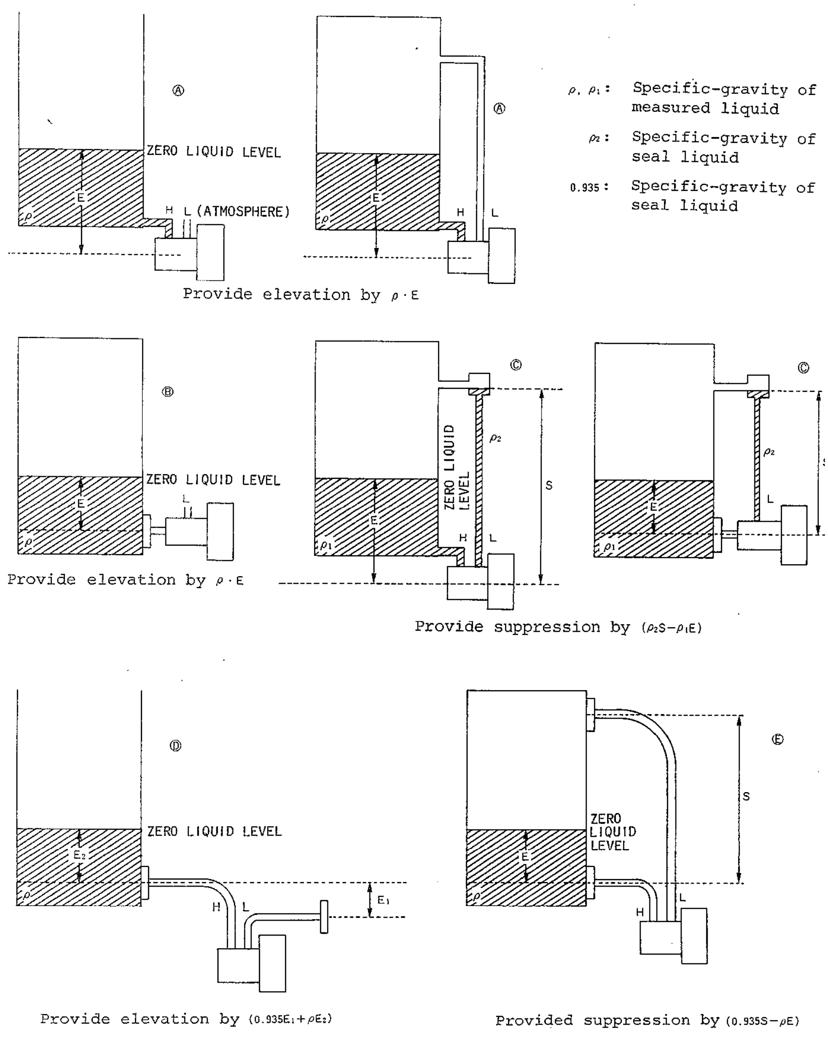


Figure 23. Calculation of Elevation/Suppression Values

Fig. 8.5 Example of piping for DPT (Pneumatic type)

6)-2 Wet leg:
If the gas in the tank can be liquefied, the method for wet leg type is adopted to eliminate the internal tank pressure (P1), as shown in **Fig. 8.6 Closed Tank (Wet Leg)**

When the gas in the tank can be liquefied, the connecting pipe between the tank and transmitter is filled with the liquid. Thus, it results in measurement error, because the liquid head pressure in the connecting pipe is fluctuating.
In order to eliminate above measurement error, the liquid for seal purpose must be filled into the connecting pipe between the tank and transmitter in advance. As a result, the liquid from the tank is prevented from entering into the connecting pipe.

6)-3 In case of Differential pressure transmitter of pneumatic type:
The High-Pressure (HP) side of the differential pressure transmitter is connected to the pipe for water level variable and changing, the liquid head pressure (Pa) in the tank (tank liquid height xγ + leg liquid height xγ + internal tank pressureP1).
(Drum level side)

$$\text{Pa side} = h \times \gamma + h_2 \times \gamma + P_1 = \text{High Press Side}$$

The Low-Pressure (LP) side of the differential pressure transmitter is connected to the pipe for water level fixed, the liquid head pressure (Pb) in the tank (seal liquid height xγ + leg liquid height xγ + internal tank pressureP1).
(Condenser seal liquid side)

$$\text{Pb side} = h_3 \times \gamma + h_2 \times \gamma + P_1 = \text{Low Press Side}$$

Consequently,

$$\text{Differential pressure } (\Delta P) = Pa - Pb$$
$$= \text{High Press Side} - \text{Low Press Side}$$
$$= h \times \gamma - h_3 \times \gamma$$

By this method, the liquid level (h) can be measured.
In this case, when the liquid level is 0%, the differential pressure signal corresponds to –100%. Moreover, when the liquid level is 100%, the differential pressure signal corresponds to 0%.
It means that the differential pressure signal in response to the liquid level increase is from –100% to 0%
We call this condition suppression by the liquid head pressure (h3).
For the differential pressure transmitter of pneumatic type, when we correct this suppression to make the proper control, we adjust the liquid head pressure (h3) by operating the elevation / suppression spring mechanically.

If the specific gravity for each liquid, liquid in the tank and liquid in the connecting pipe, is different, it must be taken into consideration, for example γ1 and γ2.

6)-4 Definition of URV and LRV:
When you input data to DPT via SFC, you have to define URV and LRV.
LRV stands for the lower range value. So, since the LRV is the low limit of range, when you define 0% level, configure Differential pressure (ΔP) at 0% level as LRV by Smart Field Communicator (SFC).

URV stands for the upper range value. So, since the URV is the upper limit of range, when you define 100% level, configure Differential pressure (□P) at 100% level as URV by SFC.

6)-4 (a) In case of Differential pressure transmitter for electrical type:
The Low-Pressure (LP) side of the differential pressure transmitter is connected to the pipe for water level variable and changing, the liquid head pressure (Pa) in the tank (tank liquid height x γ + leg liquid height x γ + internal tank pressure P1).
(Drum level side)

Pa side = $h \times \gamma + h_2 \times \gamma + P_1$ =Low Press Side

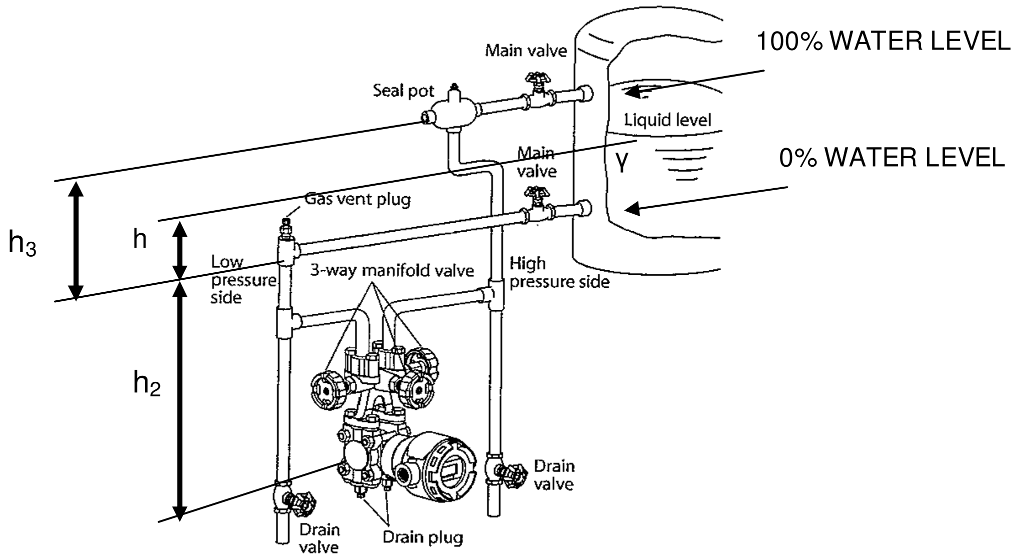


Fig. 8.6 Diagram for Wet-leg sealing normal Piping example of Closed tank

The High-Pressure (HP) side of the differential pressure transmitter is connected to the pipe for water level fixed, the liquid head pressure (Pb) in the tank (seal liquid height x γ + leg liquid height x γ + internal tank pressure P1).
(Condenser seal liquid side)

Pb side = $h_3 \times \gamma + h_2 \times \gamma + P_1$=High Press Side

The piping arrangement is shown in **Fig. 8.6**

Consequently,

Differential pressure (ΔP) = **Pb – Pa**

=High Press Side- Low Press Side

= $h_3 \times \gamma - h \times \gamma$ ($h_3 > h$, thus $\Delta P > 0$)

By this method, the liquid level (h) can be measured.
In this case, when the liquid level is 0%, the differential pressure signal corresponds to 100%. Moreover, when the liquid level is 100%, the differential pressure signal corresponds to 0%. This condition is drawn as Red broken line **shown in Fig. 8.7.**

It means that the differential pressure signal in response to the liquid level increase is from 100% to 0%.
For practical measurement, DPT must compute and convert signal sufficiently. So, for the differential pressure transmitter of the SMART electrical type, we use smart field communicator in order to configure URV and LRV.
Define LRV at 0% liquid level and URV at 100% liquid level to DPT by SFC.
Then, the micro-processor in DPT can consider following formula automatically.

$\Delta P = LRV - a \times (PL)$ ・・・ (1)

a: calculation constant

ΔP: Differential pressure

PL: Percentage of water level

In this formula, variation of Differential pressure decreases against an increasing signal of liquid level.

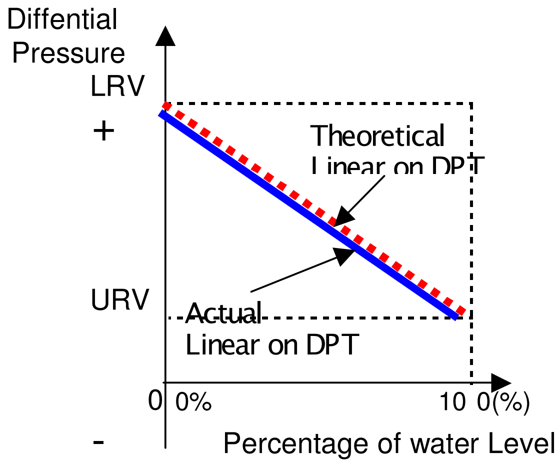


Fig. 8.7 Graph for signal from Differential pressure transmitter for electrical type

When the theoretical linear graph (Red broken line) on DPT, is consistent to the actual linear graph (Blue continuous line) on DPT, the transmitter works properly.
Substitute the following code into formula (1).

Minimum ΔP =LRV-a(0%PL) =LRV ・・・ (2)

Maximum ΔP =LRV- a(100%PL) =URV ・・・ (3)

URV: Liquid height pressure at 100% Percentage of water level =u
LRV: Liquid height pressure at 0% Percentage of water level=l
Solve the simultaneous equations: formula (2) and (3)
formula(2)- formula(3) =
LRV-URV = a(100%PL) - a(0%PL)
= a (100%PL -0%PL)
Therefore,

a = (LRV-URV) ・・・ (4)

(100%PL -0%PL)=1

Substitute the following formula(4) into formula (1).

ΔP = LRV – (LRV-URV)x (PL) ・・・ (5)

Convert formula (5) from “DP=” to “PL=”
PL= - (DP - LRV) / (LRV-URV)
= (LRV - DP) / (LRV-URV) ・・・(6)

By formula (6), DPT can calculate the percentage of water level with Differential pressure.

Finally, the maximum differential pressure signal (0% level) meets 4mA of output signal, the minimum differential pressure signal (100% level) meets 20mA of output signal, and then the midpoint differential pressure signal (50% level) meets 12mA of output signal.

6)-4 (b) What happens if we make a wrong connection at Wet-leg with Closed tank?
Let’s see what will happen if you make a wrong connection between the Low-Pressure (LP) side of the differential pressure transmitter and the High-Pressure (HP) side of the differential pressure transmitter at Wet-leg with Closed tank:

The Low-Pressure (LP) side of the differential pressure transmitter is connected to the pipe for water level fixed, the liquid head pressure (Pa) in the tank (seal liquid height x γ + leg liquid height x γ + internal tank pressure P1).
(Condenser seal liquid side)

Pa side = h_3 x γ + h_2 x γ + P_1 =Low Press Side

The piping arrangement is shown in **Fig. 8.8.**

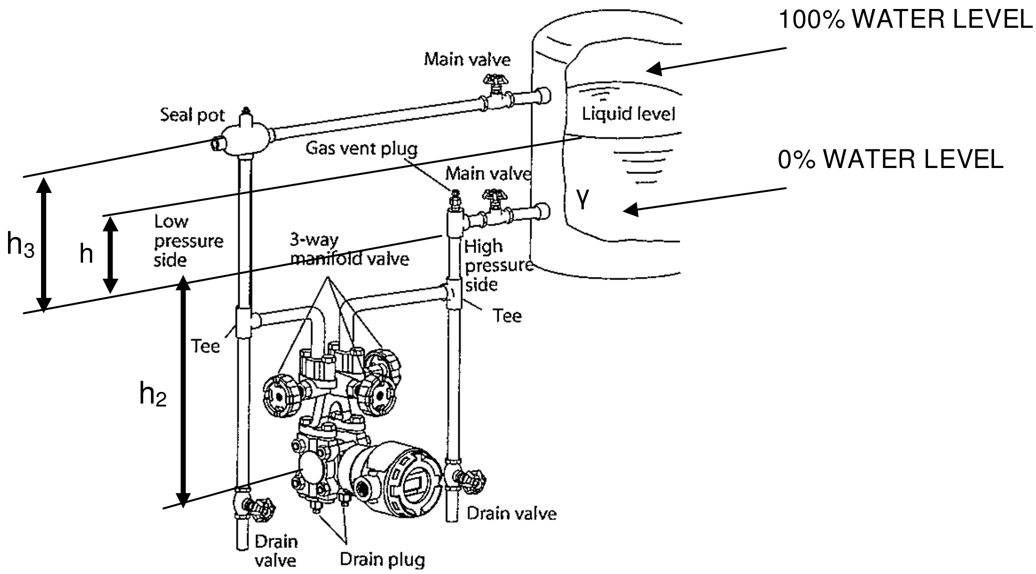


Fig. 8.8 Diagram for Wet-leg sealing wrong Piping example of Closed tank

The High-Pressure (HP) side of the differential pressure transmitter is connected to the pipe for water level variable and changing, the liquid head pressure (Pb) in the tank (tank liquid height x γ + leg liquid height x γ + internal tank pressure P1).
(Drum level side)

Pb side = h x γ + h_2 x γ + P_1=High Press Side

Consequently,

Differential pressure (ΔP) = **Pb – Pa**

=High Press Side- Low Press Side

= h x γ – h_3 x γ (h_3 >h, thus $\Delta P < 0$)

So, if you make a mistake in connecting pipe to DPT, the differential pressure will be negative.

Even if designers and operators estimate the theoretical linear graph on DPT with red broken line, the actual linear graph on DPT with blue full line affect an actual differential pressure on DPT.

When the theoretical linear graph (red broken line) on DPT is not consistent to the actual linear graph (continuous Blue line) on DPT, the transmitter doesn't work properly.

In this condition, the liquid level (h) cannot be measured by the actual linear graph (continuous Blue line) on DPT. as **shown in Fig. 8.9.**

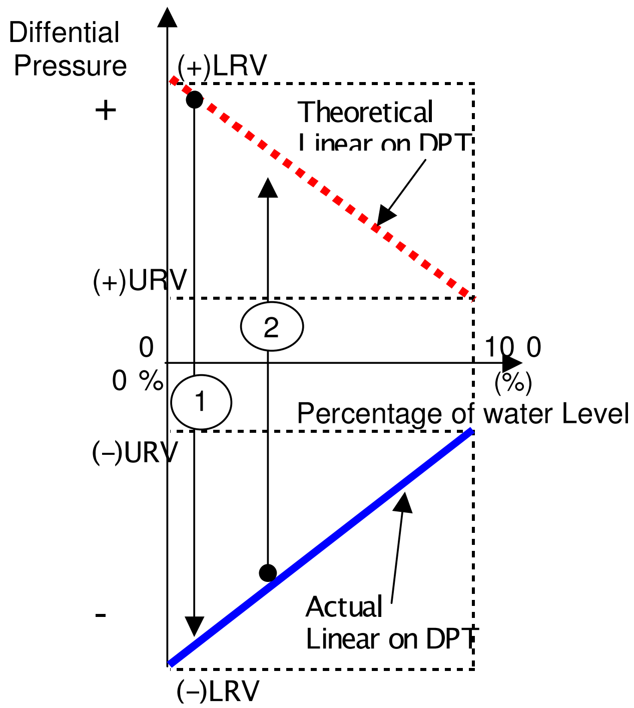


Fig. 8.9 Graph for signal from Differential pressure transmitter of electrical type with wrong connection

In this case, remedial action is as given below:

Method 1:

You can adjust the wrong condition by operating SFC.

When you define the URV and LRV on DPT by SFC, add negative on the URV and LRV calculated theoretically (-) URV and (-) LRV. As a result, you can transfer the theoretical linear graph (Red broken line) on DPT with the actual linear graph (Blue continuous line) on DPT. Then, the DPT will transmit the output signal properly.

Method 2:

You can adjust the wrong condition by changing pipe to DPT.

As the result you can transfer the actual linear graph (Blue continuous line) on DPT with the theoretical linear graph (Red broken line) on DPT.

Thus, the DPT will transmit the output signal properly.

Finally, the maximum differential pressure signal (0% level) meets 4mA of output signal, the minimum differential pressure signal (100% level) meets 20mA of output signal, and then the midpoint differential pressure signal (50% level) meets 12mA of output signal,

8.1.2 Smart Field Communicator:

In order to learn about Smart Field Communicator, we use SFC260 S-SFC II from Yamatake.

1) Introduction:

The Smart Field Communicator (SFC) allows you to communicate with the smart field instruments via a signal line.

2) Functions:

The SFC provides the following functions for communicating with smart field instruments:

(a) Start up functions

・Initiating communications

・Displaying and setting output ranges

(b)Verification functions

・Reading actual measurement values

・Reading actual output values

(c)Printout functions

・Printing out smart field instrument data

・Continuous printout of responses to key input

Note:

Communication functions are not impaired even if the printer function is not operational or if the printer itself is broken.

(d)Maintenance

・Displaying the results of smart field instrument self-diagnostics

・Rewriting the TAG numbers of smart field instrument self-diagnostics

・Output a fixed current from a smart field instrument

3) Image between DPT and SFC:

As you have already studied DPT, Smart field instrument, consists of meter body as a sensor, microcomputer as a computer, and converter as a signal generator.

For easy understanding, the image diagram is provided in **Fig. 8.10**.

SFC is a kind of man-machine interface in order to connect between human brain and micro-computer in DPT. So, SFC plays a role of a keyboard in computer system.

So, it is the most important thing for ships engineers to save data into DPT before switching off the SFC after changing data on DPT by SFC.

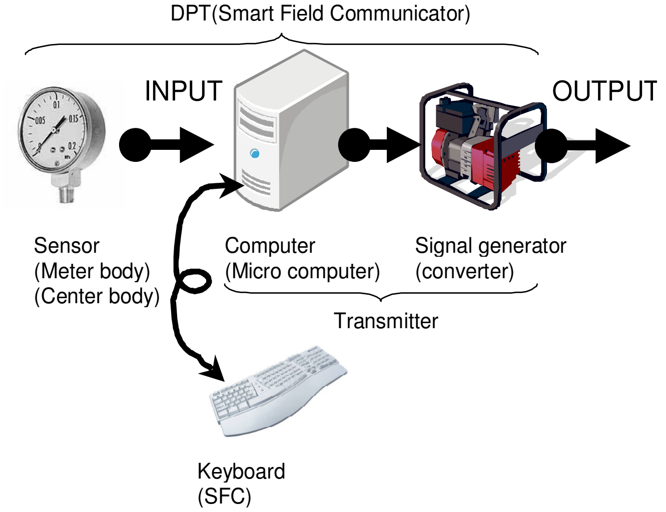


Fig. 8.10 Image between DPT and SFC

4) Connecting method:

Location of SFC: We can connect SFC to any end terminal on the 4 – 20 mA DC line using crocodile cap without disconnecting the loop cable.

Required Condition

(1) The two –wire 4-20mA DC line of any smart field instrument requires a DC power supply (24V/42V) for loop purpose.

(2)The resistance between the DC power supply for loop purposes and the SFC must be at least **250 ohms** (Ω).

Receiver is the indicator; for example, level indicator, pressure indicator, flow indicator, or Monitoring System.

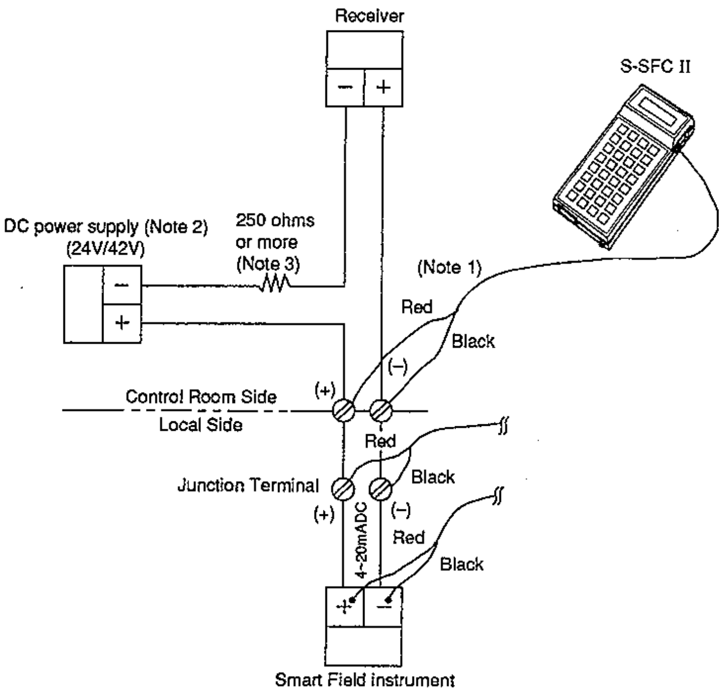


Fig. 8.11 Diagram of Connecting the SFC

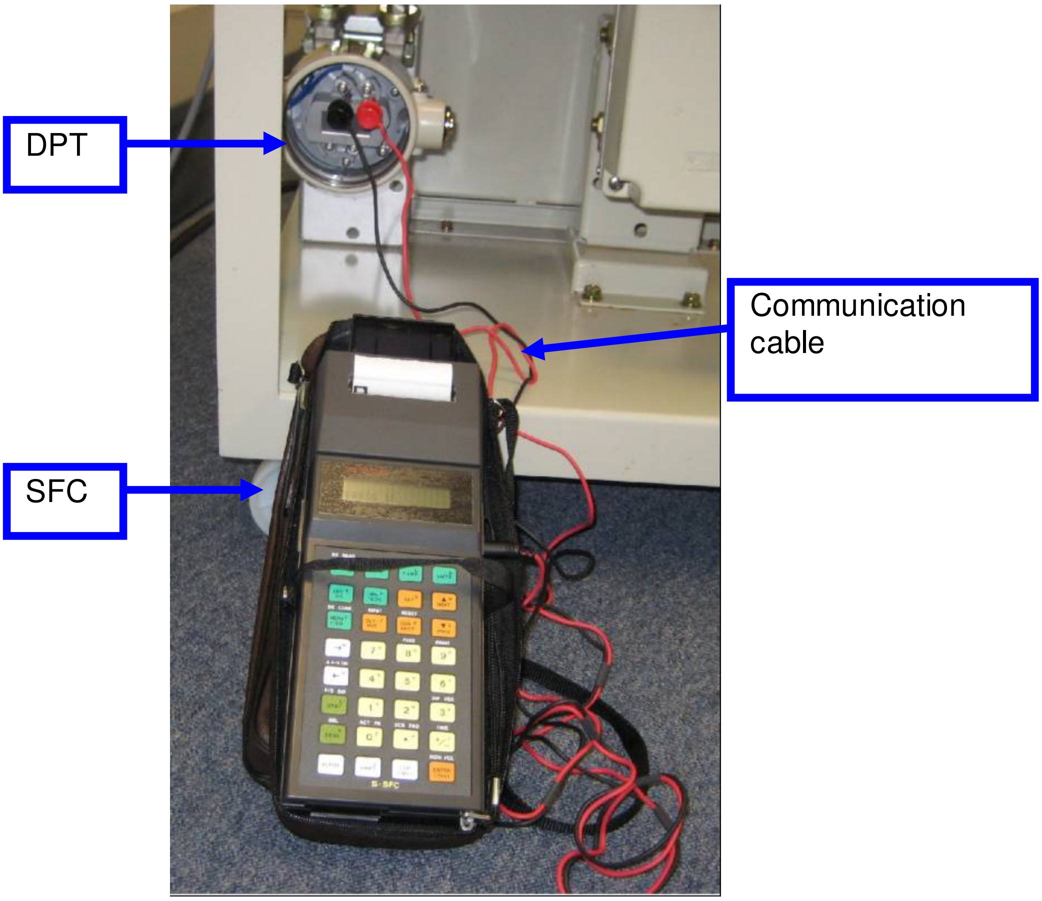
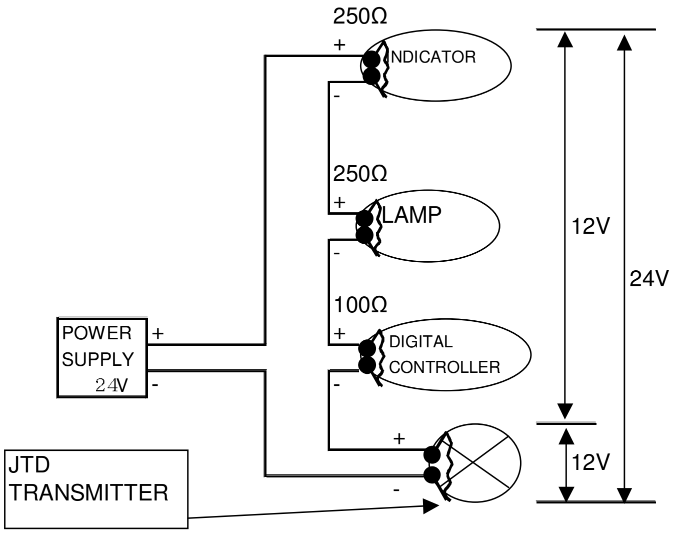


Fig. 8.12 Diagram of Connecting the SFC

5) Relation between Load resistance and supply voltage:

The Differential pressure transmitter (DPT) can be operated with 12V DC.
When DPT is connected on the loop with 24V DC, the remaining power is 12V DC. Therefore, in order to work the control signal between 4 mA DC and 20 mA DC on the loop, the total load resistance up to 600 ohms on the loop can be connected according to the ohm's Law. 12V DC=20mA DC x 600 ohms(Ω).



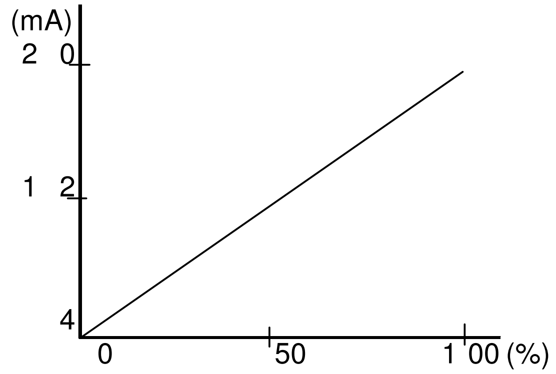
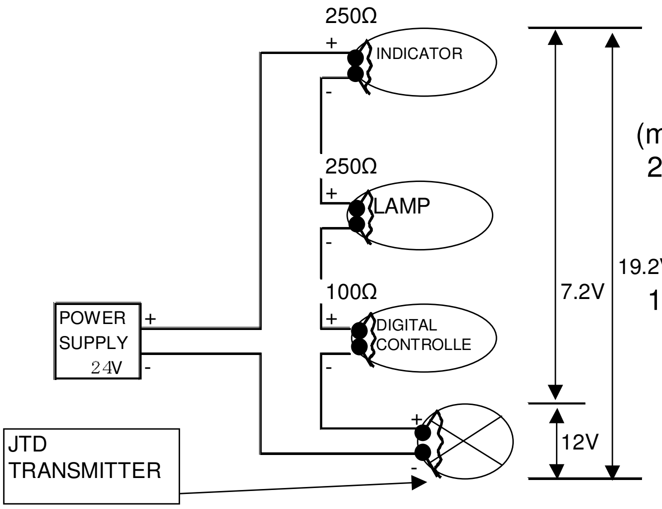


Fig. 8.13 Normal voltage supply when Load resistance is 600 ohms

Fig. 8.14 Signal and current when load resistance is in range

However, when the total load resistance of 600 ohms is connected and if the remaining voltage, other than 12 V DC for the DPT, is only 7.2V DC, then it means the total supply voltage is reduced to 19.2V DC. Thus, the working control signal peaks out at 50%(12mA=7.2V DC/600ohms) of the maximum control signal current. Consequently, the correct control signal from DPT can't be transmitted.



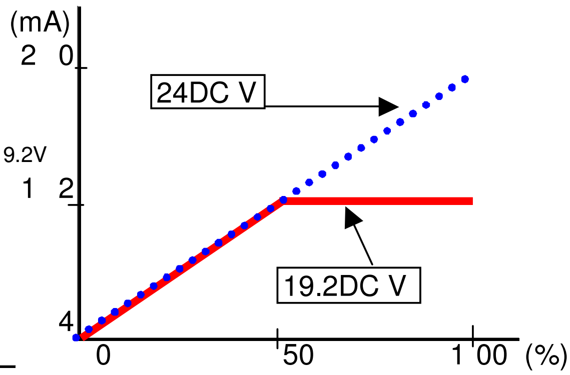


Fig. 8.15 Under voltage supply when Load resistance is 600 ohms

Fig. 8.16 Signal and current when load resistance is out of range

Since the load resistance inside of the devices is included in indicator and digital indicating controller, we must note and estimate the total load resistance on the loop before connecting those devices on the loop.

Since the load resistance inside of digital indicating controller is described in its catalogue or instruction manual, for example, as “receiving resistance” on SDC31, when you replace or install newly indicator or digital indicating controller on the existing control system, please note and estimate total load resistance on the system in advance.

The right diagram shows the relationship between load resistance and voltage supply at 20mA DC with 100% output signal.
So, with 250ohms of load resistance, voltage supply, for 20mA DC as 100% output signal, must be more than 16.3V DC.
Moreover, with 605ohms of load Resistance, voltage supply, for 20mA DC as 100% output signal, must be more than 24.0V DC.

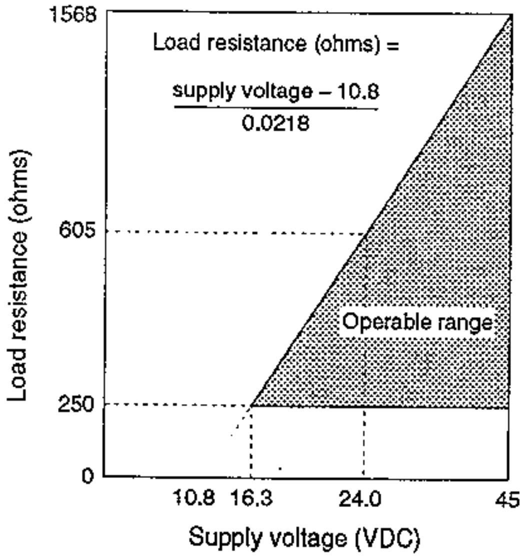


Fig. 8.17 Characteristics between Supply voltage and Load resistance

6) Intrinsic explosion safety:

Warning

There are dangerous and Non- dangerous location on the vessel such as LNG carrier, LPG carrier, VLCC, etc. For SFC operation, we must know the restriction of connection form SFC to loop.

(1) When SFC is planned to be connected to the loop on Dangerous location (the dangerous side after terminal A in Zener barrier) and Non-dangerous location (the Non-dangerous side before terminal B in Zener barrier) in order to check the condition of smart field instrument (e.g. DPT). The type of SFC must be confirmed by ensuring that an explosion･proof inspection is certified. SFC, which has the explosion proof certificate (Intrinsic explosion safety), can be connected to the loop at one of two location, either Dangerous location or Non-dangerous, as shown in the Fig. 8.18**.**

Normally SFC of Intrinsic explosion safety type doesn’t have printer. If it has a printer, a printer can generate spark and it can’t avoid explosion.

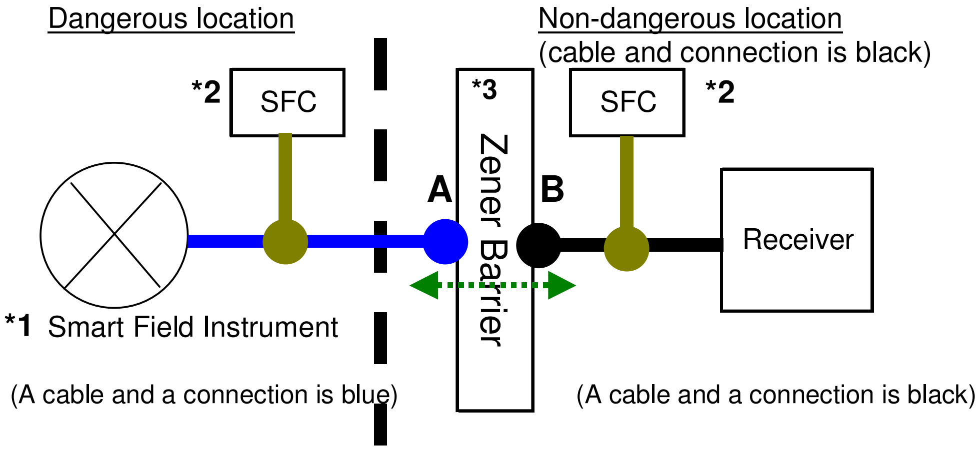


Fig. 8.18 Signal Direction and connecting location of certified SFC

Above figure shows the correct system structure to be adopted when using the SFC in an explosion-proof atmosphere
*1 Smart field instrument is approved for use in explosion-proof atmospheres and compatible with SFC.
*2 Connect the SFC at one of these two locations
*3 The Zener barrier must be approved by a classification society.
This type approval, issued by classification society, specifies a pair of Zener barrier and Smart field instrument.
It means we can't replace either Zener barrier or Smart field instrument, which are not approved in a pair.
*3 The Zener barrier must be installed in a non-dangerous location and grounded independently.

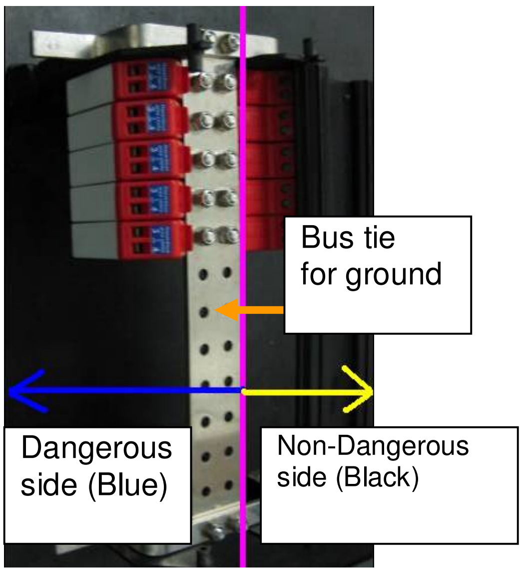


Fig. 8.19 Picture of Zener barrier

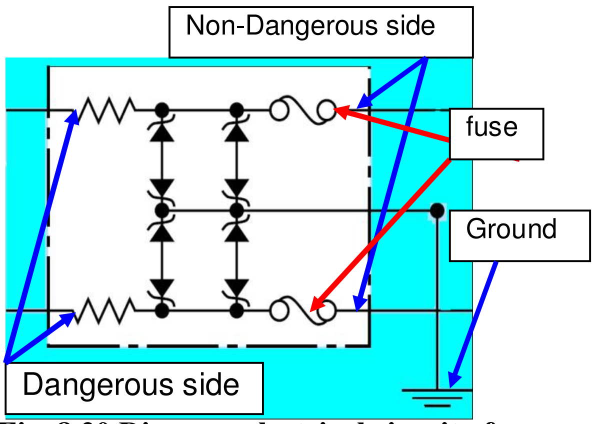


Fig. 8.20 Diagram electrical circuit of Zener barrier

(2) In case, the type of SFC is not Intrinsic explosion safe, then even if the SFC is connected to the loop in Non-dangerous location, it can't communicate to the devices on the loop. It is because the Zener barrier blocks the signal from the SFC to smart field instrument (e.g. DPT) as shown in **Fig. 8.21**. Therefore, if the condition of the smart field instruments is to be checked, they must be removed from loop, and then be connected to the SFC in order to check and diagnosis in Engine workshop. Before that, you must ensure that the electric power supply for Smart field instrument is Off by disconnecting the terminal B before Zener barrier in Non dangerous location.

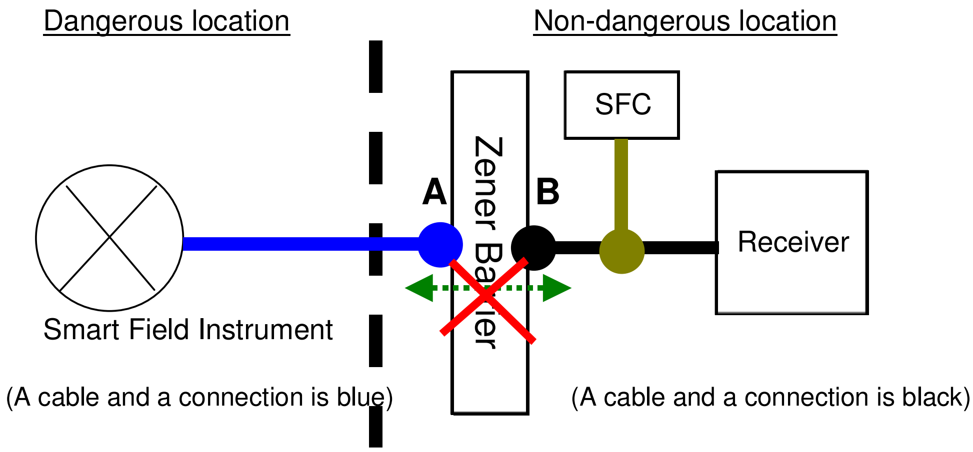


Fig. 8.21 Signal Direction and connecting location of non-certified SFC

8.1.3 Digital Indicating controller:

In order to learn about Digital Indicating controller, we use SDC 31 from Yamatake.

1) Introduction:

The digital indicating controller offers standard PID control and an advanced neural/fuzzy PID that performs process diagnostics and reduces overshoot.

It offers full, multi-range inputs, selectable from the keypad, including thermocouple, resistance temperature detector (RTD), DC voltage and DC current inputs.

It provides a comprehensive range of strategies including time proportional PID (relay output, voltage output), current output PID, and position proportional PID.

It also enhances process visibility with such functions as remote switch input, control parameters, and local set points, which can be easily set using the smart loader.

Normally the lifetime is around 5 years

(a) Basic Functions Block Diagram:

• Standard Model and Remote SP Model

• The set point value ramp function allows setting of the SP change ratio.

• Two event outputs are provided: enabling one with a timer function, and a motor opening event to be set.

• The operation modes are selectable by external switch inputs (local / remote, auto/manual, RUN/READY, selection of 8 local set points, AT start, direct/reverse action timer event start).

• Versatile optional functions support a broad range of applications:

- Events (2 points)
- Auxiliary output (1 point)
- Digital input (4 points)
- Communication (RS-485)

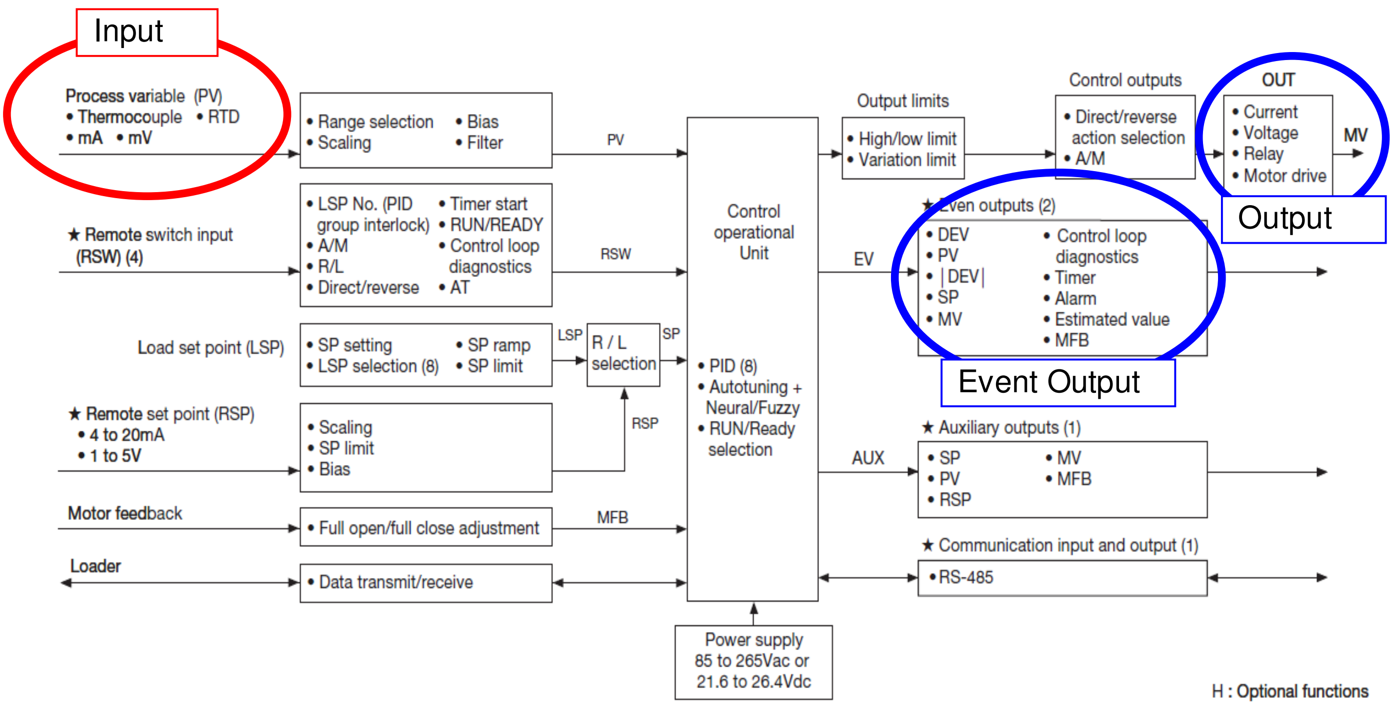


Fig. 8.22 Diagram for basic function of Digital Indicating controller

2) Steps for operation:

In order to operate the Digital Indicating controller, we have to take 5 steps i.e. Connecting cable, Setup items, Parameter data, Set point & Event, and Run as shown in Fig. 8.23.

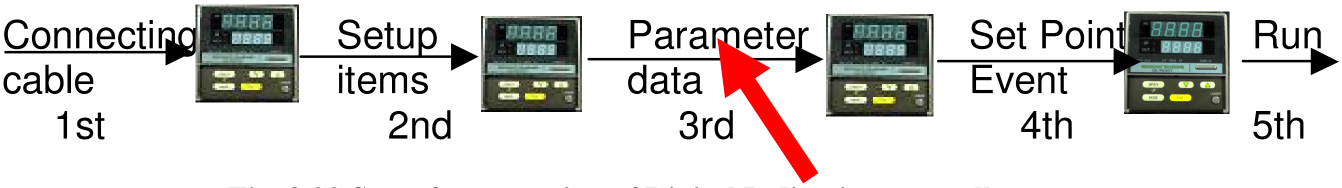
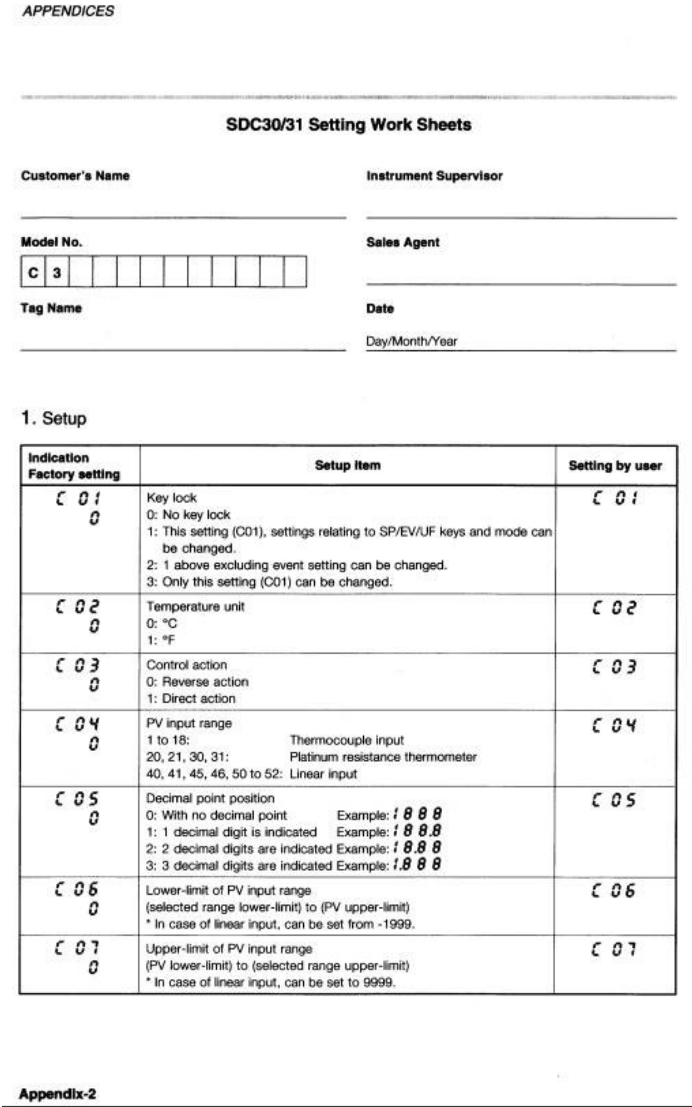


Fig. 8.22 Steps for operation of Digital Indicating controller

If there is no special data file which keeps "Setup data", "Parameter data", and "Set point & Event" on board, the Data Work Sheet of the controllers ,like right hand table, must be recorded and kept in a file as a important document by engineers on board.



APPENDICES

SDC30/31 Setting Work Sheets

Customer's Name

Instrument Supervisor

Model No. C 3

Sales Agent

Tag Name

Date Day/Month/Year

1. Setup

Indication Factory setting	Setup item	Setting by user
C01 0	Key lock 0: No key lock 1: This setting (C01), settings relating to SP/EV/UF keys and mode can be changed. 2: 1 above excluding event setting can be changed. 3: Only this setting (C01) can be changed.	C01
C02 0	Temperature unit 0: °C 1: °F	C02
C03 0	Control action 0: Reverse action 1: Direct action	C03
C04 0	PV input range 1 to 18: Thermocouple input 20, 21, 30, 31: Platinum resistance thermometer 40, 41, 45, 46, 50 to 52: Linear input	C04
C05 0	Decimal point position 0: With no decimal point Example: 1888 1: 1 decimal digit is indicated Example: 188.8 2: 2 decimal digits are indicated Example: 18.88 3: 3 decimal digits are indicated Example: 1.888	C05
C06 0	Lower-limit of PV input range (selected range lower-limit) to (PV upper-limit) * In case of linear input, can be set from -1999.	C06
C07 0	Upper-limit of PV input range (PV lower-limit) to (selected range upper-limit) * In case of linear input, can be set to 9999.	C07

Appendix-2

Fig. 8.23 Sample of the record provided in the instruction manual

3) Name and functions of component part:
Name and functions of component part is shown below.

Name	Function
REM	Lights when remote setting input(RSP) is selected・
AT	Flashes during auto tuning operation. Lights during overshoot suppression learning
4. Green belt	Lights when a difference (deviation) between PV (Process Variable) and SP (Set Point) is within a range preset in setup item C43. Flashes in the READY mode.
1. DISP key	Set the display to basic indication status・ Indicates a PV on the No.1 indicator and an SP on the No.2 indicator. Determines the contents of the No.2 indicator.
6.SP/EV/UF key	Selects the state by which SP, event and parameter settings registered to this key can be substituted
7.MODE key	Selects auto-tuning, start/ stop, AUTO/MANUAL, RUN/READY and LSP/RSP mode change items.
8.ENT key	Defined a changed numeric. Sets items such as displayed parameters to a substitute (change) state.
9.Up key	Increments numerics. Successively switches items such as displayed parameters・
10.Down key	Decrements numerics. Successively switches items such as displayed parameters.
11.Loader connector	This connector is used to connect the Handy Loader(optional).

Fig. 8.24 Name and functions of component part of Digital Indicating controller

On the front panel, there are some operation keys which are often used, e.g. SP, PV, and OUT. The function which is not used so often is monitor and changed by select mode key. When alarm is set, “event” function is used. For controller, “event” is one of the condition settings in order to transmit the output signal by any analog signal or digital signal. There, if the event is set to activate buzzer, indication light, some warning devices, and etc., it can be worked as the alarm activator. In the different point of view, the ”event” can control the different function from alarm, for example “event“ signal can work as the pump start or stop in the control system.

4) SETUP ITEMS:

The SETUP ITEMS is determined and input in order to use the controller basically for purpose of use optimally. It means this setup is a basic setting. We can’t change the setting during operation of the controller.

The installed digital indicating controllers on-board are already set up in accordance with the design of machinery’s manufacturer for an incinerator, a boiler, a viscosity controller, etc. at the delivery dock. So, a factory of the controllers, Yamatake, doesn’t know a particular and sufficient setting condition on-board. And even if the vessel orders the new controllers when these get damaged, the factory, Yamatake, can only deliver the new controller whose condition is set as factory default. Therefore, engineers on the vessel must record and keep the Data Work Sheet of the controllers as an important document in a file beforehand. Then if the controller is broken, the engineers on board can set up the new digital indicating controllers by referring the Data Work Sheet of the controllers.

There are 51 setup items from C01 to C51 (including missing numbers).on SDC31 Yamatake

Normally, setting items are between C1 and C21.

The setup table is shown in Fig. 8.25 a/b/c/d Setup table (C1～C51) of Digital Indicating controller.

Setup Parameters Table

Item	Indication	Setting condition	Default	Setting range	Remarks
Key lock	C 01	—	0	0: No key lock 1: Key lock 1 2: Key lock 2 3: Key lock 3	For details on key lock, see page 4-6.
Temperature unit	C 02	T/C or RTD	0	0: °C 1: °F	
Control action	C 03	—	0	0: Reverse action 1: Direct action	
PV input range	C 04	—		See Input Range Table, page 4-7.	
Decimal point position	C 05	See C05 setting (decimal point position), page 4-7.	0	T/C, RTD: 0 to 1 decimal digit Linear: 0 to 3 decimal digits	
Lower-limit of PV input range	C 06	—	0	(selected range lower-limit) to C07	In case of linear input, scaling is possible in range -1999 to 9999.
Upper-limit of PV input range	C 07	—	1000	C06 to (selected range upper-limit)	
SP setting system	C 08	—	0	0: Single SP 1 to 7: Multi-SP	
Lower-limit of SP	C 09	—	Range lower-limit	C06 to C07	
Upper-limit of SP	C 10	—	Range high-limit	C09 to C07	
Selection of output in case of PV abnormal	C 11	—	0	0: Output PID calculation results 1: Closed relay ON (C35=2) C12 setting (other than above) 2: Closed relay ON (C35=2)	
Control output at READY and PV abnormal	C 12	—	0%	0D, 6D, 2G: 0 to 100% 5G: -10 to +110%	Valid at READY or when C11=1 and abnormal PV
Manual initial control output selection	C 13	—	0	0: Bump-less 1: Preset	Always bump-less when C35=2 Initial control output when mode is changed to AUTO from MANUAL

Fig. 8.25a Setup table (C1～C13) of **Digital Indicating controller**

Item	Indication	Setting condition	Default	Setting range	Remarks
Preset manual value	C 14	—	0%	0D, 6D, 2G: 0 to 100% 5G: -10 to +110%	C14 value is output regardless of C13 when the power is turned ON again in the MANUAL mode. This setting is invalid when C35=2.
Initial manipu-lated variable in PID operation	C 15	—	0%	0 to 100%	
PID operation initialize	C 16	—	0	0: AUTO 1: Initialize at SP change or RSP/LSP switching 2: Do not initialize	
Zone PID operation	C 17	—	0	0: OFF 1: ON	
Control system selection	C 18	C20=1	0	0: Normal PID control 1: Overshoot relaxation 2: Learning function status 3: Fixed learning status	C18 is automati-cally set to 3 when auto-tuning ends when C20=2
Independent 2-degrees of freedom PID operation selection	C 19	—	0	0: Not used 1: Used	
Neural network auto-tuning operation selection	C 20	—	0	0: Used 1: Not used	This setting is valid when set before execution of auto-tuning.
Event 1 type	C 21	With event 1	0	0: Event OFF 1: Deviation (direct action) 2: Deviation (reverse action) 3: PV (direct action) 4: PV (reverse action) 5: Absolute value deviation (direct action) 6: Absolute value deviation (reverse action) 7: SP (direct action) 8: SP (reverse action) 9: MV (direct action) 10: MV (reverse action) 11: Motor feedback (direct action) 12: Motor feedback (reverse action) 13: Control loop diagnosis 14: Timer (sec.) 15: Timer (min) 16: Alarm (direct action) 17: Alarm (reverse action) 18: Execution at inferred position	
Event 1 standby operation selection	C 22	With event 1	0	0: Standby OFF 1: Standby ON	
Event 2 type	C 23	With event 2	0	Same as C21	

Fig. 8.25b Setup table (C14～C23) of **Digital Indicating controller**

Item	Indication	Setting condition	Default	Setting range	Remarks
Event 2 standby operation selection	C24	With event 2	0	0: Standby OFF 1: Standby ON	
Event operation at READY	C25	With event	0	0: ON 1: OFF	
Number of SPs selectable by external switch input	C26	With RSW input	0	0, 2, 4, 8	Restricted by setting of C8
External switch input 1 function	C27	With RSW1	0	At OFF/at ON 0: No operation 1: RUN/READY 2: AUTO/MANUAL 3: LSP/RSP 4: STOP/START (auto-tuning) 5: PID direct/reverse 6: Reset/start (timer EV1) 7: Reset/start (timer EV2)	PID direct/reverse is reverse of C03 setting when RSW is ON.
External switch input 2 function	C28	With RSW2	0		
External switch input 3 function	C29	With RSW3	0		
External switch input 4 function	C30	With RSW4	0		
Communication address	C31	With communi-cation function	0	0 to 127	0: No response
Transmission speed	C32	With communi-cation function	0	0: 9600 bps 2: 2400 bps 1: 4800 bps 3: 1200 bps	
Communication code	C33	With communi-cation function	0	0: 8 bits, even parity, 1 stop bit 1: 8 bits, no parity, 2 stop bits	
Dead zone	C34	2G output	10.0%	0.5 to 25.0%	
Modular control motor control method selec-tion	C35	2G output	0	0: MFB+inference 1: MFB 2: Inference	
Modular control motor start of automatic adjustment	C36	2G output	0	0: Non-adjusted state 1: Adjustment executed	Adjusted value is automatically set to C37, C38 and C39.
Modular control motor fully closed adjusted value	C37	2G output C35=1	1000	0 to 9999	Input is possible in range that satisfies condition C37<C38.
Modular control motor fully open adjusted value	C38	2G output C35=1	3000	0 to 9999	
Modular control motor fully open/ closed time	C39	2G output C35=1, 2	30 sec.	5 to 240 sec.	Manually set when C35=2

Fig. 8.25c Setup table (C27～C39) of Digital Indicating controller

Item	Indication	Setting condition	Default	Setting range	Remarks
SP ramp up gradient	C 40	—	0	0 to 9999 unit (0.1 unit)/min (hr)	No gradient at 0 Valid only for LSP
SP ramp down gradient	C 41	—	0		
SP ramp time unit selection	C 42	—	0	0: Unit/min 1: 0.1 unit/min 2: Unit/hr 3: 0.1 unit/hr	
Green belt	C 43	—	5	0 to 1/2 PV range	Lights at IPV-SPI ≤C43 condition
Auxiliary output type	C 44	With auxiliary output	0	0: PV 1: SP 2: Pre-bias RSP 3: RSP 4: MV 5: Motor valve opening	PID calculation result is output when MV is selected on 2G output.
Value of signal source at 4 mA auxiliary output	C 45	With auxiliary output	0 unit OR 0.0%	C44=0, 1, 2, 3 -1999 to +9999 unit C44=4, 5 -199.9 to +999.9 unit	Decimal point is dependent on C05 when C44=0, 1, 2, 3.
Value of signal source at 20 mA auxiliary output	C 46	With auxiliary output	1000 unit OR 100.0R	C44=0, 1, 2, 3 -1999 to +9999 unit C44=4, 5 -199.9 to +999.9 unit	Decimal point is dependent on C05 when C44=0, 1, 2, 3.
RSP value at 0% input (4 mA, 1 V)	C 47	With remote setting input	0 unit	-1999 to +9999 unit	Decimal point is dependent on C05.
RSP value at 100% input (20 mA, 5 V)	C 48	With remote setting input	1000 unit	-1999 to +9999 unit	
Cold junction compensation operation selection	C 49		0	0: ON 1: OFF	
Zener barrier adjustment	C 50	Zener barrier model C04=RTD range	0	-20.00 to +20.00	
Adjustment code	C 51	—	0		Do not change this factory setting.

Fig. 8.25d Setup table (C40～C51) of **Digital Indicating controller**

5) How to set the SETUP ITEMS:
In order to understand how to set The SETUP ITEMS, let's focus on C21.
C21 is the setting for the event1.
1) Select code 3 if you activate event as alarm, when the Process variable (PV) exceeds Event set value (EV).
If you select the code 6, the reset point of the event is Hysteresis (HYS) value below EV .
(See page 4-14 in operation manual)

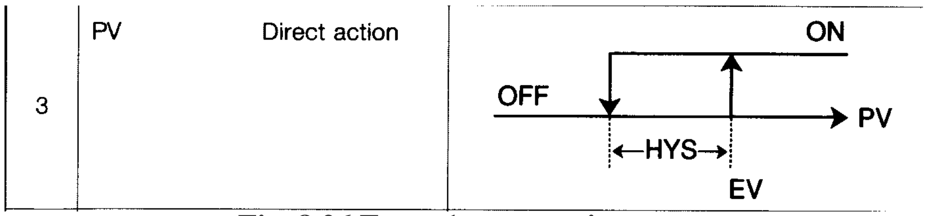


Fig. 8.26 Event 1 on setup items

6) Parameter Data:
The parameter data is determined and input in order to operate and control the controller for purpose of use optimally.
We can change the parameter even during running.
Regarding items, refer to the parameter table shown in **Fig. 8.27a/b.**
.

Parameters Table

BANK	Item	Indication	Setting condition	Default	Setting range	Remarks
SP	Set point 0 to 7	SP 0 to SP 7	C8≥1	0	Within SP lower- and upper-limit (C9, C10)	(Note 1)
PId0 (Note 2)	Proportional band	P	—	5.0%	0.0 to 999.9% 0.1 to 999.9%	ON/OFF control when 0.0 is set. 0.0 cannot be set on 2G and 5G models.
	Integral time	I	p≠0	120 s	0 to 3600 s	
	Derivative time	d	P≠0	30 s	0 to 1200 s	
	Lower-limit of manipulated variable	oL	P≠0	0%	0 to upper-limit %	Doubles as the lower- and upper-limits of the integral limitter.
	Upper-limit of manipulated variable	oH	P≠0	100%	Lower-limit to 100%	
	Manual reset	rE	I=0 & P≠0	50%	0 to 100%	
	Differential	dIFF	P=0	5 unit	0 to 100 unit	
PIdx (Note 2)	PId I to 7, r	P to dIF is followed by No. (1 to 7) or r.	(Note 3) PIdr is not displayed in case C17=1.	Same as P to dIF		
dIS0 External disturbance inhibit PID (Note 4)	Proportional band	dP	—	5.0%	0.0 to 999.9% 0.1 to 999.9%	ON/OFF control when 0.0 is set. 0.0 cannot be set on 2G and 5G models.
	Integral time	dI	P≠0	120 s	0 to 3600 s	
	Derivative time	dd	P≠0	30 s	0 to 1200 s	
dISx	dIS I to 7, r	dP to dd is followed by No. (1 to 7) or r.		Same as P to dIF		

Fig. 8.27a Parameter table of Digital Indicating controller

Parameters Table (cont'd)

BANK	Item	Indication	Setting condition	Default	Setting range	Remarks
PArA	EV1 hysteresis	HYS1	EV1 is provided C21=1 to 13	5 unit	0 to 100 unit	
	EV1 ON delay time	dL 1	EV1 is provided C21=1 to 13	0 s	0 to 9999 s	
	EV2 hysteresis	HYS2	EV2 is provided	5 unit		
	EV2 ON delay time	dL 2	EV2 is provided C23=1 to 13	0 s		
	PV filter	FILt	—	0.0 s	0.0 to 25.0 s	
	PV bias	PbIA	—	0 unit	±1000 unit	
	RSP bias	rbIA	Remote setting input is provided	0 unit	-1999 to +9999 unit	
	Time-proportional cycle	CYCL	Time-proportional output	10 s	5 to 120 s: relay 1 to 120 s: voltage	
	MC rate-of-change limit	outL	—	100.0 %	0.1 to 100.0%	
ZonE	ZONE setting	Zn x (x=1 to 7)	C17=1	100.0 %	0.0 to 100.0%	Though Zn0 is not displayed, it is 0.0%.

Fig. 8.27b **Parameter table of Digital Indicating controller**

7) How to set Parameter:
In order to understand how to set Parameter, let's focus on Event 1 with C21.
1) Set parameter Hysteresis 1 (hys1) and delay timer 1(dl 1) (See page 5-5 in operation manual)

8) Operation:
Before this section, we learnt what the setup items and the parameters are.
After configuring those items, we start operation of the Digital indicating controller.
For the operation, we surely set the Set points (SP) and the Events (EV) if you select other than code "0" on C21 of setup itmes.

9) How to set Event:
In order to understand how to set Event, let's focus on C21.
C21 is the setting for the event1.
1) Set parameter Event 1 (EV1) (See page 6-10 in operation manual)

10) Load resistance and supply voltage:

When we design the electrical circuit with Multi functional digital indication controller such as Yamatake SDC31, we have to pay attention to the current input and voltage input to the controller.
Sometimes even if the catalogue shows the current input, if the input terminal on the loop is connected with 250 ohms(Ω) resistance, the input will generate the voltage between 1 and 5 V.
In this case, in the point of view from current source, the load resistance is 250 ohms(Ω).
For example of Yamatake SDC31 case, the resistance is indicated as "receiving resistance 100 ohms(Ω)" on its specification in instruction manual. It is shown in **Fig. 8.28.**

Linear current input (under operating conditions)

Receiving resistance:	100 Ω	
Input circuit failure indication:	Down scale + AL02 (A 0 to 20 mA input circuit failure is not detectable.)	
Max. input current/voltage:	Max. input current	24 mA dc
	Max. input voltage	2.4V dc
	Normal operation will no longer be possible if these values are exceeded.	
Absolute max. input ratings:	Current:	50 mA dc
	Voltage:	5V dc
	The "absolute max. ratings" are current and voltage ratings that can be applied to input terminals without any deterioration in characteristics or mechanical breakdown. Note that these are not ranges of assured controller operation.	

Fig. 8.28 Example of Receiving resistance from Specification of SDC31

8.1.4 I/P Converter:

In order to learn I/P converter, we use KUX112 from Yamatake.

1) Introduction:

The I/P converter converts electrical input signal of 4-20mA DC into a pneumatic output signal of from 20kPa to 100 kPa or other unit.

2) Structure and features:

The I/P converter is comprised of a converter main unit (chassis assembly), a casing and a cover. The main unit is readily detachable from the casing by loosening the clamping screws. As you detach the main unit from the casing, the air connectors are automatically sealed, thereby affecting neither the pneumatic signal channel nor the air supply channel. Input check terminals are provided on the front panel, allowing you to check readily the input current signal.

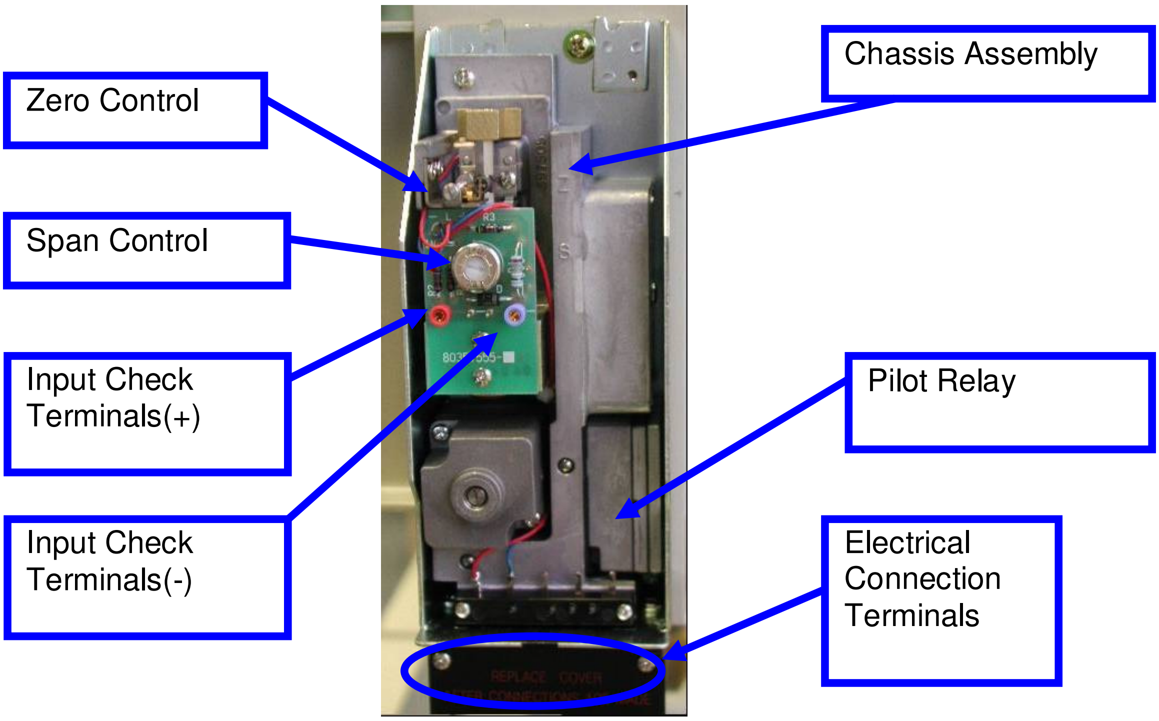


Fig. 8.29 Picture of I/P converter

3) Operating Principle:

The electrical input signal (Current signal) is converted by the magnet unit into a mechanical force which causes the beam position to change. The change in beam position is converted by the nozzle/flapper mechanism into a pneumatic signal, which is boosted by the pilot relay into the pneumatic output signal.

The pneumatic output signal is fed back via the feedback bellows to the beam, thereby attaining an equilibrium state.

Thus, the electrical input signal is converted into a pneumatic output signal which is directly proportional to the input signal.
The Block diagram and operating principle are shown in Fig. 8.30 “Block Diagram of I/P converter” and Fig. 8.31 “Diagram for Operating principle of I/P converter”

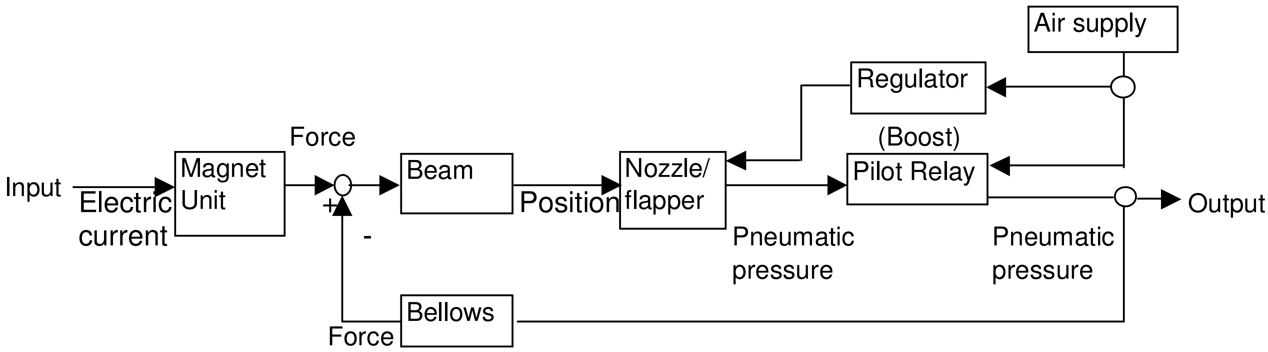


Fig. 8.30 Block Diagram of I/P converter

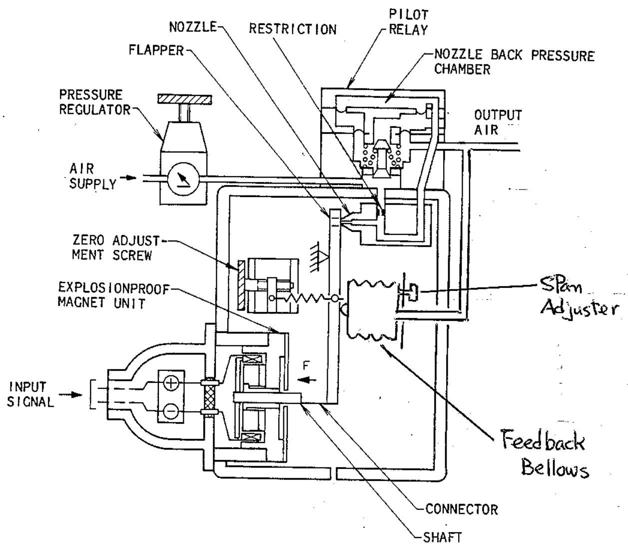


Fig. 8.31 Diagram for Operating principle of I/P converter

4) Adjustment and calibration:

(a) Connect air supply and a precision pressure gauge to the SUP and OUT connectors, respectively, at the bottom of the I/P converter.
(b) Connect a precision electrical signal source (4-20mA DC) to the electrical input terminals
(c) Feed a current signal of 4mA from the constant current source. Adjust the Zero control so that the output pressure becomes 20kPa ±0.25%. The output pressure rises as you turn the ZERO control Clockwise. (When 0%, the 4mA signal must correspond with 20kPa.)

(d) Feed a current signal of 20mA from the constant-current source. Adjust the SPAN control so that the output pressure becomes 100kPa±0.25%. The output pressure rises as you turn the SPAN control clockwise. (When 100%, the 20mA signal must correspond with 100kPa.)
(e) Repeat the procedures of steps (c) and (d) that the required Zero and span accuracies are attained.

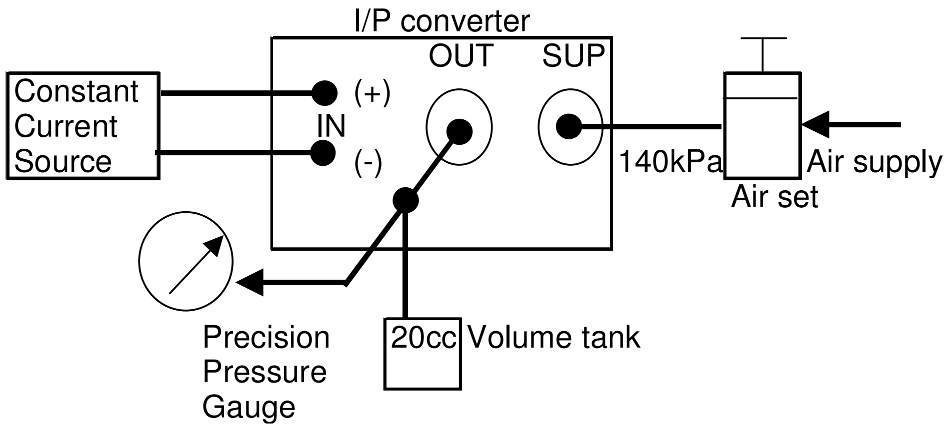


Fig. 8.32 Adjustment and calibration for I/P converter

5) Maintenace:
Normally, the I/P converter requires no maintenance service. When the I/P converter is operated in adverse conditions (such as with dusty air supply), disassemble the pilot relay and clean the restriction hole (employing a steel wire of 0.25mm dia.) and the port and seat (employing a soft cloth).
To disassemble the pilot relay, proceed as follows;
(a) Remove the clamping-screw. Loosen the five electrical connection screws.
(b) Exercising care not to touch the converting mechanism, detach the chassis assembly from the casing by pulling the chassis assembly upward.
(c) Remove the two mounting-screws of the pilot relay. Now the pilot relay can be disassembled by loosening its two assembly screws.
(e) When the pilot relay is removed, a very fine hole (a hair sized hole) on the chassis assembly side becomes accessible. The hole acts as a restriction**. Clean the hole** employing a fine steel wire (0.27mm dia.).
(f) To assemble the pilot relay, follow the above disassembly procedure in the reverse order.
The structure of the pilot relay can be shown in Fig. 8.33 "Exploded View of Pilot relay".

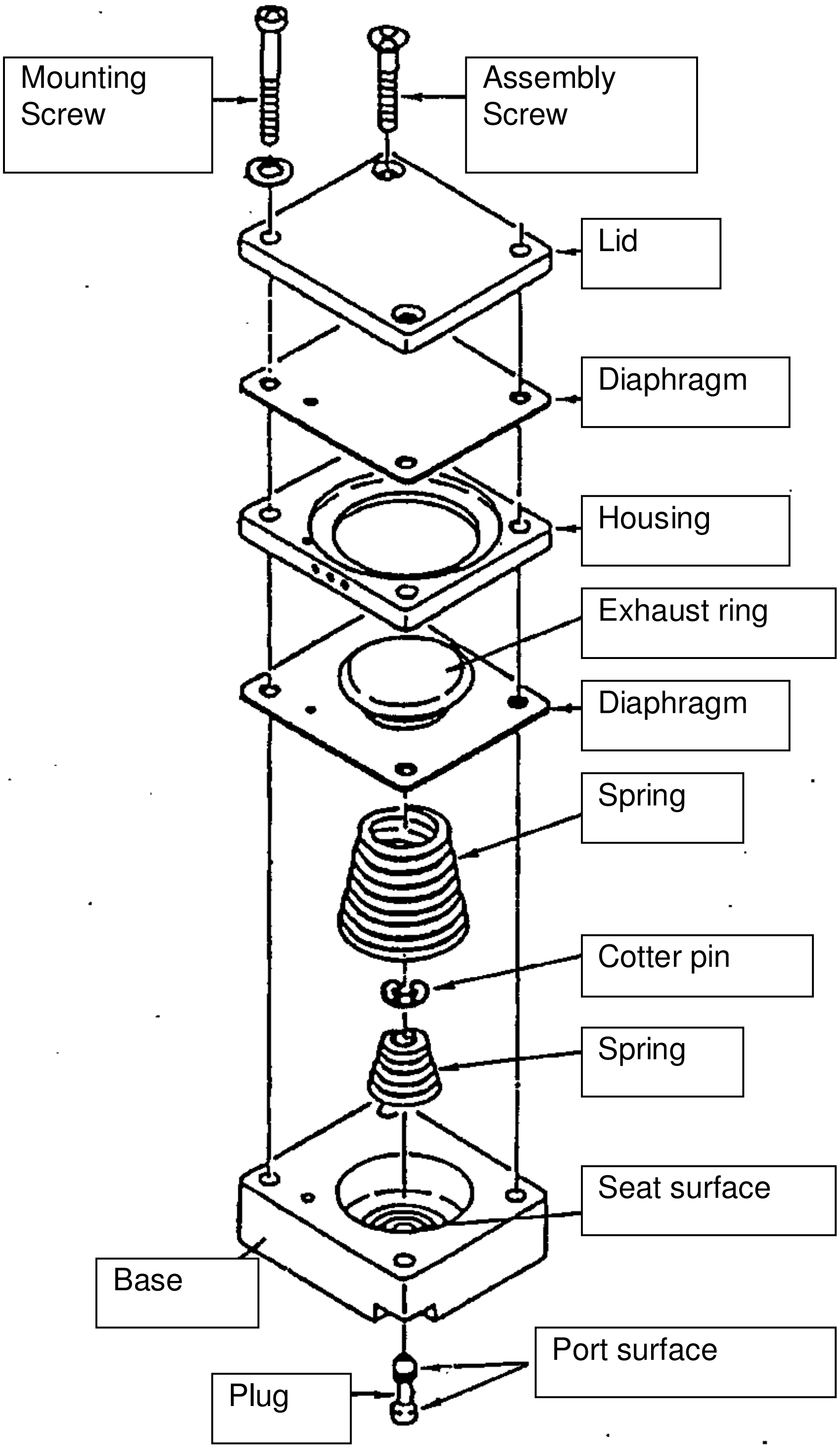


Fig. 8.33 Exploded View of Pilot relay

8.2 Maintenance:

8.2.1 Safety device test:

Method 1: To send a signal to the safety shutdown devices from level transmitter, DPT, by varying the actual water level in the steam drum actually.
(This is the image when the class surveyer requests ship's crew to demonstrate how safety devices work during the anchoring before drydock.)

(a) Confirmation of the Function of DPT

The procedure of the function test is as follows;
i) Vary the level in the boiler.
ii) Generate the alarm signal and the shut down signal from DPT to the safety devices.
iii) Activate the alarm and the shut down devices actually.
iv) Check and confirm the function of safety devices when and how the alarm and the devices are activated, depending on the actual water level signal.

(b) Confirmation of the Function for DIGITAL INDICATING CONTROLLER

The procedure of the function test is as follows;
i) Vary the level in the boiler
ii) Generate the alarm signal and the shut down signal from DPT to the DIGITAL INDICATING CONTROLLER.
iii) Activate the alarm and the shut down devices actually.
iv) Check and confirm the function of EVENT on the DIGITAL INDICATING CONTROLLER when and how the alarm and the devices are activated, depending on the actual water level signal.

Method 2: To send a signal to the safety shutdown devices from level transmitter, DPT, by generating only dummy signal from SFC, with Constant current source mode on SFC.
(This is the image when the ship's crew carries out and confirms the periodical safety device test on board, every 3 or 6 months in accordance with a instruction from ship management company.)

(a) Confirmation of the Function of DPT

i) Change the mode of the automatic feed water control system from automatic control to manual control.
ii) Connect the current signal on the electrical circuit loop on DPT
And, then check and confirm the condition by the digital multi-meter whether the electric current signal on the electrical circuit loop meets the percentage which corresponds with the actual level.
Refer pictures shown in Fig. 8.34(a)/(b) to confirm connecting methods between DPT and the digital multi-meter.
Before measurement of electrical current, be sure that you set the function switch from OFF position to mA positon on the digital multi-meter. Otherwise the digital multi-meter will be damaged before the measurement.

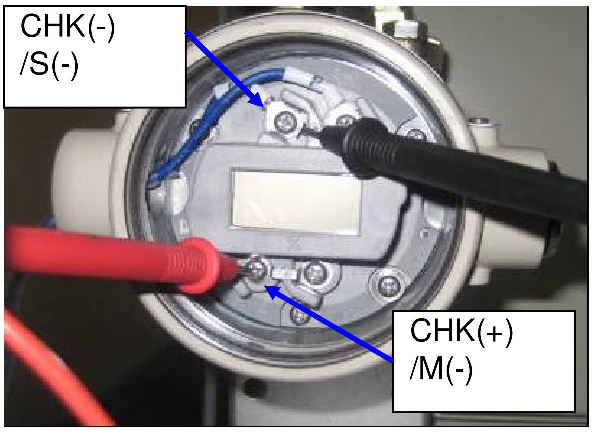


Fig. 8.34 (a) Picture of connection between DPT and the digital multi-meter

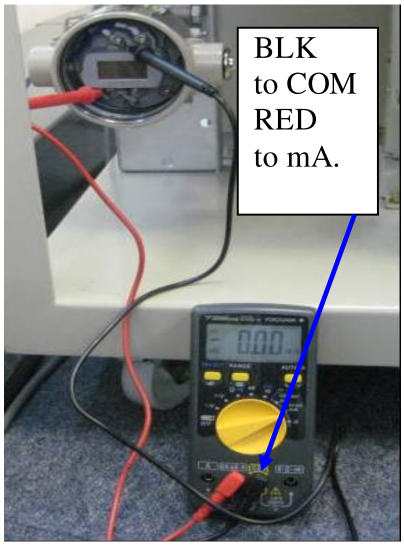


Fig. 8.34(b) Picture of connection between DPT and the digital multi-meter

iii)
1) Connect SFC to DPT.
2) Supply the signal electrical current, which corresponds the alarm point and shut down point, to electrical circuit loop by using the function of constant current source mode on SFC.
3) Activate the alarm and shut down
4) Confirm whether the alarm and shut down work properly.
5) During examining, confirm whether a current signal meets the constant current from SFC by Digital multi-meter.
iv) After testing, release current source mode.
v) Disconnect the digital multi-meter from DPT.
vi) Set the mode of the automatic feed water control system from manual control back to automatic control.

(b) Confirmation of the Function of DIGITAL INDICATING CONTROLLER
This is only the confirmation of Event function for DIGITAL INDICATING CONTROLLER.
i) Change the mode of the automatic feed water control system from automatic control to manual control.
ii) Connect the current signal on the electrical circuit loop on DPT
And, then check and confirm the condition by the digital multi-meter whether the current signal on the electrical circuit loop meets the percentage which corresponds the actual level.
iii)
1) Connect SFC to DPT.

2) Supply the signal electrical current, which corresponds the alarm point and shut down point, to electrical circuit loop by using the function of constant current source mode on SFC.
3) Activate the alarm and shut down on EVENT the DIGITAL INDICATING CONTROLLER (DIC).
4) Confirm whether the alarm and shut down work properly on EVENT of DIC.
5) During testing, confirm whether a current signal meets the constant current from SFC by Digital multi-meter.
iv) After testing, release current source mode.
v) Disconnect the digital multi-meter from DPT.
vi) Set the mode of the automatic feed water control system from manual control back to automatic control.

8.2.2 Sample of safety devices test:
1. Drum water level low
Alarm: Input 25%(-150mm fairly) of signals by using Generating constant current mode of smart field communicator.
Trip: Input 11.6%(-230mm fairly) of signals by using Generating constant current mode of smart field communicator. And confirm that boiler stops firing.
Reset: Generating constant current mode is canceled and input the ignition signal in # 1 BNR. Confirm that furnace purge operates and all air register damper open on the machine side. After that confirm that # 1 BNR ignites and the ignition sequence goes on.
2. Drum water level high （See Instruction of smart field communicator EB-73）
Alarm: Input 75% (+150mm fairly) of signals by using Generating constant current mode of smart field communicator.
Emergency shut of feed water: Input 88.4% (+230mm fairly) of signals by using Generating constant current mode of smart field communicator. And confirm the shut down of feed water motor valve on the machine side.
Reset: Generating constant current mode is canceled. And open the feed water motor valve on the machine side.

8.2.3 Check point when trouble occurred:
1) Procedure to find out a cause of trouble
When you have trouble with controller, we recommend following procedure in order to minimize time and cost by recovering it in short time.
(a) You must understand and grab the whole system first.
(b) Search where you don’t receive right signal and diagnosis the condition on the control system.
When searching, try to start attacking the cause either from upper stream or from lower stream. If you try to find in the middle, you will be confused.
(c) Inform the maintenance company of your diagnosis through your Ship management company.
(d) Then you can get good information from the maintenance company.

2) Imaging a whole system with control devices

Before we consider a cause of trouble, we have to image a whole system with control devices in advance.

(a) Case 1 for pneumatic control system

i) A piping shown in Fig.8.35 (a) is one example to control water level by a Level Control Valve.

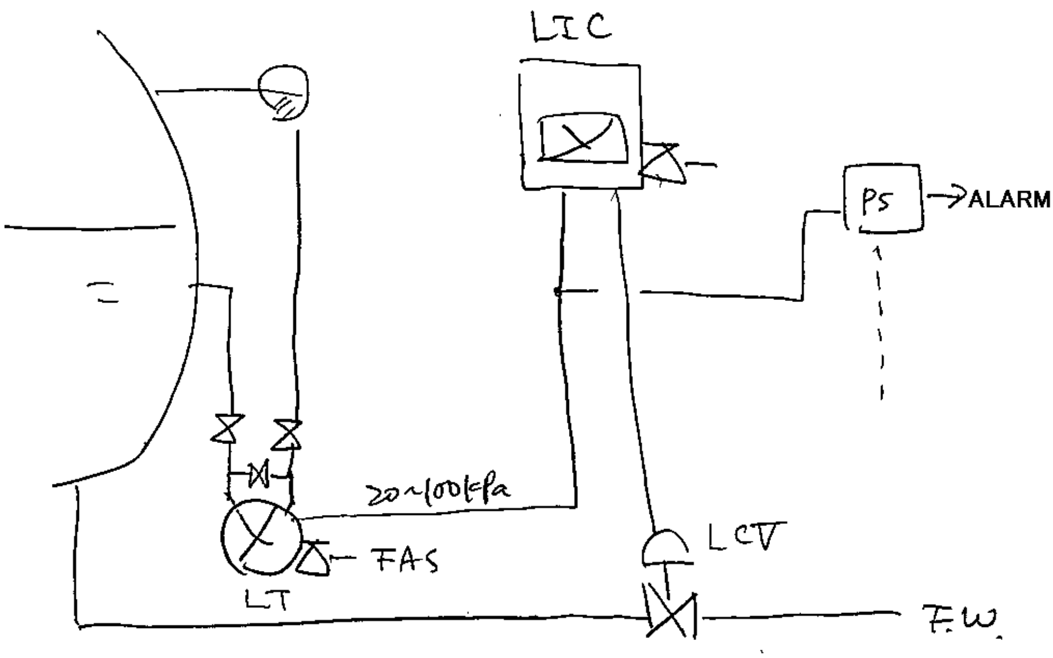


Fig. 8.35 (a) Piping of Feed Water Control system with Pneumatic controller

ii) A block diagram shown in Fig. 8.35 (b) is one example to control water level by a Level Control Valve related to above mentioned system.

Signal flow chart for Pneumatic Control System

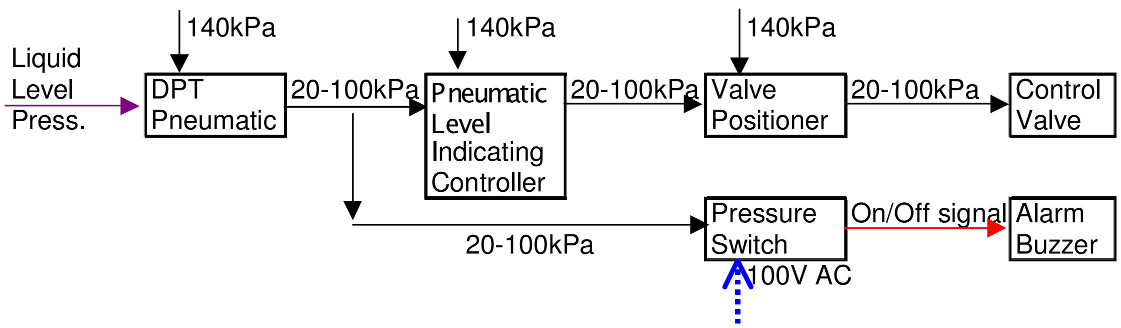


Fig. 8.35 (b) Block diagram of Feed Water Control system with Pneumatic controller

(b) Case 2 for pneumatic control system

i) A piping shown in Fig. 8.35 (c) is one example to control water level by a Pump Control.

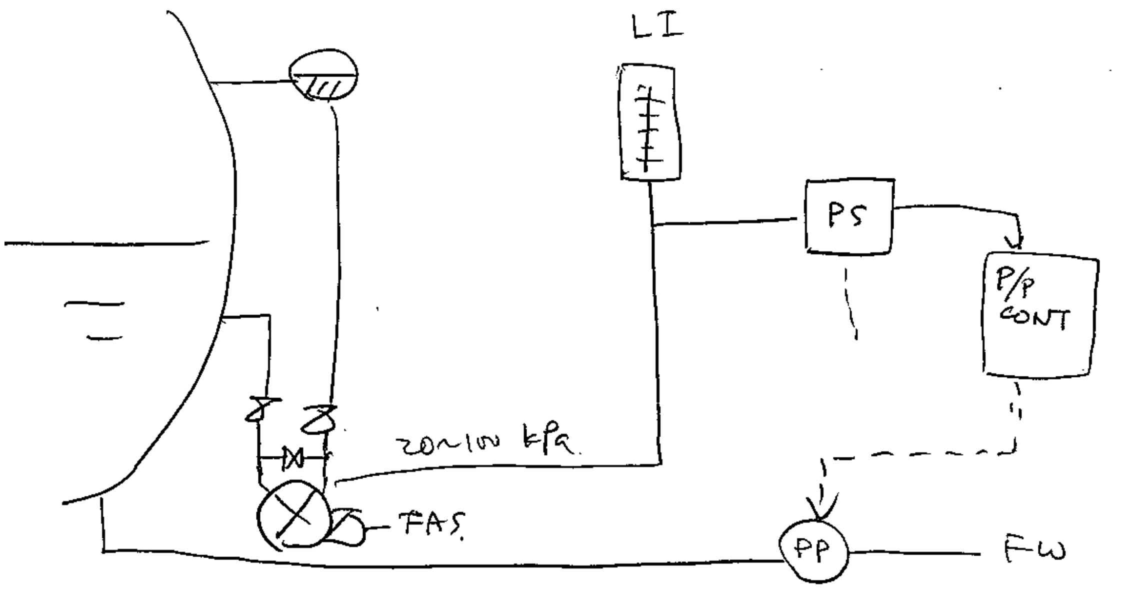


Fig.8.35 (c) Piping of Feed Water Control system with Pneumatic controller

ii) A block diagram shown in Fig. 8.35 (d) is one example to control water level by a Pump Control to above mentioned system. .

Signal flow chart for Pneumatic Control System

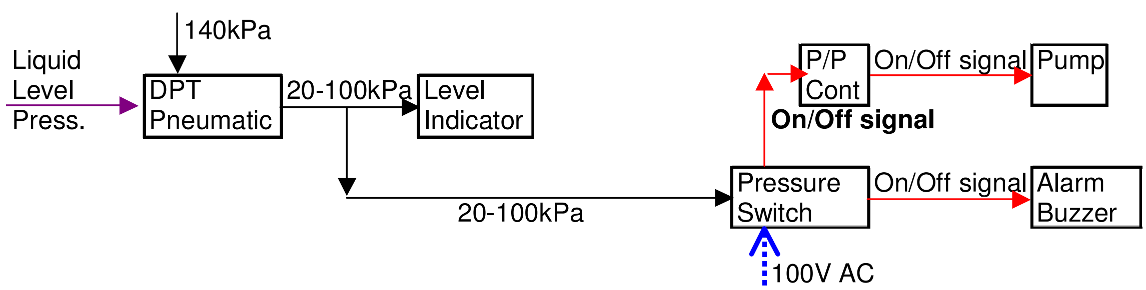


Fig. 8.35 (d) Block diagram of Feed Water Control system with Pneumatic controller

(c) Case 1 for electrical control system

i) A piping shown in Fig. 8.36 (a) is one example to control water level by a Level Control Valve.

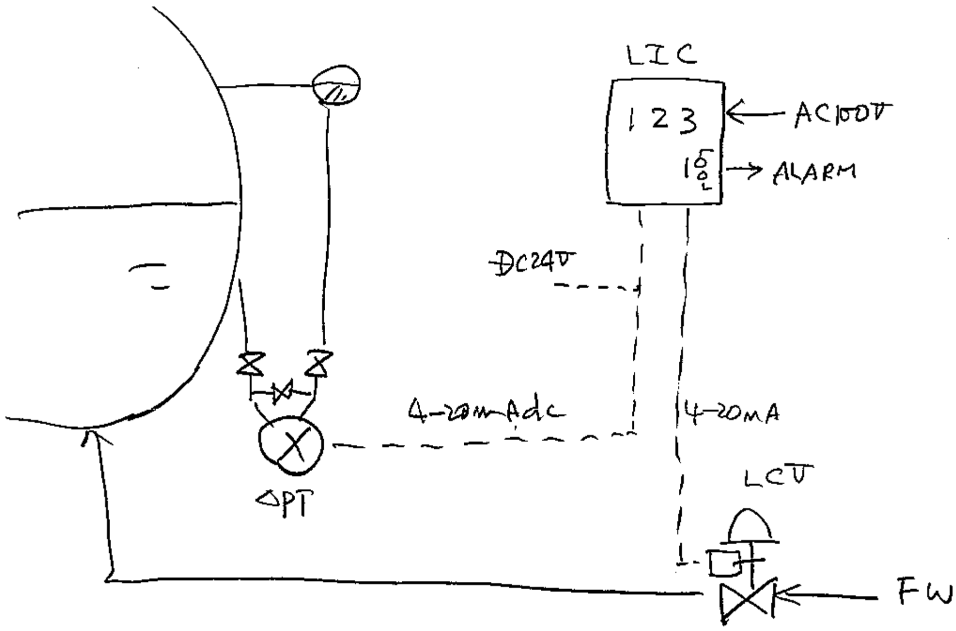


Fig. 8.36 (a) Piping of Feed Water Control system with Electrical controller

ii) A block diagram shown in Fig. 8.36 (b) is one example to control water level by a Level Control Valve related to above mentioned system.

Signal flow chart for Electric Control System

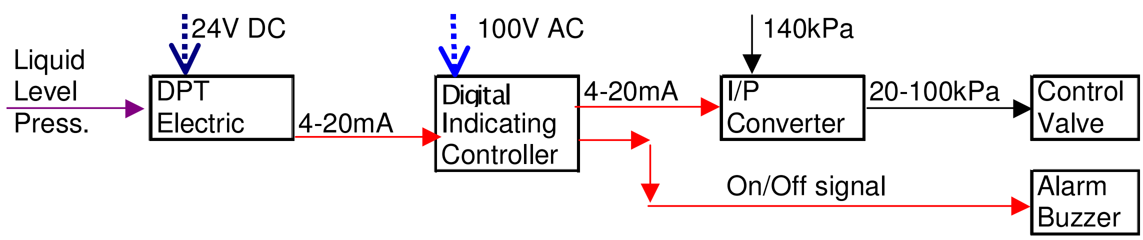


Fig. 8.36 (b) Block diagram of Feed Water Control system with Electrical controller

(d) Case 2 for electrical control system

i) A piping shown in Fig.8.36 (c) is one example to control water level by a Pump Control.

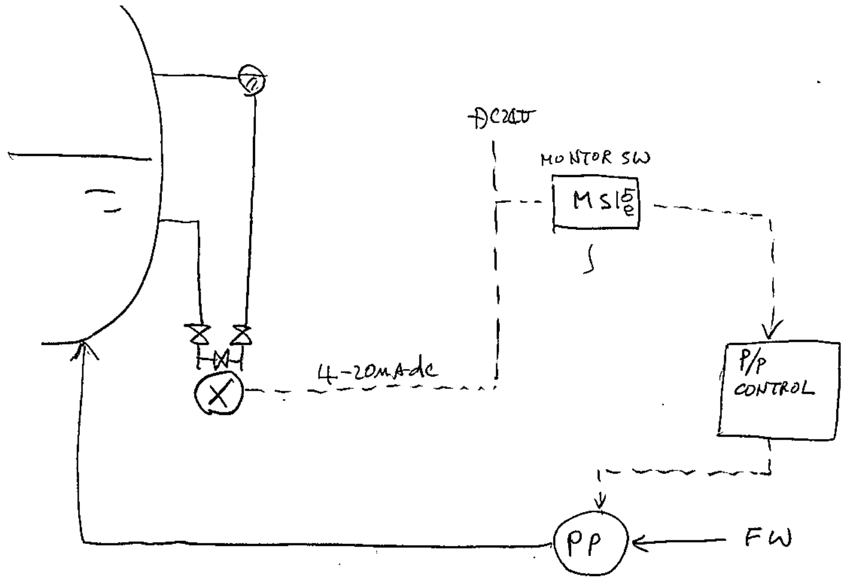


Fig. 8.36 (c) Piping of Feed Water Control system with Electrical controller

ii) A block diagram shown in Fig. 8.36 (d) is one example to control water level by a Pump Control related to above mentioned system.

Signal flow chart for Electric Control System

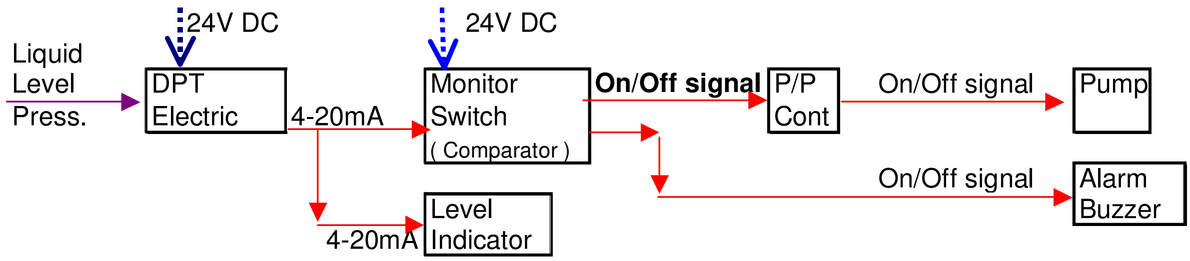


Fig. 8.36 (d) Block diagram of Feed Water Control system with Electrical controller

(e) Check point

i) Check point for Control valve

Control method	Procedure for checking
Pneumatic	1) Supply big deviation between P V* and S P*. Generate Output signal with more than 100kPa. 2) Operate the air pressure regulator, then generate output signal of 0%, 50%, and 100%. 3) Confirm if the activation of control valve corresponds to the output signal.
Electric	1) Operate the digital indicating controller in Manual mode, then generate output signal with 0%, 50%, and 100%. 2) Confirm if the activation of control valve corresponds to the output signal.

Remarks;
* P V =Process Variable. S P = Set point

ii) Check point for Pressure Switch

In case the DPT is normal, as follows;
1) Vary output signal.
2) Confirm if the activation of pressure switch corresponds to setting value.

iii) Check point for Level Control Indicator (LCI)

Control method	Procedure for checking
Pneumatic	<Abnormal of PV indication> 1) Incase of No indication at all -> The cause is the bellows, which receives input signal, is broken. 2) In case that there is some indication error, -> The cause is the there is some amounts of error on Zero point or Span range. The counter measure is to adjust the Zero point and Span range. <Hunting> 1) In case of poor balancing -> The counter measure is to trim balancing adjustment again. 2) In case of poor tuning -> The counter measure is to tune P.I.D. for better tuning again. P= Proportional, I= Integral, D=Derivative <Output error on LCI> 1) -> The counter measure is to disassemble, check, and clean inside of pilot relay.

	2) -> The counter measure is to disassemble, check, and clean inside of filter & restrictions. <Output error on air pressure regulator> 1) -> The counter measure is to disassemble, check, and clean inside of air pressure regulator.
Electric	<Abnormal of Control> The counter measure is as follows; 1) To check input electric power supply. 2) To renew the LCI (however, after renewing the LCI, it is necessary to configure the setup items data.)

iv) Check point for Deferential Pressure Transmitter (DPT)

1) Clean the piping between tank and DPT.
Generally the piping between tank and DPT is often arranged as shown in Fig. 8.37 below.

Even if the drain valve is opened, the scale, rust, and mud can't be discharged.
In order to discharge such dirt, open the drain plugs under DPT after closing the manifold valves.
When blowing the pipe, the mounted valves on the tank or boiler must be closed in order to ensure the safety operation for maintenance work in advance.
And the working fluid inside of DPT is silicon oil. The endurance temperature of silicon oil is below 125°C. So please don't blow the pipe by steam directly.

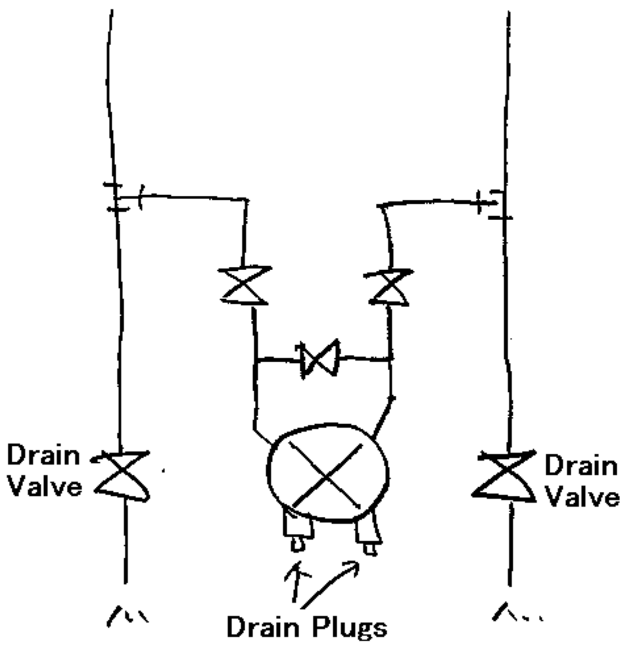


Fig. 8.37 piping between tank and DPT

2) Check after cleaning the piping

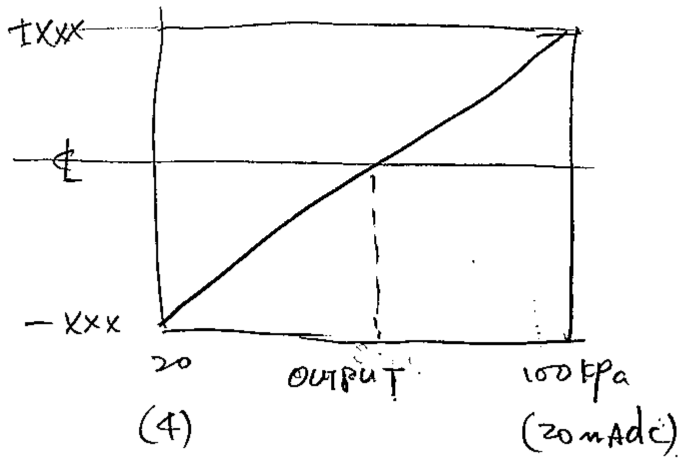


Fig. 8.38 Piping between tank and DPT.

The target of check after cleaning the piping is as follows;
・Confirm if the output from DPT corresponds to the level variable when up and down.
・Confirm if the output from DPT is proportional to the level variable when up and down.

<Confirmation method>
The confirmation method is to compare between the actual level variable and indication or process variable pointer on LCI.

<Remedial action>
In case of poor functioning,

- Dismantle the DPT from piping.
- The counter measure for pneumatic type is to disassemble, check, and clean inside of pilot relay and nozzle

<Reference 1>
Ohm's Law:

Ohm's Law deals with the relationship between voltage and current in an ideal conductor. This relationship states that:

The potential difference (voltage) across an ideal conductor is proportional to the current through it.

The constant of proportionality is called the "resistance", R.

Ohm's Law is given by:

E(V) = I(A) x R(Ω)

where E in volts (V) is the potential difference between two points which include a resistance R in ohms(Ω).

I in amperes (A) is the current flowing through the resistance.

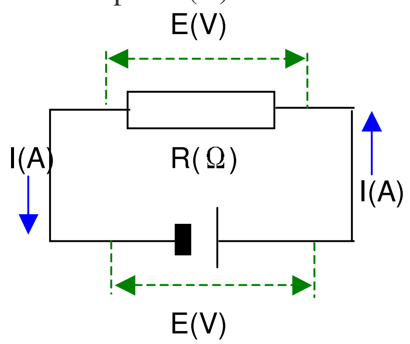


Diagram of electrical circuit

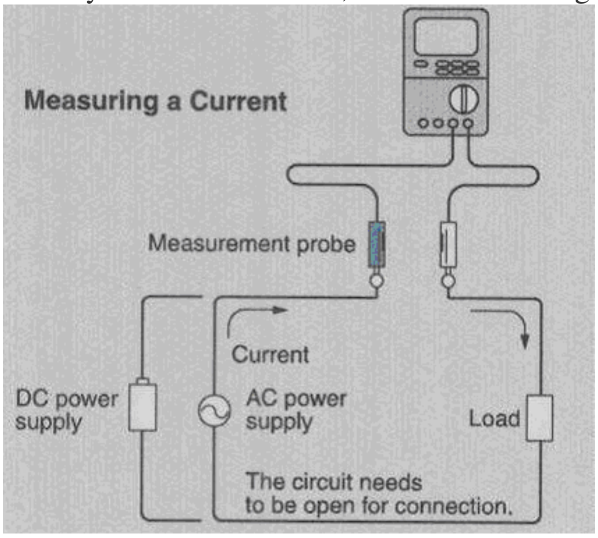
<Reference 2-a>

How do you measure electrical current and voltage by Digital multi-meter?

1. Current measurement

a) Connection

When you measure current, connect the testing lead to target in series.



b) Measurement

1) Set the function switch from OFF position to mA positon

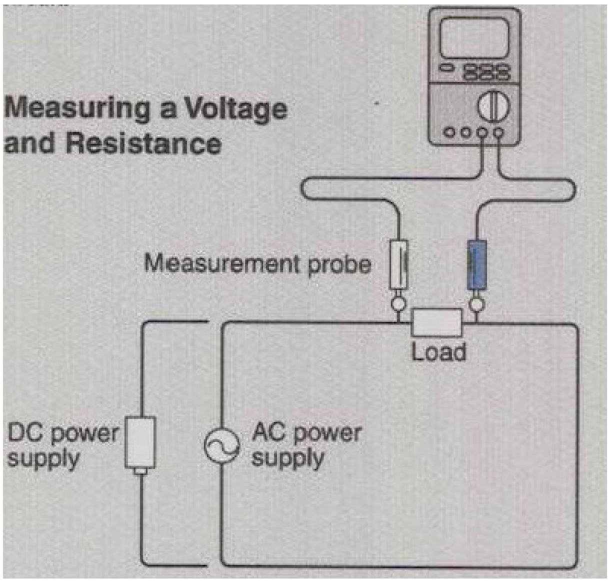
2) Plug the black testing lead in to the COM input terminal and the red testing lead in to the mA input terminal.

3) Connect the testing leads to the circuit under testing and then read the multimeter when it stabilizes.

4) When measurement is completed, disconnect the testing leads from the circuit.

5) After that set the function switch back to the OFF position and turn off the multimeter.

<Reference 2-b>
How do you measure electrical current and voltage by Digital multi-meter?
2. Voltage measurement
a) Connection
When you measure current, connect the testing lead to target in parallel.



b) Measurement
1) Set the function switch from OFF position to V position.
2) Plug the black testing lead in to the COM input terminal and the red testing lead in to the V input terminal.
3) Connect the testing leads to the circuit under testing and then read the multimeter when it stabilizes.
4) When measurement is completed, disconnect the testing leads from the circuit.
5) After that set the function switch back to the OFF position and turn off the multimeter.

<Reference3>

Linear, Square root, and Dropout (low flow cut off) for DPT configuration

(1) Linear

When the level is detect by DPT, a differential pressure between Low pressure and High pressure on DPT is proportion to the level variable.

So, when you configure a level transmitter with a differential pressure type, be sure to configure “linear”.

(2) Square root

The most popular flow meter for industrial use is a head flow meter which has orifices, nozzles or venturi tubes as a sensing element. This flow meter consists of "throttle device" to be inserted in the pipeline to produce differential pressure. In most cases, the differential pressure is converted into standard air pressure (20~100kPa) or electric current (4~20mADC) by a differential pressure transmitter.

When we insert the throttling mechanism by orifice into a pipe, we can use the principle which is the pressure difference before orifice and after orifice is proportion to the flow rate squared in accordance with Bernoulli's theorem.

$Q=K\sqrt{(P1-P2)}$

Q: flow rate

P_H: pressure before orifice

P_L: pressure after orifice

K: flow coefficient determined by the diameter of pipe and fluid density

So, when you configure a flow transmitter with differential pressure type, be sure to configure “square root”.

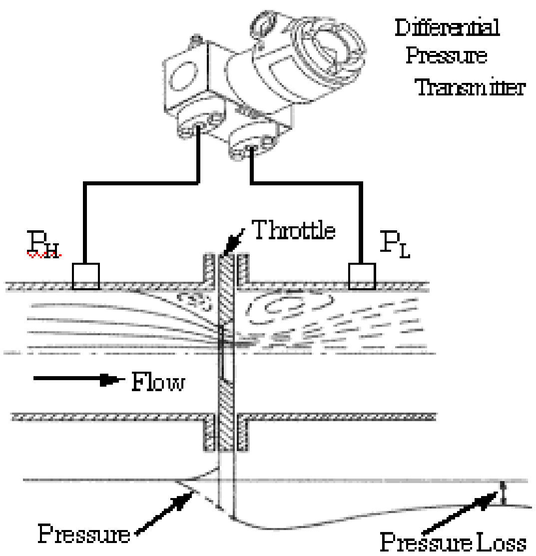
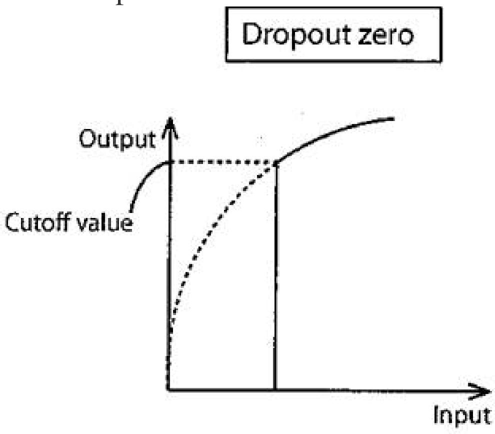


Fig. 8.39 Principle of Flow Measurement by Applying Throttle

(3) Dropout (low flow cut off)

When you measure a flow rate with differential pressure type, if we have a big pressure difference between before orifice and after orifice, we can detect the flow rate accurately. But if we have a small pressure difference between before orifice and after orifice, we hardly can detect the precise flow rate in the lower value.



From a point view of Control engineering, an input range below 20% is unreliable.
By this Dropout (low flow cut off) function, you can cut off value of a lower input signal.
So, normally we drop out the input range below 15 ～ 20% from measurement.

<Reference 4>

NK class regulation for level detection

(1)NK class rule for the survey and Construction of steel ships

Chapter 18 Automatic and Remote control

18.4.3 Automatic Feed Water Control Devices

1 Automatic feed water control devices are to be capable of controlling automatically the feed water in order to maintain the water level in the boilers in a predetermined range.

2 Main boilers are to be provided with not less than three water level detectors used for a feed water control device, a remote water level indicator, a low-water level safety device and a low-water level alarm device.

(2)NK class rule for Automatic and Remote control system

Chapter 3 Centralised monitoring and control system for machinery

3.3.3 Boilers

1 Safety devices

Safety devices are to comply with the following **(1)** and **(2)**.

(1) A self-closing valve is to be provided in the feed water piping of the main boiler, and is to operate automatically in the event of abnormal rise of the water level in the main boiler.

(2) Safety devices for low water level in the main boilers are to be put into action by means of a signal from either one of the two low water level detectors which are independent each other, however, one of which may be used for other purposes.