VIETNAM NATIONAL UNIVERSITY HO CHI MINH CITY
HCM UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING - MECHATRONICS DEPARTMENT

ME3003

Introduction to Flow Sensors and Datasheet Reading

Submitted To:
Tran Hai Nam
Asst. Professor
Faculty of Mechanical Engineering

Submitted By:
Nguyen Quy Khoi
1852158
CC02
HK201

HCMC, November 30, 2020

Abstract

Data acquisition is one of the crucial steps of designing a mechatronic system. Changes in the environment must be observed for decision making purposes.

Sensors can be seen anywhere such as natural or man-made objects. The natural sensors, like those found in living organisms, usually respond with signals having electrochemical character. In man-made devices, information is also transmitted and process in electrical form. Application for sensors is almost limitless, from simple system such as car door monitoring arrangement to extremely complex one like Mars Exploration Rover – B.

Since the topic about sensors is so vast and technical, designing a complex sensor is beyond the scope of this report. Therefore, in our project, we only focus on flow sensor, and specifically how to make the best of the sensor catalog. This goal includes what parameters are important in choosing the right flow sensor for one's project, expected failure modes during operation and maintenance of the sensor, which makes the report somewhat practical in designing the system as a whole.

Contents

List of Figures

Chapter 1

Characteristics of a sensor

When designing a mechatronic system, sensor is crucial for data acquisition and generating an adequate response. However, if a engineer only relies on the best available sensor, the product price will be higher than necessary, resulting in customers lost to competitive manufacturers. Therefore, this chapter is dedicated to accommodate selecting the right sensor for one's application with common characteristics available on datasheets.

1.1 Mobile Communication Devices

Figure 1.1: Built-in sensors in a typical present-day smartphone

Mobile Communication Devices (MCD) sensors are designed for portability and full integration with other components inside a hand-held device. It is a self-containing sensing module that detects, conditions, digitizes, processes, outputs and communicates information while being small, light, accurate, stable, fast-response, etc. A generic purpose device (e.g. smartphones, tablets, smartwatches) contains dozens of them for different applications and is categorized in 4 areas:

1. **Industrial** for detecting noncontact tempertaure, thermal imaging, humidity, air flow ionizing radiation, smell, diaelectric constant of objects, maerial composition, range (distance), air pressure, produce freshness, etc.

2. **Medical** for the inner (core) and skin body temperatures, thermal imaging, arterial blood pressure, EKG, blood factors (glucose, cholesterol, hemoglobin oxygen saturation), deep body imaging, smell (e-nose), behavior modification, etc.

3. **Military** for night vision, detecting poisonous gases, proximity, ionizing radiation, explosives, chemical and biological agents, etc.

4. **Consumer** for the body core temperature, heart rate, radon gas, pregnancy detection, breathalizer for alcohol and hydrogen sulfide, food composition, behavior modification, proximity, V level, electromagnetic pollution, surface temperature, etc.

1.2 Full-Scale Input/Output

A *span* or an *input full scale* (FS) is a dynamic range of stimuli convertible by a sensor. In a datasheet, it is regarded as the highest possible input value without causing unacceptably large error. For sensors with broad response characteristics, the span is often expressed in decibels, which is a logarithmic measure of ratios of either power or force (voltage).

A *full-scale output* (FSO) for an analog output is the difference between electrical output signals at 2 ends of the input signals. For digital output, it is the maximum digital count the A/D converter can resolve for maximum FS.

1.3 Accuracy

It is defined as *maximum*, or *typical*, or *average* error of the sensor alone. The rating of accuracy is represented in 4 common forms, depending on the application:

1. *Directly in terms of measured value of a stimulus*, which is used when error is independent on the input signal magnitude.

2. *In percentage of FS*, which is useful for a sensor with a linear transfer function and can be thought as an alternative of the approach above. For nonlinear transfer function, the representation may be misleading.

3. *In percentage of the measured signal*, which is useful for a nonlinear transfer function, even with very dynamic inputs. However, the error typically does not proportionally scale with the input magnitude.

4. *In terms of the output signal*, which is useful for sensors with a digital output format.

In reality, a datasheet mixes 2 or more forms and take whichever value is the largest. In this way, the error can be evaluated more accurately.

1.4 Possible types of error

In a datasheet, tolerance and error limit are paramount for any measuring equipment, which the manufacture always dedicates a section for. Distinguishing the types of error is helpful to determine the suitable sensor for designing a mechatronic system. Generally, there are 6 types of error:

Calibration error Calibration error occurs while adjusting a sensor. In dynamic system and control, it is categorized as *disturbance*, which is quantitative data and contributes the systematic error. Another source of errors regarding calibration is a reference sensor. This type of sensor is considered as national standard, which all manufactured sensors rely on. Therefore, for absolute accuracy, the error from "standardized sensors" is considered.

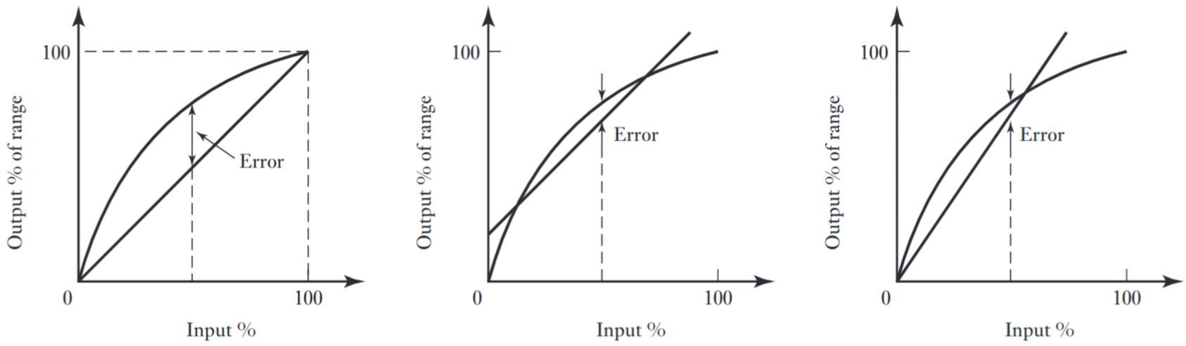


Figure 1.2: Non-linearity error using (from left to right): end-range values; best straight line for all values; best straight line through the zero point [1]

Hysteresis error Hysteresis error is the maximum deviation between output values given the same input signal. For example, if the sensitivity of the sensor is 10 mV/mm, the hysteresis error in terms of displacement units is 2 mm. Possible causes of this faulty result are geometry of design, friction or deformation of material.

Nonlinearity error If the error is assumed to , nonlinearity error will be specified to compensate for any faulty assumptions. It is the maximum deviation of a real transfer function from the approximation straight line. After several calibration runs, the worst linearity result is stated. This type of error is crucial if the output signal requires best accuracy in a small range (e.g. medical thermometer measures body temperature between 36 – 38°C). Oftentimes, manufacturers are inclined to publish the smallest possible nonlinearity error without specifying what approximation method is used.

Saturation error Saturation error occurs when the input signal exceeds the operating limit of a sensor.

Repeatability error Repeatability error causes a sensor to output different values under identical conditions. Possible noises for the error are thermal conductivity, charge, deformation, etc.

Dead band error Dead band error is the insensitivity of a sensor in a specific range of the input signals, which generates output signals between a certain value (often zero).

1.5 Resolution

Digital input-output signals are not continuous as shown in the figures in a datasheet but rather distinguish data points. The distance between 2 consecutive data points is defined as resolution. Depending on manufacturers, the step size may be specified as typical, average, or worst.

1.6 Special output characteristics

Depending on sensor types, specifying input properties might be necessary. For instance, in case of flow sensors, thermal transport sensors require identifying temperature bandwidth to give the accurate response.

Impedance When working with an electronic sensor, the output impedance of the sensor Z_{out} and the input impedance of the connecting system Z_{in} should be acknowledge. A current generating sensor should have high Z_{out} and low Z_{in}. This is the opposite for voltage generating sensor.

Format For mechatronic systems, programming a microcontroller or microprocessor needs the output format of the sensor. The output electrical characteristics may include voltage, current, charge, frequency, amplitude, phase, polarity, shape of a signal, time delay and digital code. These responses can be displayed in formats such as binary, text (ASCII), or digital output, etc. with various forms of communication (e.g. serial link, PWM, I^2C).

Excitation Analogues to a match catching fire with a spark, excitation signal could be included in a datasheet. An exapmle of an excitation signal is electric current passing through a thermistor to measure its temperature-dependent resistance.

Dynamic characteristics Besides from steady input signals, dynamic and time-varying stimuli are also considered. The sensor responses slowly to this input type, which generates dynamic error. At best, the error is a delay. At worst, it causes undesirable oscillations. In such cases, Dynamic Systems and Control course is provided to discuss extensively about this topic.

1.7 Environmental factors

Generally, all possible environmental factors that may affect the sensor performance are specified by manufacturers. In a datasheet, it is typical to include information about the following factors:

1. *Storage condition*, which specifies the highest and lowest storage temperature. It also has maximum relative humidities at these temperatures and may be mentioned as "noncondensing". Along with operating temperature range, this information is *one of the most common environmental factors* available in any datasheet.

2. *Short-term stability* is manifested as changes in the sensor's performance within minutes, hours, or days, which essentially is another way to express bidirectional repeatability.

3. *Long-term stability* is the irreversible change in the material's electrical, mechanical, chemical or thermal properties. Similar to heat treated materials, a sensor can improve its stability by *pre-aging*. For instance, a sensor may be periodically swung from freezing to hot temperatures before being calibrated and installed into a product.

4. *Environmental conditions during normal operation* affects the transfer function of a sensor. An example is a strain gauge whose sensitivity increases with temperature. Even if the manufacture does not specify these conditions in the datasheet, it is the responsibility of an engineer to simulate and prototype the end-product corresponding to the environment.

1.8 Reliability

In statistical terms, reliability is the probability that the device will function without failure over a specified time or a number of uses. Reliability specifies a failure is a temporary or permanent malfunction of a device. Although this is an important property of a sensor, the information is not readily available in most datasheet due to the absence of measuring standards of reliability. Therefore, an engineer should be ready to do the test by any means. Some example testing procedures are MTBF, extreme testing, accelerated life testing, HALT testing, FOAT testing, etc.

1.9 Application characteristics

This information includes geometry and other simple physical specifications such as design, weight, power consumption and overall dimensions. Although price heavily influences a sensor's performance, any amount of cost is justified if reliability and accuracy are of a paramount importance.

1.10 Uncertainty

While error is what we unknowably get when we measure, uncertainty is what we think how large that error might be. No matter how well a sensor is made, there always exists obscure factors. Even if they are recognized, it is impossible to measure exactly (e.g. human factor). Attempts have been made to quantitatively identify them: evaluation through statistical methods, preceding measurement data, personal experience, manufacturer's specifications, uncertainty data referenced from handbooks and manuals, etc.

Chapter 2

Introduction

2.1 Characteristics of a flow sensor

There are 2 types of moving media [2]:

- liquids. *Ex:* water, oil, gasoline.
- air and gas. *Ex:* O_2, N_2, CO_2, CH_4.

Although flow sensors may be simple as detecting velocity of the fluid or air/gas,

2.2 Several examples of flow sensors

2.2.1 Pressure gradient technique

This technique is applicable only for measuring **steady flow of nonviscous, incompressible medium** using Bernoulli equation, which relates to *flow resistance*. The working principle of this technique is as follows:

1. Create a medium impeding the flow motion in a section of the pipe, such as orifices, porous plugs, and Venturi tubes.
2. Place 1 differential pressure sensor between the normal sections or 2 absolute pressure sensors in each normal section of the pipe.
3. Because the high resistance area creates a slight pressure difference in the flow, the mass transferred through the pipe can be estimated.

The equation for finding mass flow is:

$$q = \epsilon A_2 \sqrt{\Delta p} \tag{2.1}$$

where

- q is the mass flow per unit time, kg/s.
- ϵ is the calibration coefficient.
- A_2 is the cross section of the high resistance area, m^2.

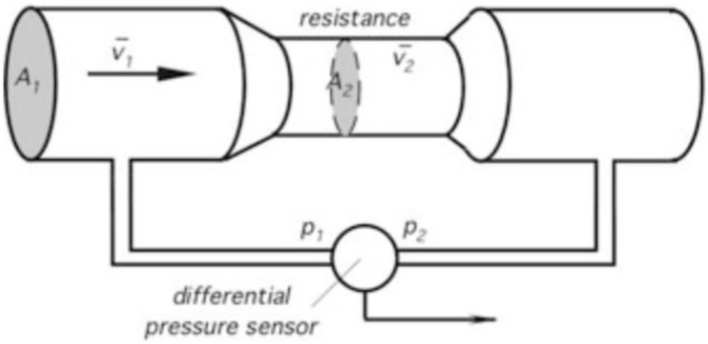


Figure 2.1: Pressure gradient technique example using narrow channel flow [2]

- Δp is the pressure difference, Pa.

Derivation of the equation is provided in chapter 12 [2].

Advantage of the pressure gradient method is in the absence of moving components and use of standard pressure sensors that are readily available. A disadvantage is in the restriction of flow by a resistive device.

2.2.2 Thermal transport sensors

Thermal transport sensors work by "marking" the flowing medium and detecting the movement of the mark. They are also called *thermoanemometers*. Thermoanemometers are sensitive and have a broad dynamic range. Since the "mark" moves, no moving component is required and low flow rates can also be measured, unlike pressure differential sensors. Another benefit is detection of material change in composition.

A thermoanemometer design determines its operating limit. The upper limit of FSO is determined experimentally.

Data processing system for thermoanemometers must receive at least 3 variable input signals: a flowing medium temperature, a differential, a heating power signal. The signals are multiplexed (i.e. MISO operation), converted into digital form, and processed by a computer to calculate characteristics of flow, displayed in velocities, volume rates or mass rate

Hot-wire/hot-film Anemometers

It is a single-part sensor. The wire resistance typically is $2 - 3\,\Omega$. The operating principle is based on warming up the wire by electric current to $200 - 300°C$. No media temperature compensation is required. As the flow moves through the wire, it reduces the temperature of the hot wire. The faster the media flows, the stronger the cooling. This phenomena is also known as *forced convection*.

There are 2 methods of controlling temperature and measuring a cooling effect: constant voltage and constant temperature.

- Constant voltage: reduction in the wire temperature is measured while the voltage between 2 ends of the wire is constant.

- Constant temperature: the temperature remains constant. The power feeds to the wire compensates for temperature loss.

The compensating voltage δV for a small change in resistance R_w is:

$$\delta V = V_{out}\left(\frac{R_w + \delta R_w}{R_w + \delta R_w + R_1} - \frac{R_w}{R_w + R_1}\right) \approx V_{out}\frac{\delta R_w}{R_w + R_1}$$

Then, relation between R_w and temperature change of the hot wire is obtained through experiments and in-depth research regarding the topic. Typical design of the hot-wire sensor is shown

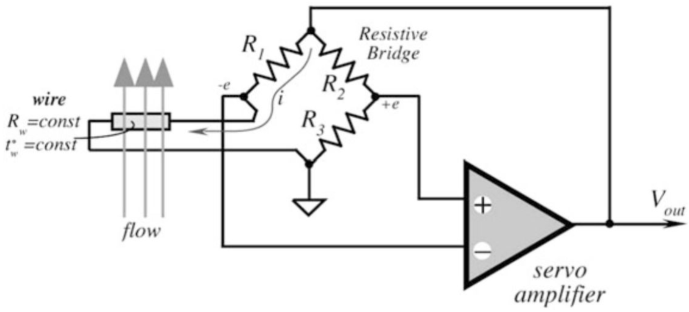


Figure 2.2: Null-balanced bridge for a constant temperature hot-wire anemometer [2]

in **Figure 2.3**. Common materials for the wires are:

- tungsten. The wires are strong and have high temperature coefficient (0.004°C^{-1}). However, they are prone to high temperatures in many gases due to poor oxidation resistance. This is the most common material at present.
- platinum. The wires have high oxidation resistance and temperature coefficient (0.003°C^{-1}). However, they are weak, especially at high temperatures.
- Platinum-iridium alloy. The wires have good oxidation resistance and are more durable than platinum. However, they have low temperature coefficient (0.00085°C^{-1})

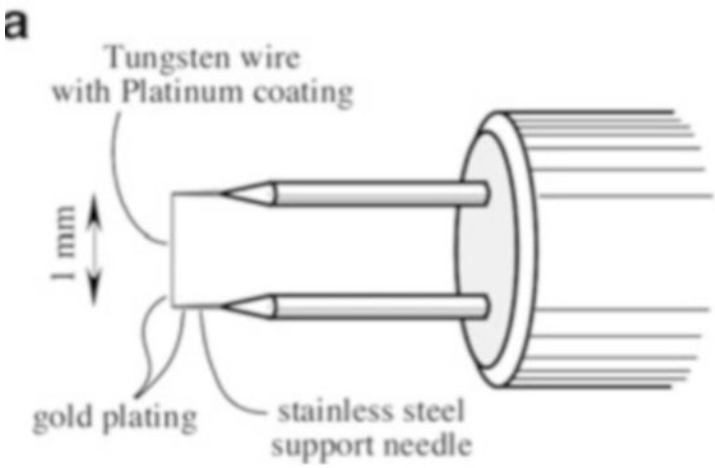


Figure 2.3: Hot-wire probe typical design [2]

Typical design of hot-film sensor is shown in **Figure 2.4**. A common material for the film layer is platinum. The insulator could be made of ceramic substrate.

The hot-film sensor has several advantages over hot-wire sensor:

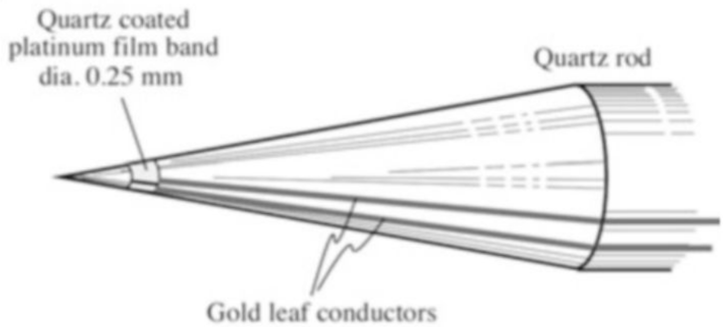


Figure 2.4: Hot-film probe with cone-shaped design [2]

- Better frequency response due to large surface area with the same rod diameter.
- Lower heat conduction to the supports due to low thermal conductivity of the substrate material.
- More flexible configurations (e.g. wedge, conical, parabolic shapes).
- Less susceptible to fouling and easier to clean.

Three-part Thermoanemometer

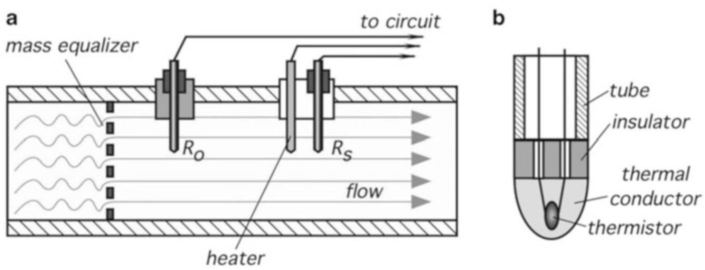


Figure 2.5: Schematic representation and cross-sectional view of a three-part themoanemometer [2]

This type of thermoanemometer is used primarily for liquids but can also be used for gases. The design makes it resistant to contaminated environments. The temperature detector R_o measures the current temperature of the flowing medium. The heater then warms up the medium and the elevated temperature is measured by the second temperature detector R_s. Through convection phenomena, the amount of heat dissipation is converted to the flow rate of the medium. However, laminar flow must be obtained before measurements for accurate result.

In industry and scientific measurements, resistance temperature detectors (RTDs) is preferable for higher linearity, predictable response and long-term stability over a broader temperature range.

In medicine, thermistors are often preferred for higher sensitivity.

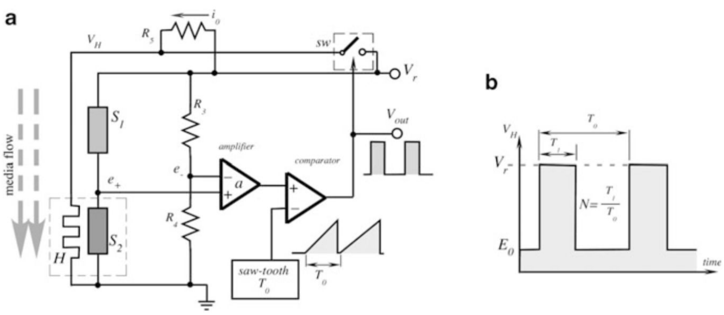


Figure 2.6: Control circuit of a themoanemometer with PWM modulator [2]

Two-part Thermoanemometer

Fast-response sensors like hot-wire and hot-film sensors are expensive and delicate. More robust and resistant sensors without need of responsiveness (about 0.5 s) requires different design approaches. The working principle of two-part thermoanemometers is similar to three-part thermoanemometer: measuring temperature of the flowing media; heating the media; monitoring the cooling effect caused by the flow. However, the heat and the second temperature sensor are combined into one sensor.

The thermoanemometer works by a control circuit with a Wheatstone bridge. It generates an output PWM signal where the duty cycle *N* represents the airflow rate.

Another thermoanemometer used in precise semiconductor manufacturing is microflow thermal transport sensors. This sensor is developed with MEMS technology. This topic is very advanced and beyond the scope of this report.

2.2.3 Ultrasonic Sensors

The working principle of the sensor can be categorized in 2 ways:

- detection of frequency. It uses Doppler effect.
- phase shift caused by flowing medium. It relies on the detection of the increase or decrease in effective ultrasound velocity in the medium.

To use the sensor, it is desirable to calibrate the ultrasonic sensors with actual fluids over the useful temperature range so that contribution of a fluid viscosity is accounted for.

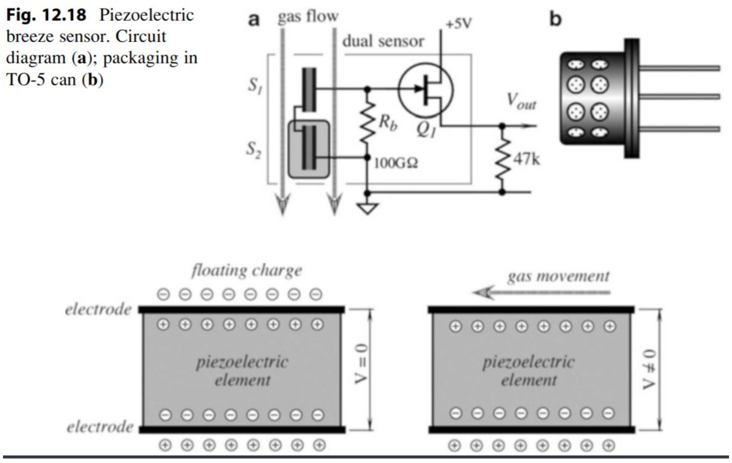
2.2.4 Electromagnetic Sensors

The electromagnetic flow sensors are useful for measuring the movement of conductive liquids. The operating principle is based on the discovery of Faraday and Henry of the electromagnetic induction. The voltage is induced with an alternating magnetic field. The frequency of magnetic field must be at least 2 times higher than the highest frequency of flow rate variations (Nyquist frequency). This value is typically around 100 – 1000 Hz.

2.2.5 Breeze Sensors

Breeze sensors are used when detection of change in the air/gas movement is needed but not its instantaneous velocity. Gas movement strips off electric charges from surface of piezoelectric

Figure 2.7: Electromagnetic sensors MC162



element. The voltage induced by piezoelectricity phenomena is applied to the JFET follower creates an output signal at the terminal.

2.2.6 Coriolis Mass Flow Sensors

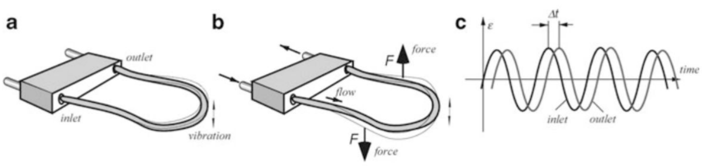


Figure 2.8: Coriolis sensor's working principle. The phase shift relates to the mass flow

The sensors measure flow of mass directly. Since they are essentially unaffected by the fluid pressure, temperature, viscosity and density, the sensors can be used without recalibration and without compensating for parameters specific to a particular type of fluid. Moreover, gas applications can benefit greatly with these sensors. The Coriolis force is calculated using the following equation:

$$F = 2m\omega v$$

where m is the mass, ω is the rotation speed, v is the vector of the average fluid velocity. The design of this sensor is shown in **Figure 2.8**. Although having many great advantages, the cost of the sensor is high (about 60,000,000 VND). Therefore, depending on application types (such as measuring multiple fluids), the usage value can offset the initial price.

Figure 2.9: Coriolis mass flow sensor

2.2.7 Drag Force Flowmeter

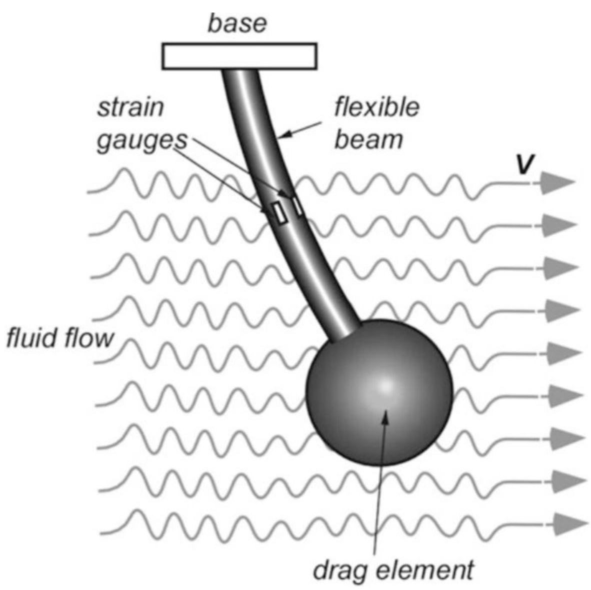


Figure 2.10: Schematic of the drag force sensor

For sporadic, multi-directional, turbulent fluids, a drag force flow is efficient. However, it requires environmental monitoring, meteorology, hydrology, maritime studies to measure speeds of air or water flow and turbulence close to surface. The force exerted by the fluid on the drag element is measured (strain measurement of deformation) and converted to an electrical signal indicative of a value for flow speed. This approach can measure 3 dimensional flow instead of 1 dimension like other sensors. A variation of this sensor using MEMS technology is cantilever MEMS sensors, which is again, beyond the scope of the report.

2.2.8 Dust and Smoke Detectors

Although airflow is not monitored, their operation requires movement of gases through the detection chamber of the sensor. To detect presence of small particles suspended in the air, their are 2 types of sensors are widely employed: ionization and optical detectors.

Ionization Detectors

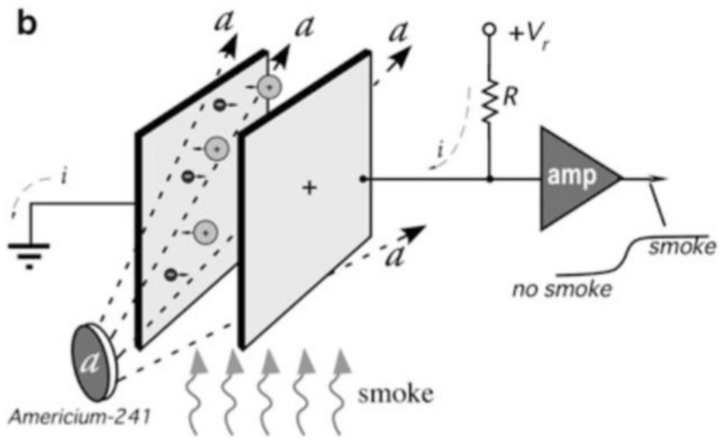


Figure 2.11: Schematic representation of ionization process in smoke detectors

An ionization chamber containing Americium-241. The radioactive isotope produces alpha particles with a half-life of 432.2 years. If no smoke goes through the space between 2 plates, the alpha particles emanated by Americium-241 ionizes the air molecules by breaking them into positively charged ions and negatively charged electrons. This creates a small current or "virtual wire" for the voltage source V_r goes to the ground on the left side plate.

If smoke goes through the space between 2 plates, the alpha particles can no longer ionize the air molecules inside the chamber, thus cutting off the "virtual wire". The voltage source then goes through the amplifier "amp", indicating that smoke exists in the room.

Optical Detectors

The effect is the same with optical detectors. If the light source is obstructed from the detector by the smoke, it signals that there is smoke inside the room. However, distinguishing the light coming from the emitter and ambient light with the scattered light from the smoke is the main problem. A possible design is illustrated in **Figure 2.12**. Depending on the designer's implementation, each smoke detector will have different positioning schemes.

For responding to the light pulses resulted from larger particles, the electronic interface circuit should have a sufficiently wide frequency bandwidth. The optical smoke detectors are

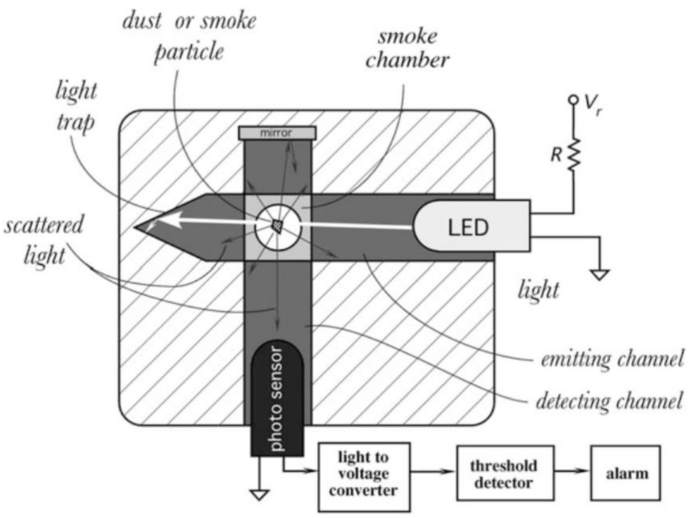


Figure 2.12: Cross section of an optical smoke detector. The photosensor and LED could be crossed at less than 90 degree at the expense of mechanical complexity [2]

less prone to false alarm resulted from steam or cooking fumes in kitchen than the ionization smoke alarms

Chapter 3

Availability in the market

3.1 Type of sensor's manufacture

3.1.1 Competition of products

Gas sensor can be made for measuring of especially large flow rates and uses the calorimetric measuring principle. Available in two versions: - Standard - Heavy Duty (in the Heavy Duty version the sensor is encapsulated in stainless steel).

Air flow sensor provides low pressure drop in the customer's application, highly stable null and full scale:

- Does not require recalibration in most applications.
- Compact package design: Occupies less space in the customer's enclosure, potentially reducing production costs. Enclosure size may also be reduced for easier fit into space constrained applications.
- Low hysteresis and repeatability errors (less than 0.35% of reading).
- Provides better system accuracy, enhanced response flow time of $6ms$.
- Low power consumption: Allows for use in portable devices and battery-powered applications.

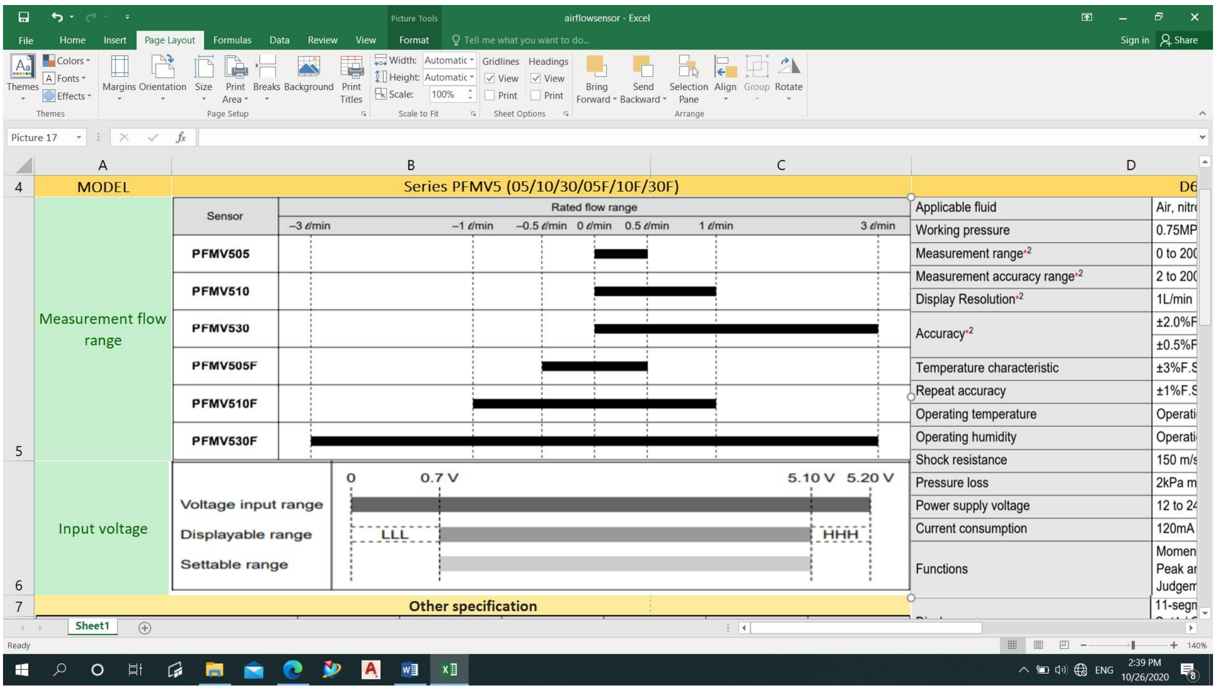
Flow meter sensor operates according to Faraday's law of induction. The conductive medium flowing through a pipe in a magnetic field (M) generates a voltage which is proportional to the flow velocity (v) or volumetric flow quantity. This voltage is tapped via electrodes (E) and converted in the evaluation unit. Its resistant materials mean the sensor is suitable for a multitude of media.

3.2 Data sheet example

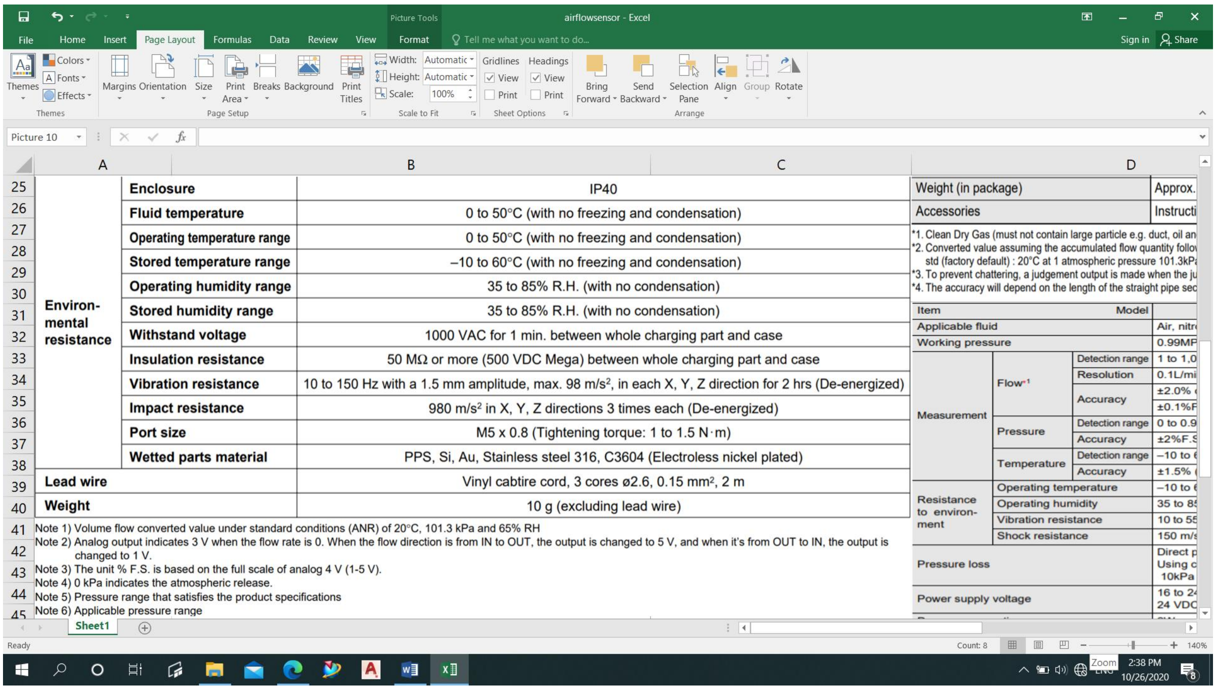
3.2.1 Air/gas flow sensor

Table 3.1: Typical Features of four groups of flow sensors

Speciality	Sensor types			
	Differential pressure	Electromagnetic	Coriolis flow	Ultrasonic
Volumetric flow rate measurement	volume	volume	mass	volume
Velocity measurement of gas / liquid	unsuitable for gas with low flow rate	unsuitable for gas flow	unsuitable for flow rate larger than $20m^3/min$	unsuitable for gas flow
Special / viscous flow	suitable conditions	measured	suitable conditions	suitable conditions
Liquid/gas mixture	-	suitable conditions	suitable conditions	suitable conditions
Liquid condition	-	conductive	-	-
Liquid of food / drink	-	measured	measured	mostly measured
Installation / maintenance	easy, periodic cleaning	moderate, little maintenance	hardly maintenance	easy installation and maintenance
Accuracy	0.6 – 2% measuring range	0.2 – 1% readable value	0.1 – 0.5% readable value	0.35% readable value; 2% measuring range

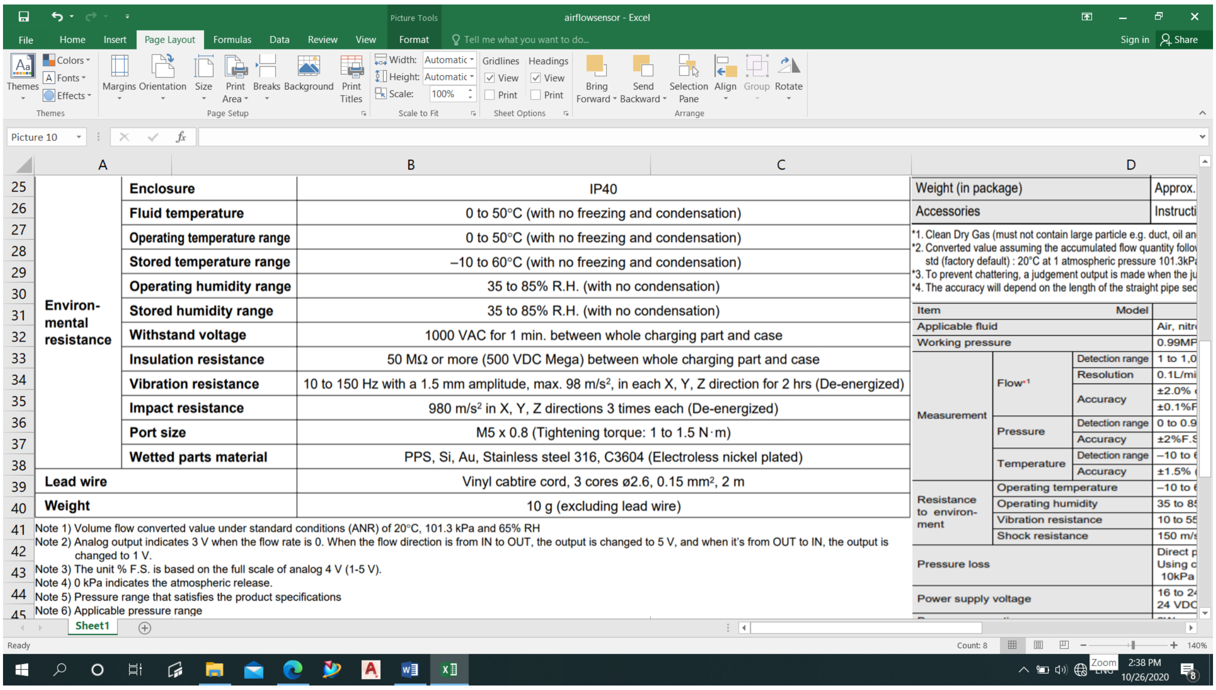


- Thermal mass flow measurement.
- Integrated inlet and outlet pipes for flow conditioning.
- Pipe sizes up to 2″.
- Integrated display.
- Standard and Heavy Duty version available.



	A	B	C
25	Environ-mental resistance	Enclosure	IP40
26		Fluid temperature	0 to 50°C (with no freezing and condensation)
27		Operating temperature range	0 to 50°C (with no freezing and condensation)
28		Stored temperature range	–10 to 60°C (with no freezing and condensation)
29		Operating humidity range	35 to 85% R.H. (with no condensation)
30		Stored humidity range	35 to 85% R.H. (with no condensation)
31		Withstand voltage	1000 VAC for 1 min. between whole charging part and case
32		Insulation resistance	50 MΩ or more (500 VDC Mega) between whole charging part and case
33		Vibration resistance	10 to 150 Hz with a 1.5 mm amplitude, max. 98 m/s², in each X, Y, Z direction for 2 hrs (De-energized)
34		Impact resistance	980 m/s² in X, Y, Z directions 3 times each (De-energized)
35		Port size	M5 x 0.8 (Tightening torque: 1 to 1.5 N·m)
36		Wetted parts material	PPS, Si, Au, Stainless steel 316, C3604 (Electroless nickel plated)
37	Lead wire		Vinyl cabtire cord, 3 cores ø2.6, 0.15 mm², 2 m
38	Weight		10 g (excluding lead wire)

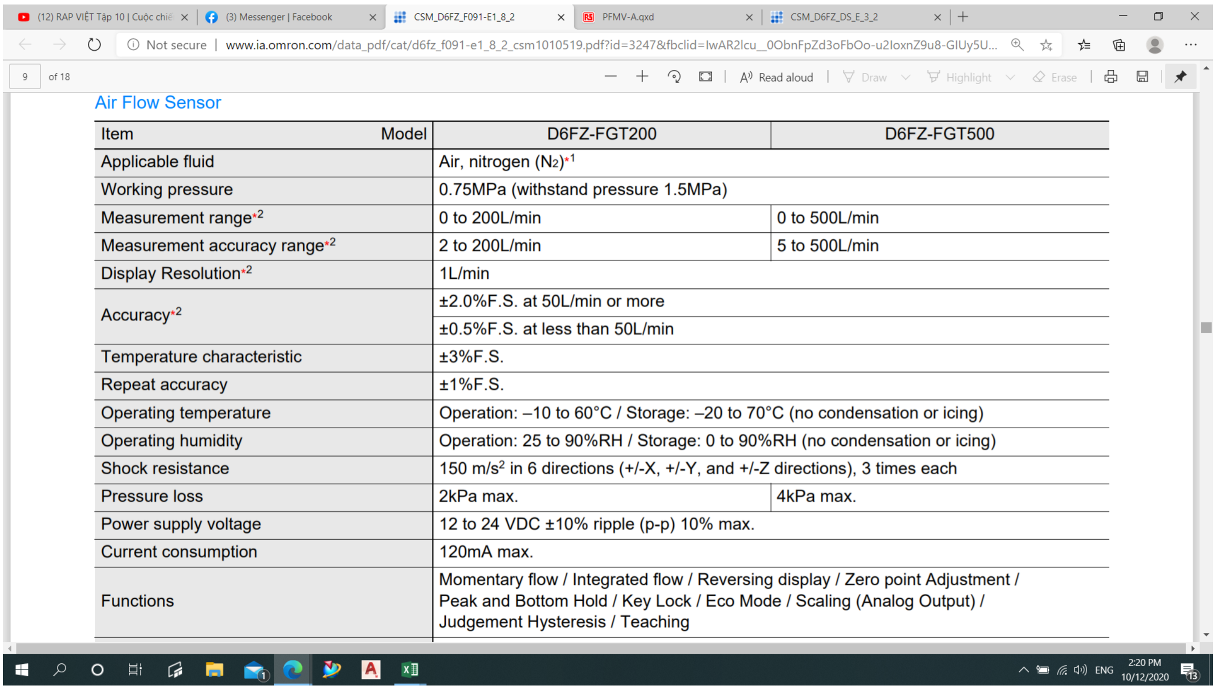
Note 1) Volume flow converted value under standard conditions (ANR) of 20°C, 101.3 kPa and 65% RH
Note 2) Analog output indicates 3 V when the flow rate is 0. When the flow direction is from IN to OUT, the output is changed to 5 V, and when it's from OUT to IN, the output is changed to 1 V.
Note 3) The unit % F.S. is based on the full scale of analog 4 V (1-5 V).
Note 4) 0 kPa indicates the atmospheric release.
Note 5) Pressure range that satisfies the product specifications
Note 6) Applicable pressure range



	A	B	C
25	Environ-mental resistance	Enclosure	IP40
26		Fluid temperature	0 to 50°C (with no freezing and condensation)
27		Operating temperature range	0 to 50°C (with no freezing and condensation)
28		Stored temperature range	–10 to 60°C (with no freezing and condensation)
29		Operating humidity range	35 to 85% R.H. (with no condensation)
30		Stored humidity range	35 to 85% R.H. (with no condensation)
31		Withstand voltage	1000 VAC for 1 min. between whole charging part and case
32		Insulation resistance	50 MΩ or more (500 VDC Mega) between whole charging part and case
33		Vibration resistance	10 to 150 Hz with a 1.5 mm amplitude, max. 98 m/s², in each X, Y, Z direction for 2 hrs (De-energized)
34		Impact resistance	980 m/s² in X, Y, Z directions 3 times each (De-energized)
35		Port size	M5 x 0.8 (Tightening torque: 1 to 1.5 N·m)
36		Wetted parts material	PPS, Si, Au, Stainless steel 316, C3604 (Electroless nickel plated)
37	Lead wire		Vinyl cabtire cord, 3 cores ø2.6, 0.15 mm², 2 m
38	Weight		10 g (excluding lead wire)

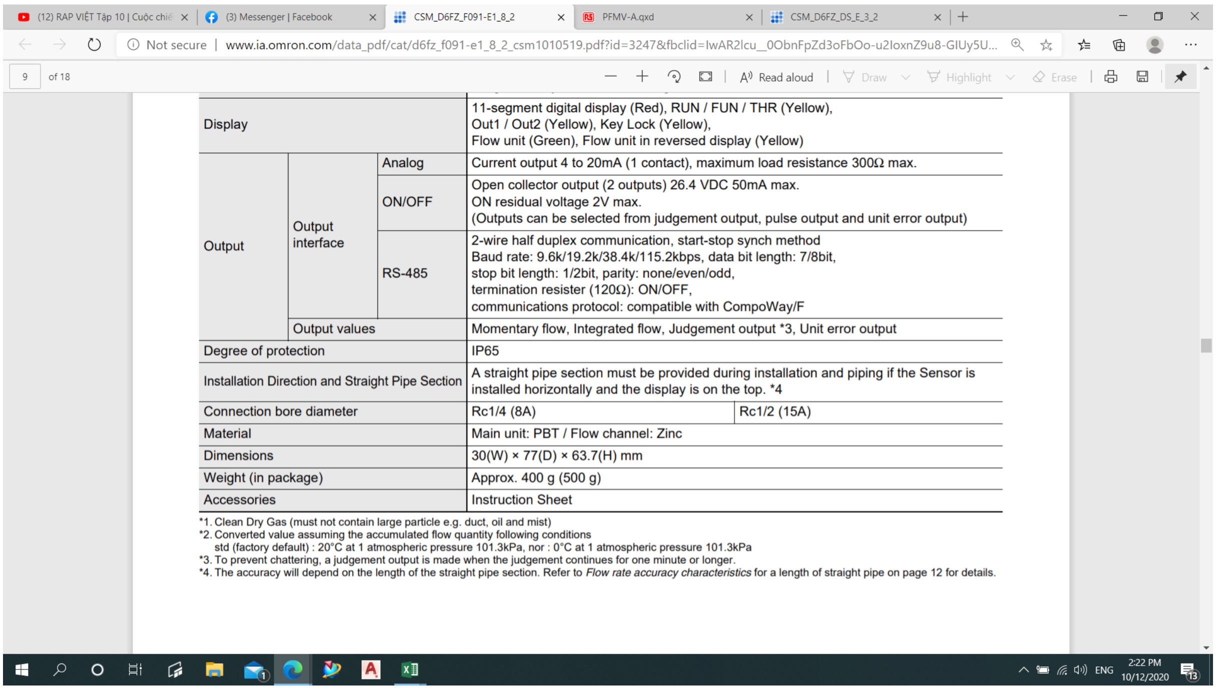
Note 1) Volume flow converted value under standard conditions (ANR) of 20°C, 101.3 kPa and 65% RH
Note 2) Analog output indicates 3 V when the flow rate is 0. When the flow direction is from IN to OUT, the output is changed to 5 V, and when it's from OUT to IN, the output is changed to 1 V.
Note 3) The unit % F.S. is based on the full scale of analog 4 V (1-5 V).
Note 4) 0 kPa indicates the atmospheric release.
Note 5) Pressure range that satisfies the product specifications
Note 6) Applicable pressure range

3.2.2 Liquid flow sensor



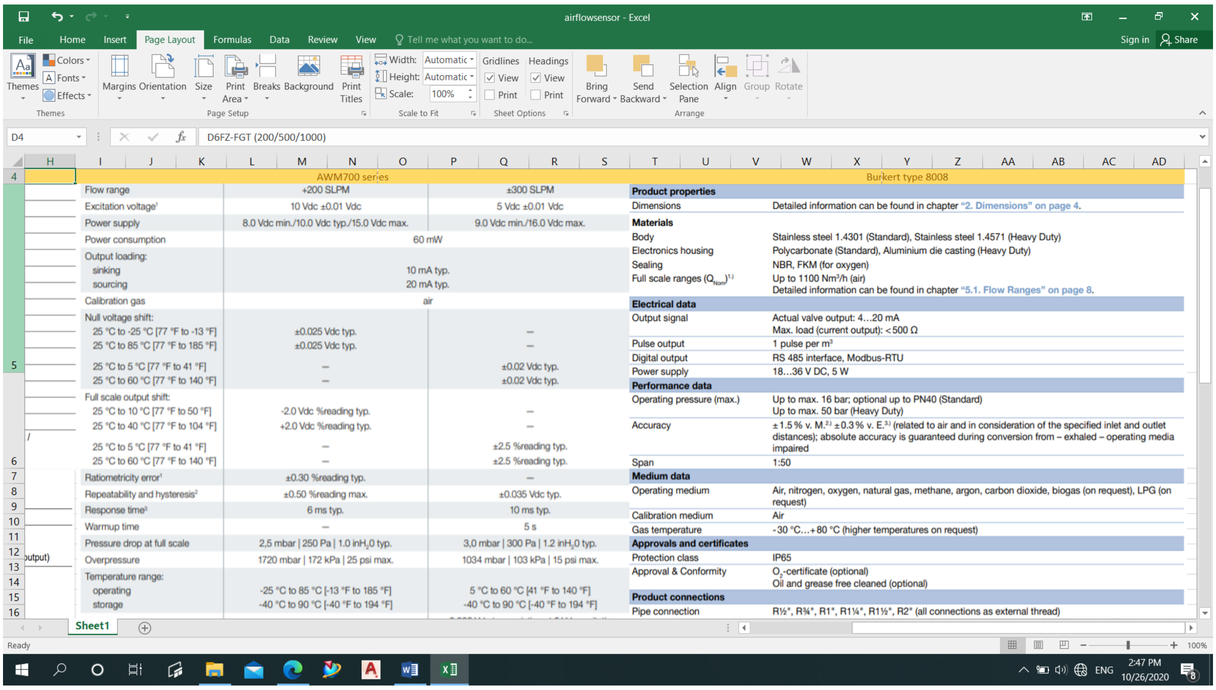
Air Flow Sensor

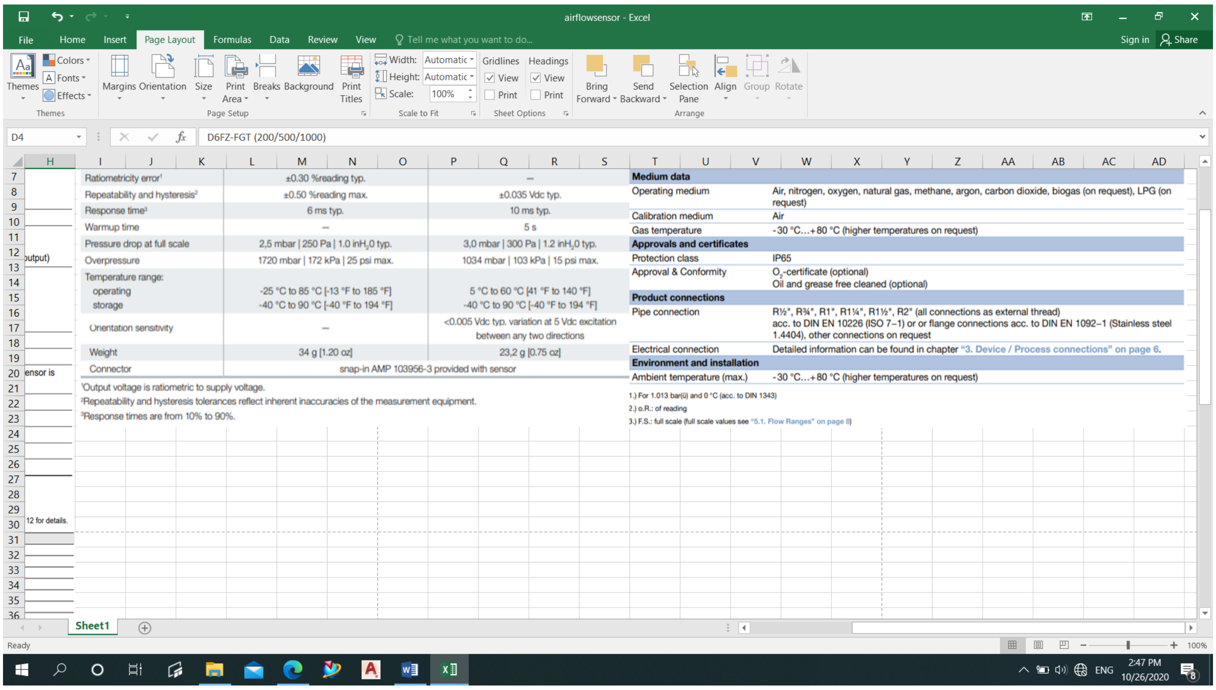
Item / Model	D6FZ-FGT200	D6FZ-FGT500
Applicable fluid	Air, nitrogen (N_2)*1	
Working pressure	0.75MPa (withstand pressure 1.5MPa)	
Measurement range*2	0 to 200L/min	0 to 500L/min
Measurement accuracy range*2	2 to 200L/min	5 to 500L/min
Display Resolution*2	1L/min	
Accuracy*2	±2.0%F.S. at 50L/min or more	
	±0.5%F.S. at less than 50L/min	
Temperature characteristic	±3%F.S.	
Repeat accuracy	±1%F.S.	
Operating temperature	Operation: –10 to 60°C / Storage: –20 to 70°C (no condensation or icing)	
Operating humidity	Operation: 25 to 90%RH / Storage: 0 to 90%RH (no condensation or icing)	
Shock resistance	150 m/s^2 in 6 directions (+/-X, +/-Y, and +/-Z directions), 3 times each	
Pressure loss	2kPa max.	4kPa max.
Power supply voltage	12 to 24 VDC ±10% ripple (p-p) 10% max.	
Current consumption	120mA max.	
Functions	Momentary flow / Integrated flow / Reversing display / Zero point Adjustment / Peak and Bottom Hold / Key Lock / Eco Mode / Scaling (Analog Output) / Judgement Hysteresis / Teaching	



Display			11-segment digital display (Red), RUN / FUN / THR (Yellow), Out1 / Out2 (Yellow), Key Lock (Yellow), Flow unit (Green), Flow unit in reversed display (Yellow)	
Output	Output interface	Analog	Current output 4 to 20mA (1 contact), maximum load resistance 300Ω max.	
		ON/OFF	Open collector output (2 outputs) 26.4 VDC 50mA max. ON residual voltage 2V max. (Outputs can be selected from judgement output, pulse output and unit error output)	
		RS-485	2-wire half duplex communication, start-stop synch method Baud rate: 9.6k/19.2k/38.4k/115.2kbps, data bit length: 7/8bit, stop bit length: 1/2bit, parity: none/even/odd, termination resister (120Ω): ON/OFF, communications protocol: compatible with CompoWay/F	
	Output values		Momentary flow, Integrated flow, Judgement output *3, Unit error output	
Degree of protection			IP65	
Installation Direction and Straight Pipe Section			A straight pipe section must be provided during installation and piping if the Sensor is installed horizontally and the display is on the top. *4	
Connection bore diameter			Rc1/4 (8A)	Rc1/2 (15A)
Material			Main unit: PBT / Flow channel: Zinc	
Dimensions			30(W) × 77(D) × 63.7(H) mm	
Weight (in package)			Approx. 400 g (500 g)	
Accessories			Instruction Sheet	

*1. Clean Dry Gas (must not contain large particle e.g. duct, oil and mist)
*2. Converted value assuming the accumulated flow quantity following conditions
std (factory default) : 20°C at 1 atmospheric pressure 101.3kPa, nor : 0°C at 1 atmospheric pressure 101.3kPa
*3. To prevent chattering, a judgement output is made when the judgement continues for one minute or longer.
*4. The accuracy will depend on the length of the straight pipe section. Refer to *Flow rate accuracy characteristics* for a length of straight pipe on page 12 for details.





3.3 Future developments

3.3.1 Orifice Plate flowmeters for steam applications

Advantages

- Simple and rugged.
- Good accuracy.
- Low cost.

- No calibration or recalibration is required provided calculations, tolerances and installation comply with ISO 5167.

Disadvantages

- Turndown is limited to between 4:1 and 5:1 because of the square root relationship between flow and pressure drop.
- The orifice plate can buckle due to waterhammer and can block in a system that is poorly designed or installed.
- The square edge of the orifice can erode over time, particularly if the steam is wet or dirty. This will alter the characteristics of the orifice, and accuracy will be affected. Regular inspection and replacement is therefore necessary to ensure reliability and accuracy.
- The installed length of an orifice plate flowmetering system may be substantial; a minimum of 10 upstream and 5 downstream straight unobstructed pipe diameters may be needed for accuracy.

This can include the boiler house and applicawhere steam is supplied to many plants, some on-line, some off-line, but the overall flowrate is within the range.

3.3.2 Turbine flowmeters for steam applications

Advantages

- A turndown of 10:1 is achievable in a good installation with the turbine bearings in good condition.
- Accuracy is reasonable (±0.5% of actual value).
- Bypass flowmeters are relatively low cost.

Disadvantages

- Generally calibrated for a specific line pressure. Any steam pressure variations will lead to inaccuracies in readout unless a density compensation package is included.
- Flow straighteners are essential (see Tutorial 4.5).
- If the flow oscillates, the turbine will tend to over or under run, leading to inaccuracies due to lag time.
- Wet steam can damage the turbine wheel and affect accuracy.
- Low flowrates can be lost because there is insufficient energy to turn the turbine wheel.
- Viscosity sensitive: if the viscosity of the fluid increases, the response at low flowrates deteriorates giving a non-linear relationship between flow and rotational speed. Software may be available to reduce this effect.
- The fluid must be very clean.

Typical Applications

- Superheated steam.
- Liquid flowmetering, particularly fluids with lubricating properties. As with all liquids, care must be taken to remove air and gases prior to them being metered.

3.3.3 Variable Area flowmeters for steam applications

Advantages

- Linear output.
- Turndown is approximately 10:1.
- Simple and robust.
- Pressure drop is minimal and fairly constant.

Disadvantages

- The tube must be mounted vertically.
- Because readings are usually taken visually, and the float tends to move about, accuracy is only moderate. This is made worst by parallax error at higher flowrates, because the float is some distance away from the scale.
- Transparent taper tubes limit pressure and temperature.

Typical Applications

- Metering of gases.
- Small bore airflow metering - In these applications, the tube is manufactured from glass, with calibrations marked on the outside. Readings are taken visually.
- Laboratory applications.
- Rotameters are sometimes used as a flow indicating device rather than a flow measuring device.

Chapter 4

Summary and Conclusions

In summary, the report introduces a general list of considerations before deciding to buy a sensor. It also introduces a number of flow sensors available in the market. Since the author's knowledge regarding sensor technology is poor, the report is only limited to studying working principles of simple sensors. However, what is more desired for university students is to acknowledge and appreciate the design of many existing sensors. In addition, knowing how to read datasheets and implement the sensor in designing mechatronic systems is extremely crucial, which is the initial goal of this project.

References

[1] W. Bolton. *Mechatronics: Electronic control systems in mechanical and electrical engineering*. Pearson Education Limited, 2015. ISBN: 9781292081595. URL: https://books.google.com.vn/books?id=ql1TDwAAQBAJ.

[2] Jacob Fraden. *Handbook of modern sensors: physics, designs, and applications*. 5th ed. Vol. 1. Springer International Publishing Switzerland, 2016, pp. 453–484.