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Exam: **MEASURING SYSTEMS AND DATA ACQUISITION**

Report Format /05	
Executive Summary /05	
Introduction Content /05	
Technical Content /30	
Graphs, tables and animation /20	
Arduino Code /20	
Conclusion/Recommendations – Content and Logic /05	
Proper use of References /10	
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1 Level Measurement

In this Section, we are going to talk about the different types of level sensors used in the industry.

1.1 Executive Summary

We will talk about several types of level sensors with a theory of operation for each and some applications. Each sensor may measure more than the level but we will have the concept that leads to have the level measurement correctly where they may use pressure, sound, waves, buoyancy rules. As it's very important to know the product that we will sense it's level and type of feedback that the application required to have an efficient control loop.

1.2 Introduction

To control the level of fluid in the container 2 methods can be used. The first method is the Point level measurement method it gives either 1 or 0 where the tank is empty it will give a signal to start filling as sensor gives 0 and when the tank is filled the sensor will give 1 so the process will stop. The second method is the Continuous level measurement method where you can have the desired level of water any time as you can accurately know the level. and this will help to have a better control loop as shown in Figure 1 to have good control of the industrial process.

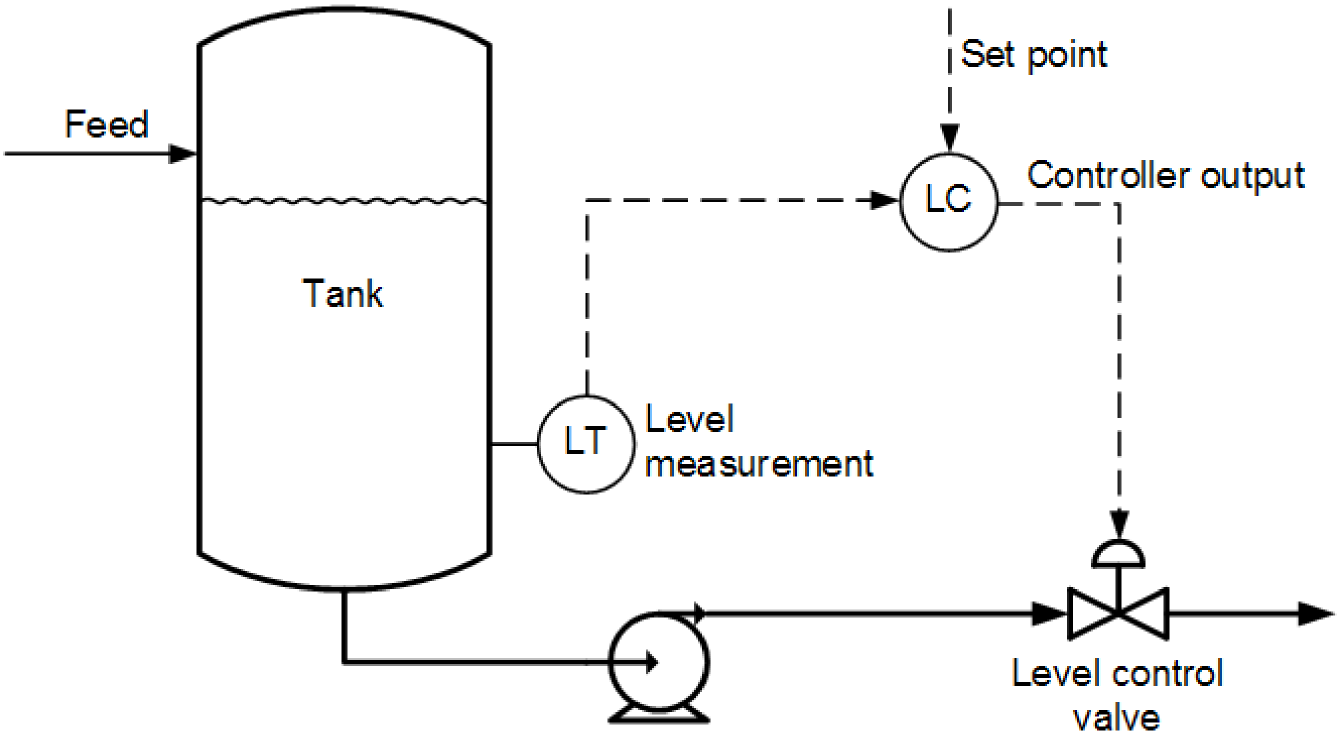


Figure 1: Level Sensor in control loop

1.3 Types of measurements

Using Level sensors in level measurement is classified into two main types Each Type use different method each use specific sensor where each sensor may be used in more than 1 way and shown in Figure 2 the two types with some examples at each

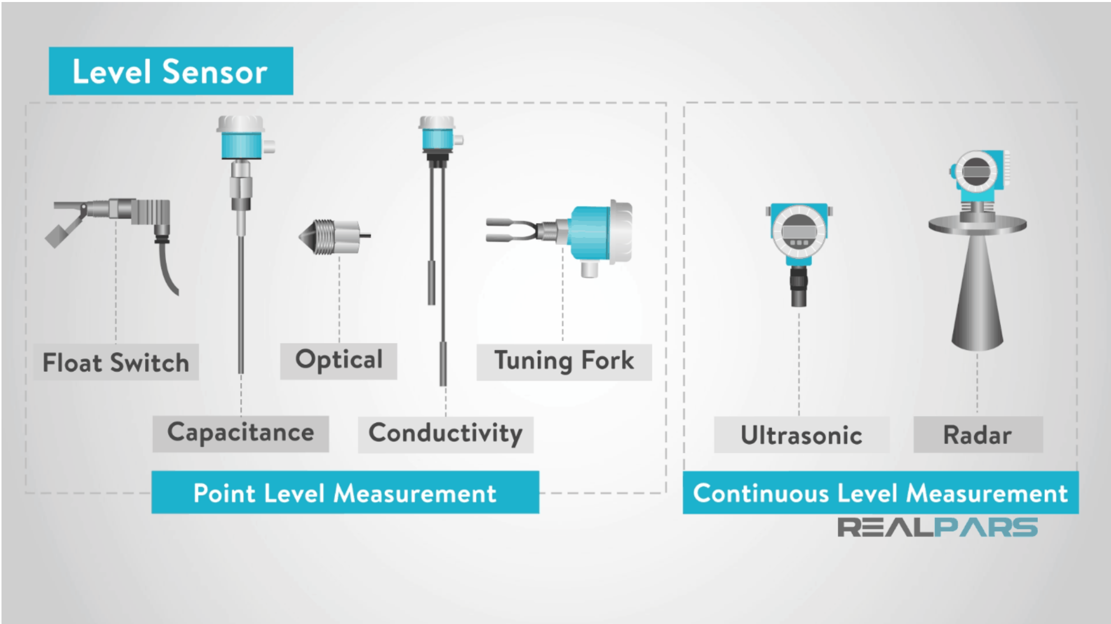


Figure 2: Classifications of Level Sensors

1.3.1 Continuous level measurement

In this type, we can get the signal to detect the level and compare it with the desired point to achieve. then we will have an output of analog signal 4 and 20 mA where is signal have a direct relation with the level. Where it's programmed to convert into information that represent values used to show the level as (Height, Weight, Pressure, Distance, Percentage).

We could achieve this with many methods:

- Ultra Sonic sensor
  Ultrasonic level sensors working as they send a wave of sound to the level surface and receive it back where this wave will reflect and measure the time between sending and receiving that sound wave as shown in Figure 3. where (distance = speed * time) and we already know the speed of sound as constant so the distance will be easily calculated from the sensor place to the level. knowing the full height of the tank so remove the difference to real height easily.

(a) Send Wave (b) Wave Return (c) Measured Time

Figure 3: Ultra-Sonic Sensor

- Pulse Radar (microwave)
  This sensor is like the ultrasonic sensor in the method of measurement but it sends microwaves by an antenna on the radar sensor and this wave will be reflecting and return to the sensor and time between sending and receiving the waves is estimated as shown in Figure 4. there are 2 examples of radar gauges with different frequencies where the higher the transmission frequency the easier the detection of dry, non-conductive materials, and those examples are the 5.8GHz and 24GHz systems.

(a) Send Wave (b) Wave Return (c) Measured Time

Figure 4: Radar Sensor

- Differential Pressure Sensor

  Using hydro-static pressure measurements will measure the level of container that has an atmospheric pressure (Top is exposed) but the liquid level inside a pressurized tank will be measured by differential pressure transducer as in this case the measured pressure is that of the above the liquid and the pressure above the liquid also. so a low pressure is input to the D/P transmitter connected to the top of the tank as shown in figure 5 to measure that vapor space pressure so the differential pressure transducer will subtract those values to get the reading which represents the hydro-static head which will later be converted to level height of the container.

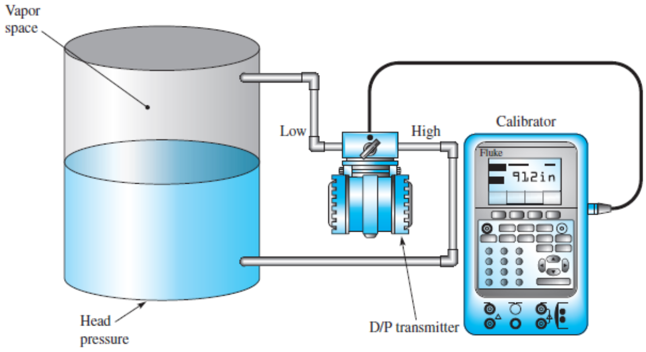


Figure 5: Differential Pressure sensor

- Simple Sight Glasses

  The sight glass, shown in Figure 6, by getting holes to the side of the vessel then connect a tube with tank height to it so this tube will have the same fluid at it with the same height. This method will enable users to see the vessel level any time and locate any change in level visually. This method will be used when other methods can as if we have hot or corrosive fluid so the other method will have many errors. This method also suffers from obscure for the visual quality as foam formed to the fluid.

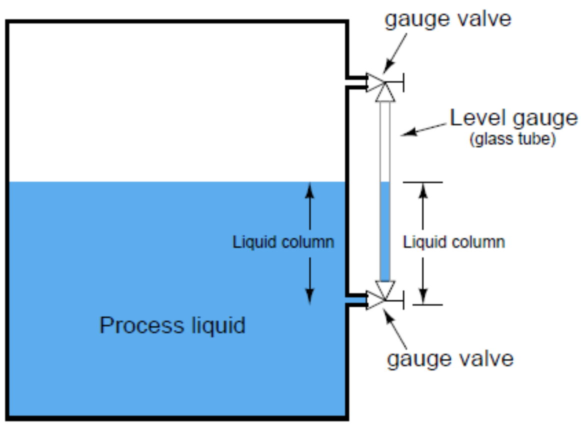


Figure 6: Simple Sight Glass attached to container

- Float-Type Level Indicator

  Using a spherical floating element that will be let to float on the surface of the liquid to detect the fluid level as shown in figure 7 where we can make this a method for a point (as will be discussed later) or continuous measurement.

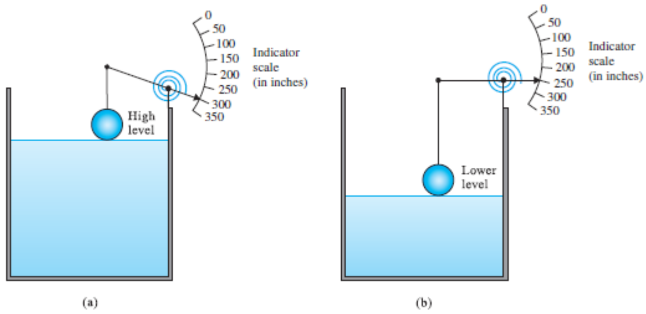


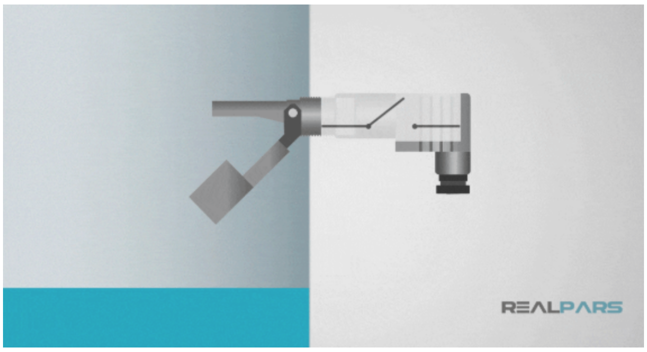
Figure 7: Float-type level indicator

1.3.2 Point level measurement

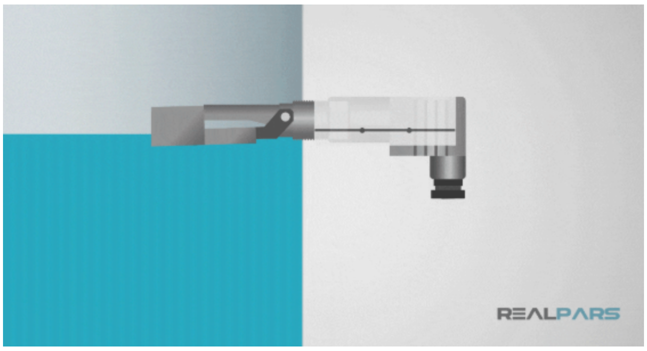
Here the sensor only detects the presence of the fluid in their level. As these sensors provide a high or low signal depends on the fluid level and more than one sensor is needed to know the high and low limits of the tank and if it's required more level to be known so more sensors must be added.

- Float Switch

  This simply a switch that is will change it's position as the level of the fluid changed around it and it is mechanically connected to another circuit where it will an electrical switch state as level changes as shown in Figure 8



(a) Open Circuit



(b) Closed Circuit

Figure 8: Float Point Sensing

- Conductive level sensor

  This is a cheap and simple sensor where it's just an electrode merged in a tank with the open terminal as shown in Figure 9 which connected to an electrical signal and sending a continuous current and when the fluid reaches its level the terminals will be closed by the fluid and fluid will conduct this current so signal is sent

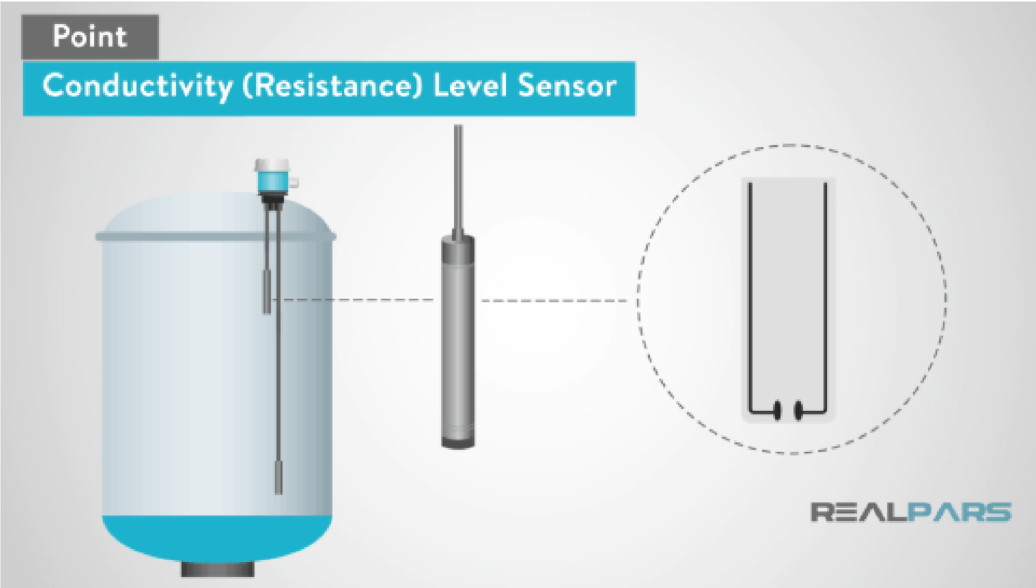
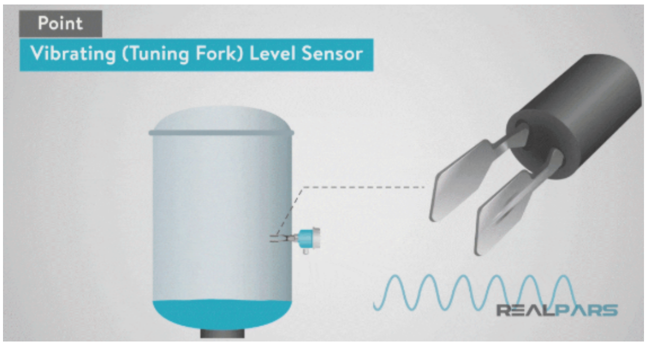


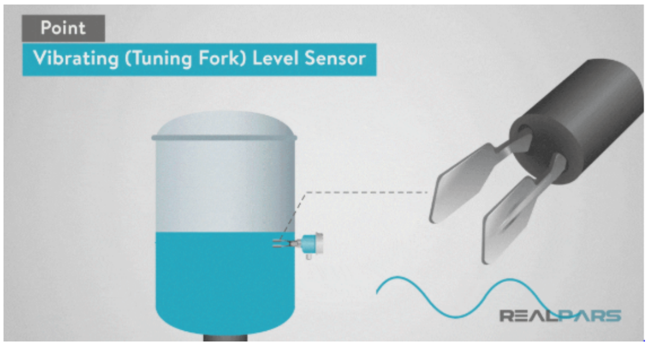
Figure 9: Conductive level sensor

- Vibrating (Tuning Fork) Level sensor

  To have the vibration effect a fork shape element is placed in a take where it has 2 main frequencies the first is it's natural frequency and second it's frequency in damping fluid as shown in Figure 10 so as we measure this vibration we could detect if the tank level reaches the fork or still lower.



(a) Low Level



(b) Reached the desired level

Figure 10: Tuning Fork Sensing

1.4 Typical Applications

- Oil Manufacturing Plants Splash
- Water Treatment
- Paper and Pulp Production Divisions
- Petrochemical and Chemical Making Refinery Units
- Waste Material Handling Industry
- Beverage and Food Manufacturing Factories
- Pharmaceutical Processes
- Power Generating Plants

1.5 Installation Consideration

When the tank isn't pressurized it would be easy to remove the sensor from the tank and those sensors will have less chance to have a leak in their internal components. and they can be gauged manually to have 2 advantages that we can still have a measurement even when the equipment fails and it will be easily calibrated But if the tank is pressurized we will suffer from removing and installing the sensors as it will be needed to remove all these pressure first and the used equipment needed to be chosen according to its ability to handle this pressure and the sensor fixation need to be done properly as the pressure head may change it's position so give an error in reading and presence of foam and vapor may affect the performance.

and it's recommended to read the selection tables well before choose the sensors and this is an example for selection tables shown in Figure 11

Table 4: Orientation Table for Selecting Level Sensors

TDR = Time Domain Reflectometry; PDS = Phase Difference Sensors; AS = in % of actual span; E = Excellent; FS = in % of full scale; F = Fair; G = Good; L = Limited; P = Poor; UL = Unlimited

				APPLICATIONS								
				LIQUIDS					SOLIDS			
TYPE	MAX. TEMP. (°F)	AVAILABLE AS NONCONTACT	INACCURACY (1 in. = 25.4 mm)	CLEAN	VISCOUS	SLURRY/SLUDGE	INTERFACE	FOAM	POWDER	CHUNKY	STICKY	LIMITATIONS
Air Bubblers	UL		1-2% FS	G	F	P	F					Introduces foreign substance into process; high maintenance
Capacitance	2,000		1-2% FS	G	F-G	F	G-L	P	F	F	P	Interface between conductive layers and detection of foam is a problem
Conductivity Switch	1,800		1/8 in	F	P	F	L	L	L	L	L	Can detect interface only between conductive and nonconductive liquids. Field effect design for solids
Diaphragm	350		0.5% FS	G	F	F			F	F	P	Switches only for solid service
Differential Pressure	1,200		0.1% AS	E	G-E	G	P					Only extended diaphragm seals or repeaters can eliminate plugging. Purging and sealing legs are also used
Displacer	850		0.5% FS	E	P	P	F-G					Not recommended for sludge or slurry service
Float	500		1% FS	G	P	P	F					Moving parts limit most designs to clean service. Only preset density floats can follow interfaces
Laser	UL	X	0.5 in	L	G	G		F	F	F	F	Limited to cloudy liquids or bright solids in tanks with transparent vapor spaces
Level Gages	700		0.25 in	G	F	P	F					Glass is not allowed in some processes
Microwave Switches	400	X	0.5 in	G	G	F	G		G	G	F	Thick coating is a limitation
Optical Switches	260	X	0.25 in	G	F	E	F-G	F	F	P	F	Refraction-type for clean liquids only; reflection-type requires clean vapor space
Radar	450	X	0.12 in	G	G	F	P		P	F	P	Interference from coating, agitator blades, spray, or excessive turbulence
Radiation	UL	X	0.25 in	G	E	E	G	F	G	E	E	Requires NRC license
Resistance Tape	225		0.5 in	G	G	G						Limited to liquids under near-atmospheric pressure and temperature conditions
Rotating Paddle Switch	500		1 in						G	F	P	Limited to detection of dry, non-corrosive, low-pressure solids
Slip Tubes	200		0.5 in	F	P	P						An unsafe manual device
Tape-Type Level Sensors	300		0.1 in	E	F	P	G		G	F	F	Only the inductively coupled float is suited for interface measurement. Float hangup is a potential problem with most designs
Thermal	850		0.5 in	G	F	F	P	F				Foam and interface detection is limited by the thermal conductives involved
TDR/PDS	221		3 in	F	F	F			G	G	F	Limited performance on sticky process materials
Ultrasonic	300	X	1% FS	F-G	G	G	F-G	F	F	F	G	Presence of dust, foam, dew in vapor space; sloping or fluffy process material interferes with performance
Vibrating Switches	300		0.2 in	F	G	G	F		F	G	G	Excessive material buildup can prevent operation

Figure 11: level sensor selection table

1.6 Impact On Over All Control Loop

The level sensors are fast in their response and don't add lag to the control system as they provide a continuous reading to the tank state. But it's better to use more that one sensor with different sensing methods and have limit switches for the high and low limits as if one of the sensors goes out of calibration then we have a back and process continuous and to provide a safety element to the system.

1.7 Manufacturers

Those sensors are used in many field so many companies are now providing them and those are some of the leading companies that provides level sensors with most of it's types and find there websites :

- Sierra Instruments
- Mercury Displacement Industries, Inc.
- United Electric Control
- Fluid Components International LLC
- Proteus Company for Smart Sensors

1.8 Arduino Code/Simulation

For the simulation I used ultra-sonic sensor where it's the sensor that need to programmed and can be simulate unlike the float type which will be just a switch.

In Figure 12 , 13 Find the proteus simulation for ultra-sonic sensor where the distance is simulated as variable resistance

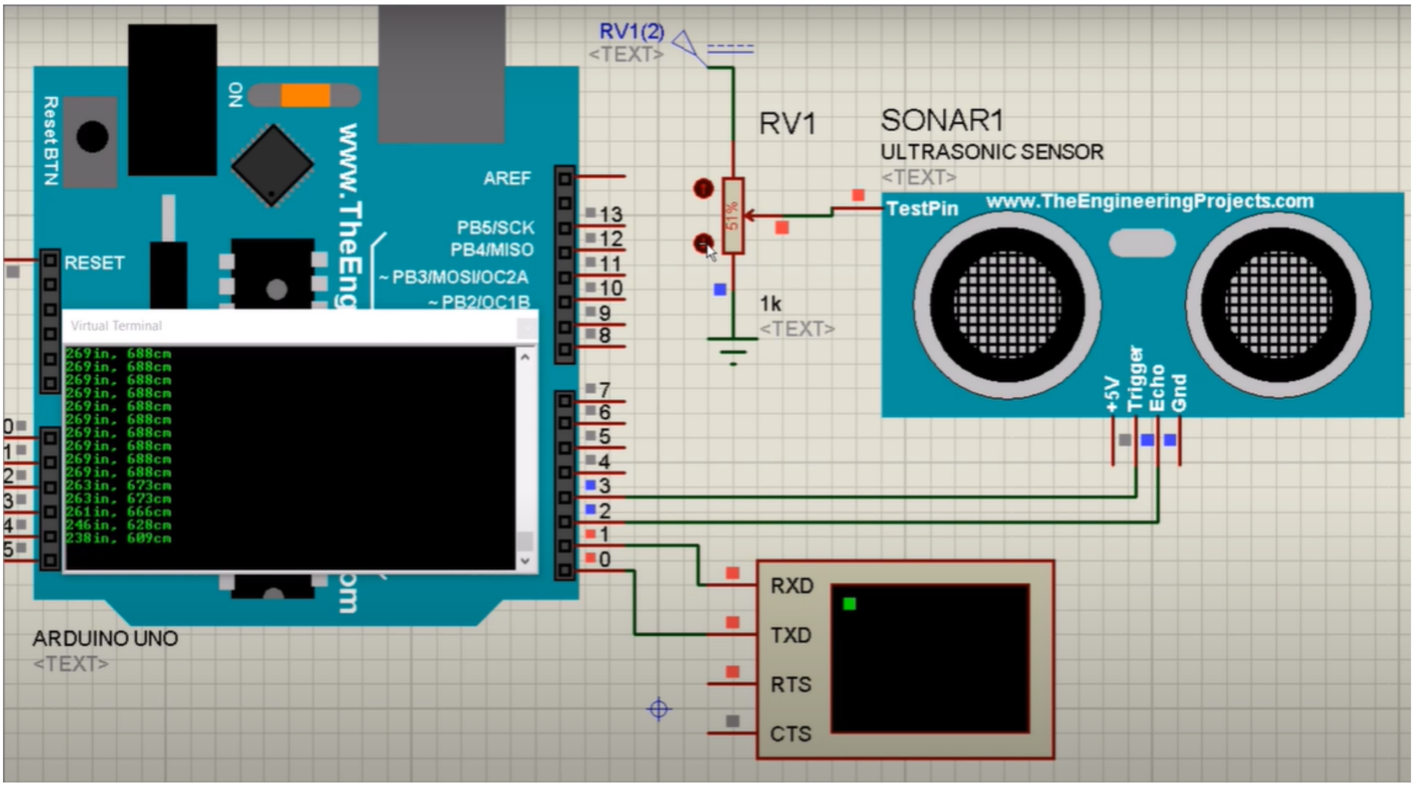


Figure 12: Proteus Simulation for Ultra-Sonic Sensor Measurement 1

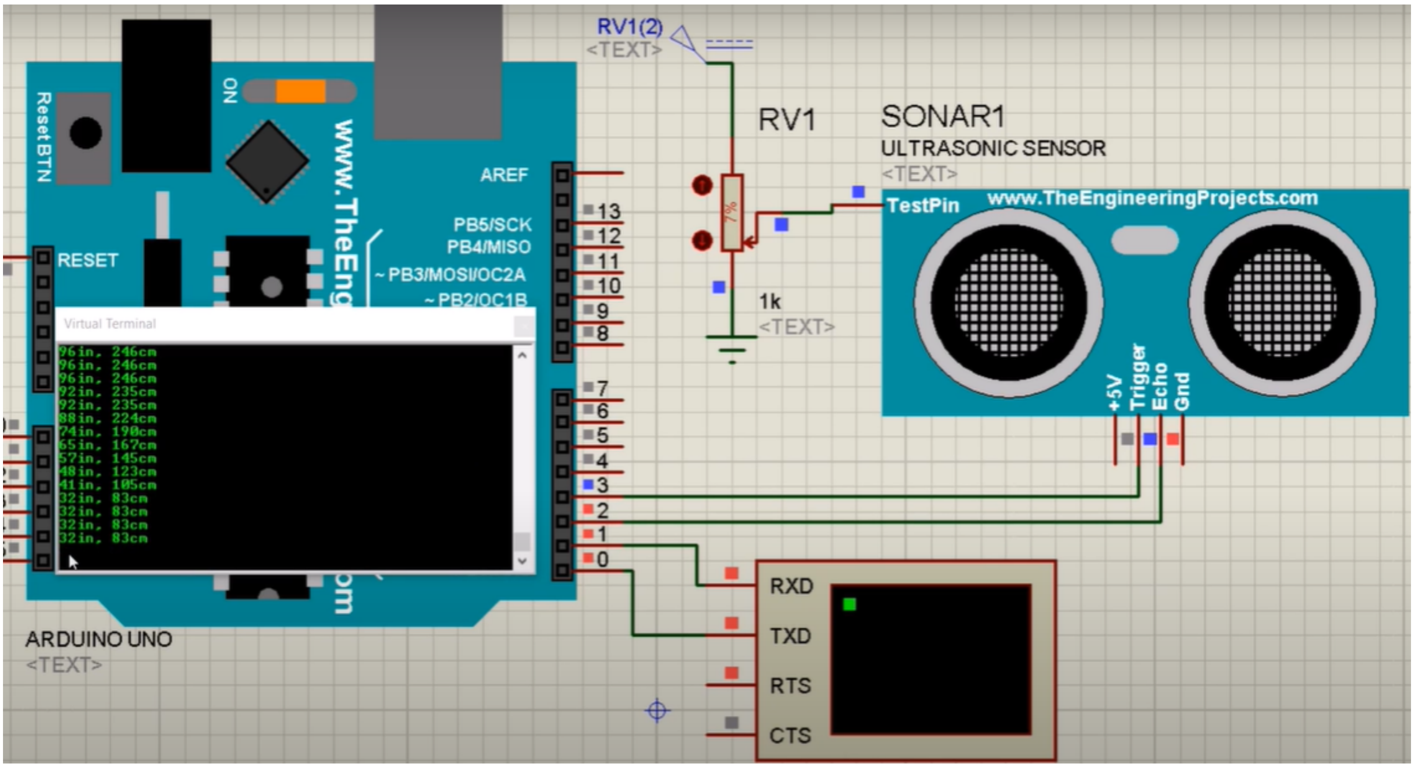


Figure 13: Proteus Simulation for Ultra-Sonic Sensor Measurement 2

In Figure 14 Find the arduino code used

```
const int echoPin = 2;
const int pingPin = 3;
void setup()
{ Serial.begin(9600);
  pinMode(pingPin, OUTPUT); pinMode(echoPin, INPUT); }
void loop()
{ long duration, inches, cm;
  digitalWrite(pingPin, LOW);
  delayMicroseconds(2);
  digitalWrite(pingPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(pingPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  cm = microsecondsToCentimeters(duration);
  Serial.print(inches);
  Serial.print("in, ");
  Serial.print(cm);
  Serial.print("cm");
  Serial.println();
  delay(100);}
long microsecondsToInches(long microseconds)
{return microseconds / 74 / 2;}
long microsecondsToCentimeters(long microseconds)
{return microseconds / 29 / 2;}
```

Figure 14: Arduino Code For Ultra-Sonic sensor

1.9 Conclusion/Recommendation

We will conclude from the previous that level measurement could be done in many methods each is used in its application and the continuous development for level sensors show its importance and they already used in many fields with various ways and couldn't replace and as a pro for them that they have a very positive impact to the control loop as a whole where they have a very small delay to there job.

But it is always recommended to use those sensors after carefully study the vessel cases where they will easily have wrong readings due to wrong calibration or wrong application and maybe those sensors install and remove is easier than many sensors but it still costly.

2 Flow Measurement

In this Section, we are going to talk about the different types of Flow meters.

2.1 Executive Summary

To measure the flow in a pipe it's needed to know well the fluid behavior and start to use the available knowledge in all fields to measure it.
Now the flow could be measured by many methods as generating waves(ultrasonic - magnetic), vibration, change in pipe area, and measuring the pressure.
As the flow measurement has many applications to be used in so many companies start to focus them having for use now a very professional sensors that helps a lot in many industrial fields.
It's important to always know the environment of the sensor in order not to run out of the calibration and gives error leads to financial loss. and having flow meters in control loop need to have more care and try to increase the number of meters if possible and better it use different concept as now we have many methods to ensure a better measure.

2.2 Introduction

There are many types of flow meters available for use in industrial automation. Depending on the product to be measured, whether it be liquid or gas, some basic principles apply to how the meters work.

2.3 Types of measurements

There is 3 main ways to measure the flow by:

- Mass Flow
- Velocity
- Volumetric flow

Where volumetric flow is generally for gases flow and liquid as the are in compressible so mass flow is used and the velocity alone can give a flow quantity flow without knowing the area of the pipe. And the following are some of the methods of measuring with there basic concepts.

2.3.1 Thermal Flow Meter

Thermal flowmeters are contained of 2 electrodes one as a reference to measure the temperature of the fluid and the other to heated by passing an electric current through as shown in Figure 15 and as fluid flows the heated electro start to lose heat energy which will be later compensated by more electrical current flow so that will increase current reading as it calibrating the velocity of fluid could be determined using the heat transfer rules and by knowing the cross-section of pipe the amount of flowing substance could be determined

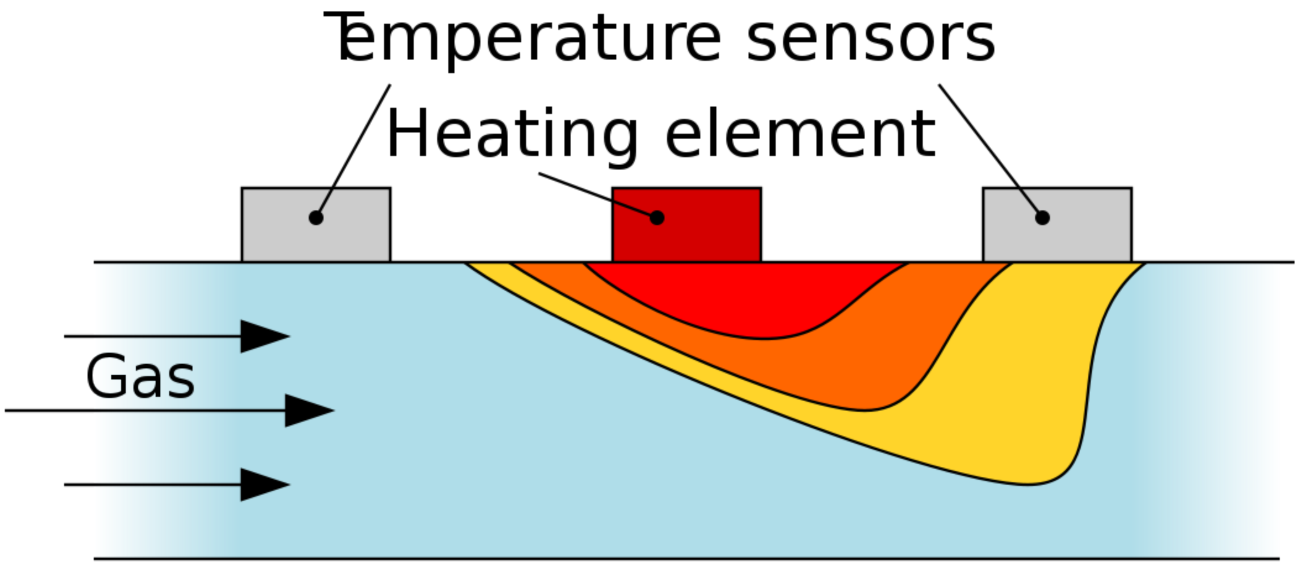


Figure 15: Thermal Flow Meter with heat contours

This meter is good for any cross-section pipe and most of the liquids except that affected by heat

2.3.2 Differential Pressure/Variable Area Flow meters

Installing Orifice between pipes with a smaller area so the fluid will pass through will have a change in velocity as shown in Figure 16 and also may use ventri cross section for less losses and more accuracy therefore a pressure drop before and after it and measuring this difference in pressure and using the fluid mechanics rules to have relation between the pressure difference and the fluid speed so the flow rate is determined.

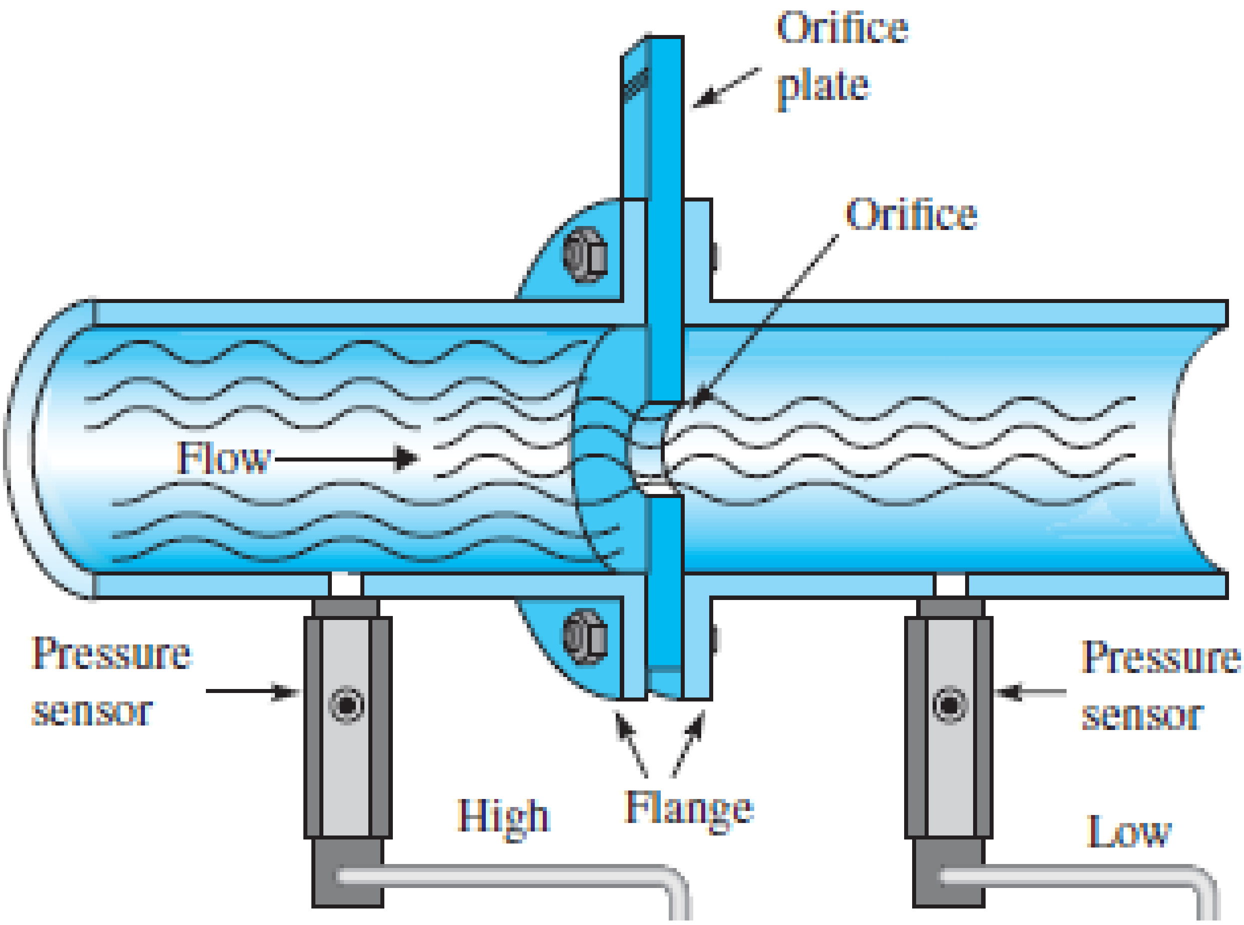


Figure 16: Orifice Flow Meter

2.3.3 Magnetic Flow meters

This meter need to have a conducting fluid in the pipe where magnetic flow meters use Faraday's Law of Electromagnetic Induction to determine the flow of liquid in a pipe. As a magnetic field is generated and channeled into the liquid flowing through the pipe and a volt is generated due to that flow interfere with the magnetic field as shown in figure 17 this volt is directly proportional with speed of the conducting fluid in the pipe hence the speed is determined so the flow rate is calculated.

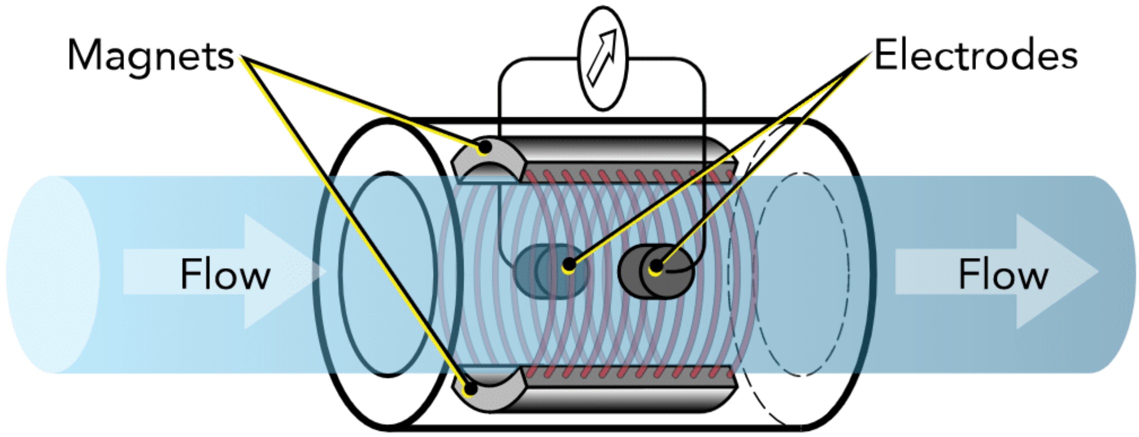


Figure 17: Magnetic Flow Meter

2.4 Typical Applications

- Compressed air measurement
- Gas mixing and blending applications
- Burner control
- Liquid measurement
- Steam flow measurement
- Natural gas pumping

2.5 Installation Consideration

Placing of the sensor is very important and it's needed to maintain the fluid level in the pipe. May the circumstances lead us to not to take the level of fluid into account, anyway this the expensive alternative but we can add the loss in pressure to the lower section of pipe which has the flow meter installed as shown in Figure 18 at so the fluid pools in that area.

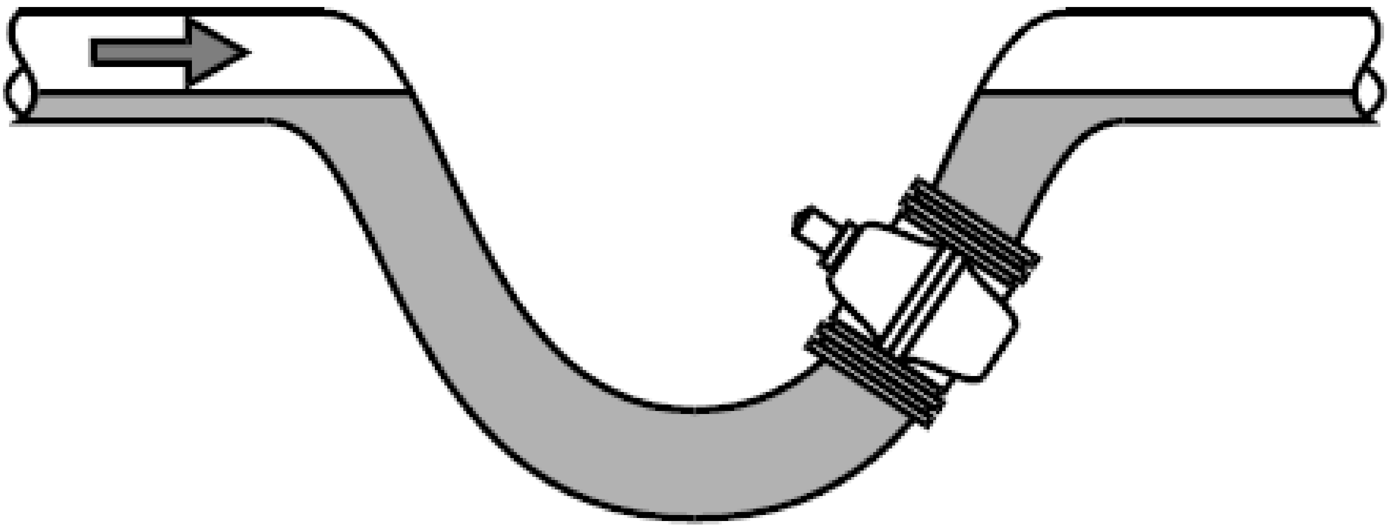


Figure 18: flow meter installed and remains full

It's recommended to read the selection tables well before choose the sensors and always compare with more than one table to insure your need this is an example for selection tables shown in Figure 19 , 20.

Technology / Attribute	Category	Turndown Ratio	Fluid Types	Accuracy	Pipe Sizes	Max Temp	Max Press	Press Drop	Straight Run Req'd
Variable Area	Rotameter	10:1	Gas, Liquid Clean	Low	Sm-Med	Low-High	Med-High	Med	None
Orifice	DP Flow Element	4:1 better w/ multivariable	Gas, Liq, Steam	Low	Med-Lg	High	High	High	Yes
Pitot	DP Flow Element	4:1	Gas, Liquid Clean	Low	Med-Lg	High	High	Low	Yes
Magmeter	Velocity	30:1	Conductive Liquids	High	Med-Lg	Med	High	None	Yes
Paddlewheel / Propeller	Velocity	10:1	Clean Liquid	Med	Med-Lg	Low	Low	Med	Yes
Turbine	Velocity	10:1	Gas, Liquid Clean	Med-High	Sm-Lg	High	High	Med	Yes
Ultrasonic	Velocity	50:1	Gas, Liquid,	Med-High	Med-Lg	High	High	None	Yes
Vortex	Velocity	25:1	Gas, Liquid, Steam	Med-High	Med-Lg	Med	Med	Med-High	Yes
Oval Gear Positive Displacement	Volumetric	10:1	Liquid Clean	High	Sm-Lg	Med	Med	Med	None
Thermal Mass	Mass	50:1 - 100:1	Gas Clean	Med	Sm-Lg	Low	High	Low	Yes
Coriolis	Mass	20:1 – 80:1	Gas, Liquid	High	Sm-Lg	Med	High	High	Yes

Figure 19: flow sensor selection table 1

Flowmeter Technology	Accuracy (±)	Range - ability	Fluids	Pipe sizes (in.)	Max press (PSIG)	Tempe-rature range (°F)	Rel. Press. loss
Inferential Meters							
Orifice & DP xmtr	1-5%F	4:1	L,G,S	≥2	6000	≤1000	H
Integral orifice assembly	1-2%F	4:1	L,G,S	0.5-1.5	3000	-40-300	H
Variable area-purge	5-10%F	10:1	L,G	0.125-1.5	200	0-250	M
Variable area-glass tube	1-2%F	10:1	L,G	0.25-2	500	0-250	M
Variable area-metal tube	2-10%F	10:1	L,G	0.5-6	6000	≤1000	M
Velocity Meters							
Electromagnetic	0.25%-1%R	30:1	L	0.15-60	5000	≤350	L
Vortex	0.5%-1.25%R	20:1	L,G,S	1-8	1500	-150-800	M
Turbine	0.15-0.5%R	10:1	L	0.5-30	6000	-450-	M
Propeller	2%R	15:1	L	2-12	230	6000	M
Vane	2.5%R	10:1	L	1	5000	0-300	M
						≤180	
Mass Meters							
Coriolis	0.15%R	80:1	L,G,S	0.25-3	1450	-400-400	L
	0.2%R	20:1	L,G,S	0.06-6	5700	-400-400	M
	0.2%R	20:1	L,G,S	0.5-1.5	900	32-800	M
	0.2%R	20:1	L,G,S	0.25-2	1500	-400-400	M
Thermal	1%F	50:1	G	0.125-8	4500	32-150	L
	0.5%F	50:1	L	0.06-0.25	4500	40-165	L
Volumetric Meters							
BiRotor PD	0.15-0.5%R	10:1	L	1.5-16	1440	-20-450	M
Oval Gear PD	0.25-0.5%R	10:1	L	0.25-4	300	-40-600	M
Nutating disc	2.0%R	10:1	L	1.25	2000	32-200	H
Oscillating piston	0.5%R	5:1	L	0.5-2	400	≤300	H

Figure 20: flow sensor selection table 2

2.6 Impact On Over All Control Loop

There are two main Problems at low flow rates:

2.6.1 The minimum flow

As flow meter is designed we had is consider the maximum allowable flow rate that will flow through but unfortunately, some times the flows decrease too much even to less allowable minimum flow that sensor can sense so to increase the range of the sensor (Turndown ration: maximum flow / minimum flow)) a parallel pipe is used in it so if the flow is low use a single pipe and when the flow increase start to use others so the reading accuracy won't affect.

2.6.2 The increased error

Each sensor has it's own error but the problem occurs with the differential pressure measurement as the error depends on the span and to have high turndown ratios we need to check the accuracy and its components which are:

- Static pressure effect
- Reference accuracy
- Ambient temperature effect
- Time drift each could be reduce by different method for example the temperature effect error could be reduced by having suitable operating environment.

2.7 Manufacturers

Those sensors are used in many field so many companies are now providing them and those are some of the leading companies with there websites that provides those sensors:

- Sierra Instruments
- HydraCheck
- Endress Hauser AG
- SeaMetrics, Inc.
- Spirax Sacro, Inc.
- FTI Meters

2.8 Arduino Code/Proteus Simulation

This is a code for the flow meter available for study shown in Figure 21

```
volatile int flow_frequency; float vol = 0.0,l_minute;
unsigned char flowsensor = 2; unsigned long currentTime;unsigned long cloopTime;
#include <LiquidCrystal.h>
LiquidCrystal lcd(12, 11, 5, 4, 3, 9);
void flow () {flow_frequency++;}
void setup(){pinMode(flowsensor, INPUT);
   digitalWrite(flowsensor, HIGH);Serial.begin(9600); lcd.begin(16, 2);
   attachInterrupt(digitalPinToInterrupt(flowsensor), flow, RISING);
   lcd.clear(); lcd.setCursor(0,0); lcd.print("Water Flow Meter");
   lcd.setCursor(0,1); lcd.print("Circuit Digest");
   currentTime = millis(); cloopTime = currentTime; }
void loop (){currentTime = millis();
   if(currentTime >= (cloopTime + 1000))
   {cloopTime = currentTime;
    if(flow_frequency != 0){l_minute = (flow_frequency / 7.5);
      lcd.clear();lcd.setCursor(0,0);lcd.print("Rate: ");lcd.print(l_minute);
      lcd.print(" L/M");l_minute = l_minute/60;
      lcd.setCursor(0,1); vol = vol +l_minute; lcd.print("Vol:");  lcd.print(vol);
      lcd.print(" L"); flow_frequency = 0;
      Serial.print(l_minute, DEC); Serial.println(" L/Sec");}
      else {Serial.println(" flow rate = 0 ");
      lcd.clear();lcd.setCursor(0,0);lcd.print("Rate: ");
      lcd.print( flow_frequency );lcd.print(" L/M");
      lcd.setCursor(0,1);lcd.print("Vol:");lcd.print(vol);lcd.print(" L");}}}
```

Figure 21: Arduino Code For Flow Meter

In Next video u can find the using of this code on the sensor https://youtu.be/3FCK7l4cMbY as the sensor package for simulation wasn't available.

2.9 Conclusion/Recommendation

Many Types with many concepts to measure the flow some are attached out of the pipe without interfere the flow but those are expensive and more complex while some others with more simpler concept to also measure the flow but will need to connect them to the pipe as shown in Figure 22 and suffer when it's required to replace them as many changes will occur. There is also a basic science behind each type but maybe it's important to be known for better selection but the more important is the operation and calibration of each type and using more the one method for measurement for but precision. It's always recommended to have a continuous maintains for those sensors as contaminations may leads to error and use the sensor within the limits of the flow not less and care about the turndown ratio and its need and its limits.

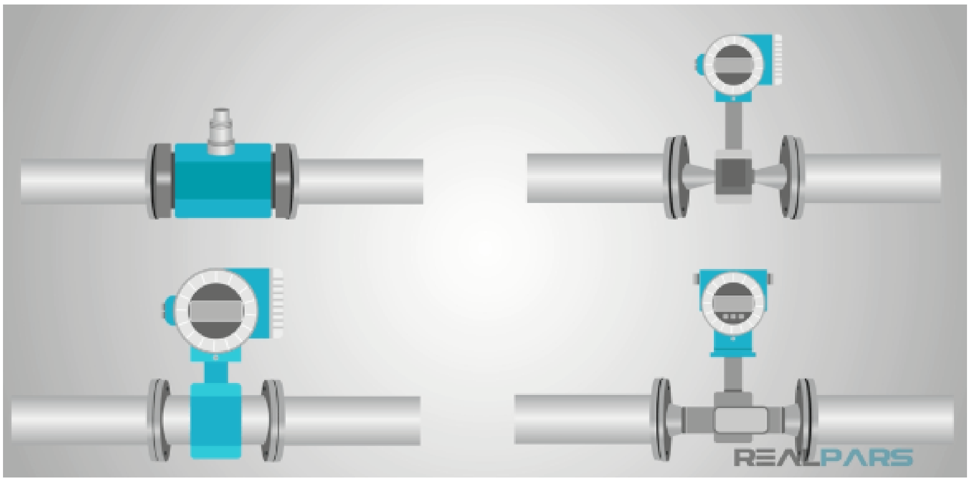


Figure 22: Flow Meter Connected in pipes

3 References

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3. Lessons In Industrial Instrumentation by Tony R. Kuphaldt

4. Sierra instruments company products over view videos

5. Realpars level sensor article

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