PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

ECOLE NATIONALE POLYTECHNIQUE

ELECTRONICS DEPARTMENT

In partial fulfillment of the requirement for the
Master's Degree
(Electronics Engineering)

Fluid Flow Measurement Based on Ultrasound

Abdelhak BOUDEHANE

Supervised by:
AP. Mourad ADNANE
AP. Rabie MESSAHLI

Publicly presented and discussed on 22/06/2016

Jury members:

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Acknowledgments

This work would not have been possible without the advice and support of many people. First, and foremost, I would like to express my deepest gratitude to my teacher and thesis supervisor AP. Mourad ADNANE for this opportunity and his valuable guidance at the different stages of this work. It would have been quite difficult to carry on the research part without his precious help and encouragement.

I am also deeply indebted to AP. Rabie MESSAHLI for his immense support and help in the hydraulic laboratory to set up our experiments. I genuinely appreciate his continuous counselling, encouragement and availability throughout this project.

I am most grateful to all the jury members: Pr. Adel BELOUCHRANI, President of the jury and AP. Boualem BOUSSEKSOU, the examiner of our project thesis.

Finally, my heartiest thanks go to all my family members whose support, proximity and affection provided me with confidence and comfort during all my study period.

ملخص

يقام بقياس التدفق بواسطة فرق الضغط الذي يكون غالبا تحت الحد الأدنى لدقة أجهزة الإستشعار. مقياس فرق الضغط على شكل U المملوء بالماء يبقى دائما الأكثر دقة بين أجهزة القياس حين يتعلق الأمر بقيم صغير للضغط. من جهة أخرى، يطرح هذا المقياس العديد من المشاكل مثل قراءة القياسات، غياب المراقبة اللحظية و التخزين.

جهاز الإرسال و الإستقبال بالموجات فوق الصوتية، الموضوع على طرفي مقياس الضغط يقترح حلولا للمشاكل المطروحة سابقا.

جمع مقياس فرق الضغط بجهاز الإرسال و الإستقبال بالموجات فوق الصوتية يقدم إمتيازات القياس الإلكتروني و الميكانيكي في آن واحد.

جهاز القياس الناتج من هذه التركيبة ذو كفاءة و فعالية عندما يستعمل على أنبوب Pitot .

الكلمات المفتاحية: قياس، تدفق، فارق الضغط، أجهزة استشعار.

Résumé

La mesure du débit est faite en utilisant la pression différentielle qui est souvent sous la limite de la précision des capteurs. Les manomètres tube en U rempli d'eau demeurent toujours les plus précis des instruments de mesurent quand il s'agit de petites valeurs de pression. De l'autre coté, ils posent plusieurs problèmes comme la lecture de la mesure, l'impossibilité de la visualisation en temps réel et le sauvegarde

Les Emetteurs-récepteurs ultrasoniques, placé sur les pieds du manomètre, offrent des solutions pour les problèmes posés en haut.

La combinaison des émetteurs-récepteurs ultrasoniques avec le manomètre tube en U offre les avantages de la mesure électronique et mécanique en même temps. L'instrument de mesure qui résulte de cette combinaison est performant et efficace lorsqu'il est appliqué à un tube de Pitot et résout le problème de mesure du débit.

Mots clés : Mesure, débit, différence de pression, capteurs.

Abstract

Flow measurement is done using differential pressure that is often below sensors' precision limit. Water filled U tube manometers remain the most accurate measuring instruments for low pressure values. In the other hand, they impose many problems like readability, impossibility of real time visualisation and storage. Ultrasonic transceivers, when placed above the manometer's legs, offer solutions for the problems mentioned above. The combination of both ultrasonic transceiver with a U tube manometer offers the advantages of electronic and mechanical measurement together. This resulting measurement instrument shows efficiency and performance when applied on Pitot tube and solves the flow rate measurement problem.

Key words: Measurement, flow, difference of pressure, sensors.

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Introduction

Electronic measurement show a great efficiency dominating over all the other measurement methods. Despite their performance, their price remains a problem due to many reasons such as their complexity and small dimensions especially for high precision devices.

As for mechanical methods, they are cheap but less efficient. Even when mechanical measurement instruments are accurate, they don't offer data processing and storage or real-time visualisation.

Combining both electronic sensors and mechanical instrument can take advantage of both mechanical and electronic characteristics. Face to a flow rate measurement problem in airlift hydraulic system, this combination can be magical and simple at the same time.

This thesis proposes a method to measure compressed air flow rate using Pitot tube, manometer and ultrasonic transceivers. The first part details generalities about different phenomena interfering in flow measurement and explains the physical aspect with theoretical equations. The second part gives an overview about the different flow measurement methods. The third part explores the experimental aspect with results' analysis. The last part is a general conclusion about the solution given in this thesis.

Chapter 1

Generalities

The understanding of the flow measurement system proposed in this article requires some general physical knowledge about fluid velocity characteristics. Hence, this section contains phenomena definitions and details about their physical characteristics.

1.1 Flow velocity

The flow velocity is a local vector quantity describing the motion of a fluid in a certain position and time. The velocity vector's length indicates the flow speed while its direction indicates the flow direction. Hence, the velocity of a fluid in a pipe is described by a field of vectors indicating the flow direction and the speed in every point. These vectors can be relative to each other in laminar flow or randomly changing in turbulent flow.

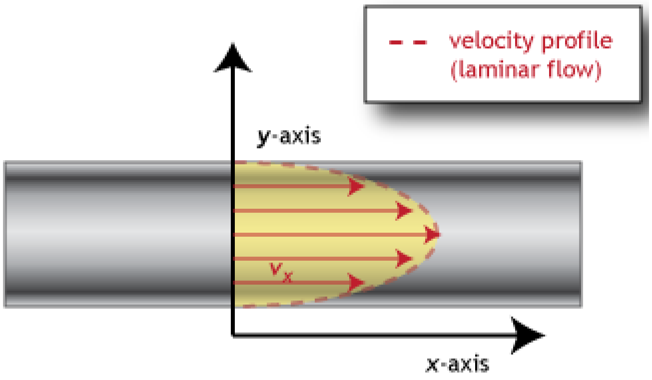


Figure 1.1: Laminar velocity profile [10]

Resistance to flow in a pipe

When a fluid flows through a pipe, the inner wall's roughness resists against the current generated by the fluid flow. Pipes with smooth walls such as glass, copper, brass and polyethylene have only a small effect on the frictional resistance. Pipes with less smooth walls such as concrete, cast iron and steel will create larger eddy currents which will sometimes have a significant effect on the frictional resistance.

The velocity profile in a pipe will show that the fluid at the centre of the stream will move more quickly than the fluid towards the edge of the stream. Therefore friction will occur between layers within the fluid. Fluids with a high viscosity will flow more slowly and will generally not support eddy currents and therefore the internal roughness of the pipe will have no effect on the frictional resistance. This condition is known as laminar flow.

Laminar flow

Occurs when a fluid flows in parallel layers, with no disruption between the layers, no cross currents or eddies perpendicular to direction of flow. Laminar flow can be divided into two flow subtypes [5]:

- Stable laminar flow : This type of laminar flow prove stable towards imposed disturbances acting from outside.

- Unstable laminar flow : A laminar flow is considered unstable when disturbances introduced into it are amplified, but a certain regularity in the excited disturbance is maintained, i.e. due to the disturbance the investigated flow merges into a new laminar flow state.

Turbulent flow

Characterized by rapid mixing. Cross currents flow perpendicular to direction of motion[5].

Reynolds number

The Reynolds number Re of a flowing fluid is obtained by dividing the inertia force of the fluid (velocity v x pipe diameter D) by the kinematic viscosity ν (viscous force per unit length), see equation 1.1.

$$Re = \frac{vD}{\nu} \tag{1.1}$$

Where the Reynolds number is less than 2300 laminar flow will occur and the resistance to flow will be independent of the pipe wall roughness. Turbulent flow occurs when the Reynolds number exceeds 3000. Between the two numbers, the flow is unstable laminar to turbulent flow.

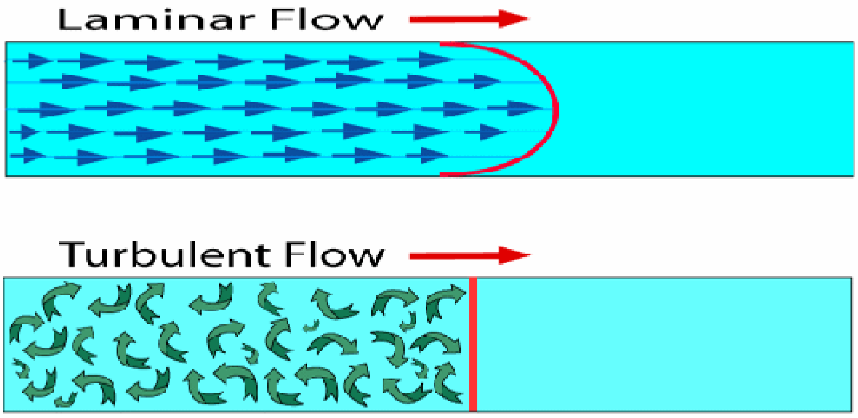


Figure 1.2: Laminar flow and turbulent flow [6]

1.2 Fluid flow rate

The flow rate of a fluid or volumetric flow rate represents the volume of fluid crossing a transverse section per time unit. It is generally given by cubic meters per second (m^3/s) but often liters per minute (L/min) is used to in medical field to quantify the blood flow. The flow depends on the dimension of the crossed section and the velocity of the fluid. The flow is written, using fluid volume V and time t, in equation 1.2.

$$Q = \frac{V}{t} \tag{1.2}$$

For a cylindrical shaped uniform pipe, the section is a disc as shown in figure 1.3. So, velocity is uniform along the pipe and the flow can be written in function of velocity v and section S :

$$Q = vS \tag{1.3}$$

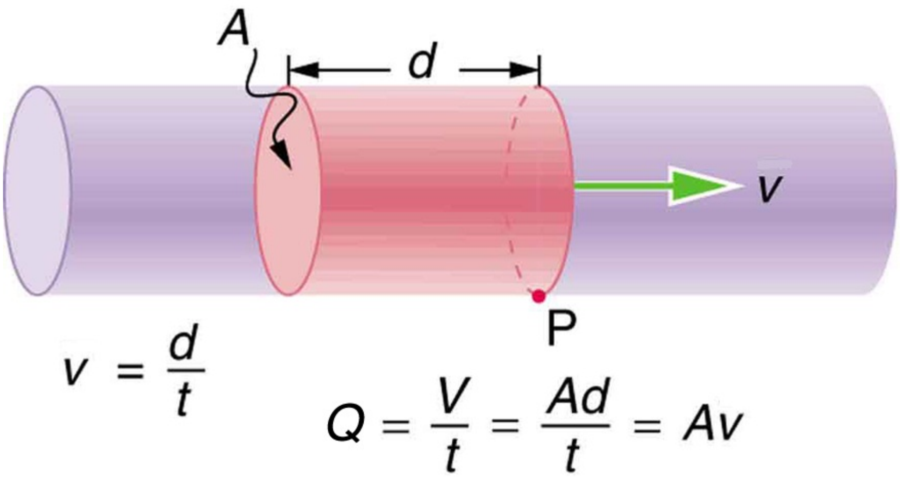


Figure 1.3: Flow rate in a uniform cylindrical pipe [11]

Continuity equation

For incompressible fluids (constant density ρ), the flow rate along a pipe is always constant regardless of the variation of it's section. This comes from the fact that the conservation of mass impose that same amount of fluid flows across all the sections of the pipe as illustrated in equation 1.4 and 1.5 where m is the mass, S the cross section, v the velocity of fluid, ρ is the density of fluid and T is the time of that needs the mass m to cross the section S.

$$dm = \rho S v \; dt \tag{1.4a}$$

$$m_1 - m_2 = \rho S_1 v_1 T - \rho S_2 v_2 T \tag{1.4b}$$

Since $m_1 = m_2$ and ρ and T are constants so we have :

$$Q = S_1 v_1 = S_2 v_2 = constant \tag{1.5}$$

The equation 1.5 is called the Continuity equation. This equation shows that the flow rate is always constant regardless of the section variation along the pipe. We also conclude that when the section is decreased, the velocity is increased.

1.3 Bernoulli's principle

Bernoulli's principle is a principle to enable us to determine the relationships between the pressure, density, and velocity at every point in a fluid. The conservation of energy in a constant volume for an incompressible fluid leads us directly to the equation of Bernoulli (equation 1.6).

$$p + \rho g z + \frac{1}{2}\rho v^2 = constant \tag{1.6}$$

Where P is the static pressure, $\frac{1}{2}\rho v^2$ is the dynamic pressure and $\rho g z$ is the potential energy. From this equation we conclude that an increase in the speed of fluid flow results in a decrease in the pressure.

For example, in figure 1.4 we notice that when cross section is smaller, velocity is is greater which means lower pressure according to Bernoulli.

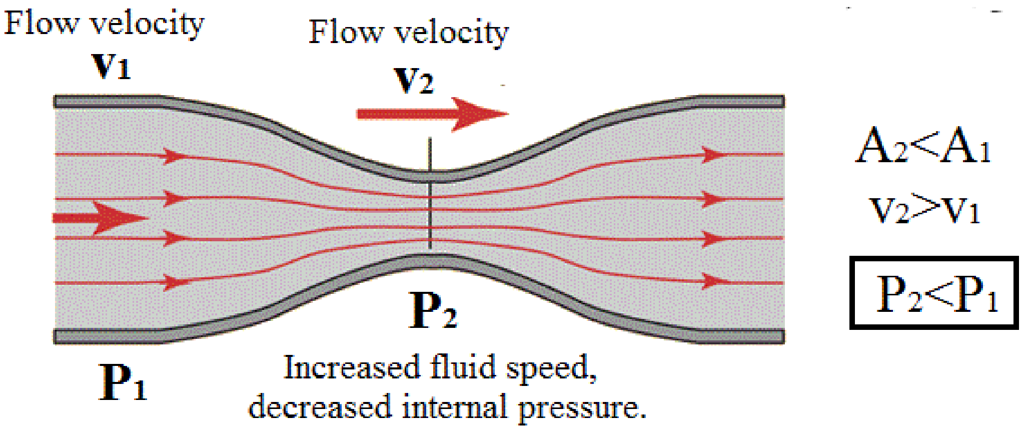


Figure 1.4: Flow rate in a uniform cylindrical pipe

The equation of Bernoulli is written in this case (equation 1.7) :

$$p_1 + \rho g z_1 + \frac{1}{2}\rho v_1^2 = p_2 + \rho g z_2 + \frac{1}{2}\rho v_2^2 \tag{1.7}$$

The fact that the velocity and pressure are linked by Bernoulli's equation makes it possible to determine the flow rate using the differential pressure between two points with different sections. The system used to measure differential pressure in this case is called Venturi meter.

Venturi meters

Venturi meters are flow measurement instruments which use a converging section of pipe to give an increase in the flow velocity and a corresponding pressure drop from which the flow rate can be deduced. They have been in common use for many years, especially in the water supply industry [8].

The classical Venturi meter, whose use is described in ISO 5167-1: 1991, has the form shown in figure 1.5.

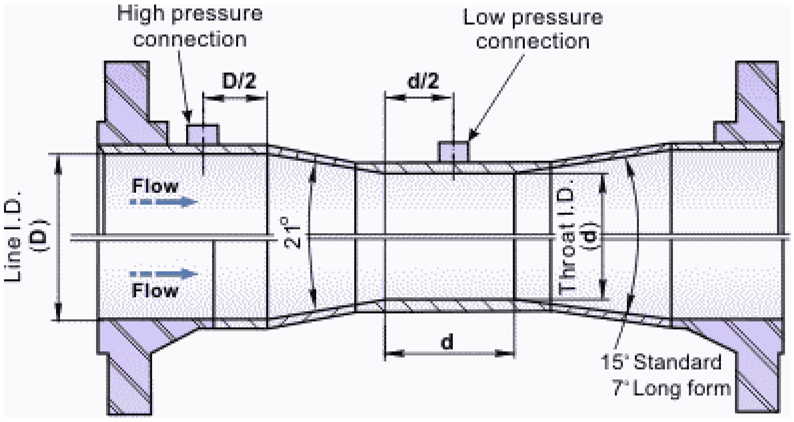


Figure 1.5: Classical Venturi meter [8]

For Venturi pipe and from continuity equation and Bernoulli's equation, the flow rate is written in function of differential pressure in equation 1.8

$$Q = \frac{\pi d^2}{4} \frac{1}{\sqrt{1 - (\frac{d}{D})^4}} \sqrt{\frac{2(p_1 - p_2)}{\rho}} \tag{1.8}$$

Where Q is flow rate, d and D are the diameters of the big and the small sections, $p1$ and $p2$ are the pressure values.

Chapter 2

Flow measurement methods

2.1 Ultrasonic Doppler flow meter

Ultrasound waves are affected by the Doppler effect. when transmitting an ultrasonic wave towards a flowing fluid, the motion of fluid causes frequency shifting of the reflected ultrasonic signal. Doppler frequency can be written in function of the emitted frequency and the fluid velocity in equation 2.1.

$$f_d = \frac{2vf_0\cos(\theta)}{v_t} \tag{2.1}$$

Where f_d is Doppler frequency, v is velocity, f_0 is emitted frequency, θ is the incidence angle between the signal and the flow direction and v_t is the ultrasound speed.

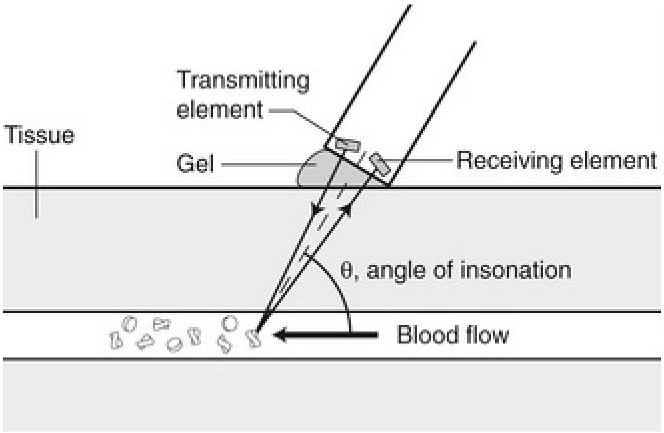


Figure 2.1: Blood velocity measurement using ultrasonic Doppler effect [4]

This method cannot measure flow for all types of fluids, it only works with fluids having bubbles or sound reflecting particles.

2.2 Coriolis Flow meter

Direct mass measurement sets Coriolis flow meters apart from other technologies. Mass measurement is not sensitive to changes in pressure, temperature, viscosity and density. With the ability to measure liquids, slurries and gases, Coriolis flow meters are universal meters.

Figure 2.2: Coriolis flow meter [3]

Coriolis Mass Flow meter uses the Coriolis effect to measure the amount of mass moving through the element. The fluid to be measured runs through a U-shaped tube that is caused to vibrate in an angular harmonic oscillation. Due to the Coriolis forces, the tubes will deform and an additional vibration component will be added to the oscillation. This additional component causes a phase shift on some places of the tubes which can be measured with sensors [9].

2.3 Electromagnetic flow meter

An electromagnetic flow meter operate on Faraday's law of electromagnetic induction that states that a voltage will be induced when a conductor moves through a magnetic field. The liquid serves as the conductor and the magnetic field is created by energized coils outside the flow tube.

The voltage produced is directly proportional to the flow rate. Two electrodes mounted in the pipe wall detect the voltage which is measured by a secondary element.

Electromagnetic flow meters can measure difficult and corrosive liquids and slurries, and they can measure flow in both directions with equal accuracy.

Electromagnetic flow meters have a relatively high power consumption and can only be used for electrical conductive fluids as water [9].

2.4 Orifice plate flow meter

As the fluid approaches the orifice the pressure increases slightly and then drops suddenly as the orifice is passed. It continues to drop until the "vena contracta" (The minimum cross sectional area of the jet) is reached and then gradually increases until at approximately 5 to 8 diameters downstream a maximum pressure point is reached that will be lower than the pressure upstream of the orifice. The decrease in pressure as the fluid passes through the orifice is a result of the increased velocity of the gas passing through the reduced area of the orifice. When the velocity decreases as the fluid leaves the orifice the pressure increases and tends to return to its original level. All of the pressure loss is not recovered because of friction and turbulence losses in the stream. The pressure drop across the orifice (figure 2.3) increases when the rate of flow increases. When there is no flow there is no differential. The differential pressure is proportional to the square of the velocity, it therefore follows that if all other factors remain constant, then the differential is proportional to the square of the rate of flow [7].

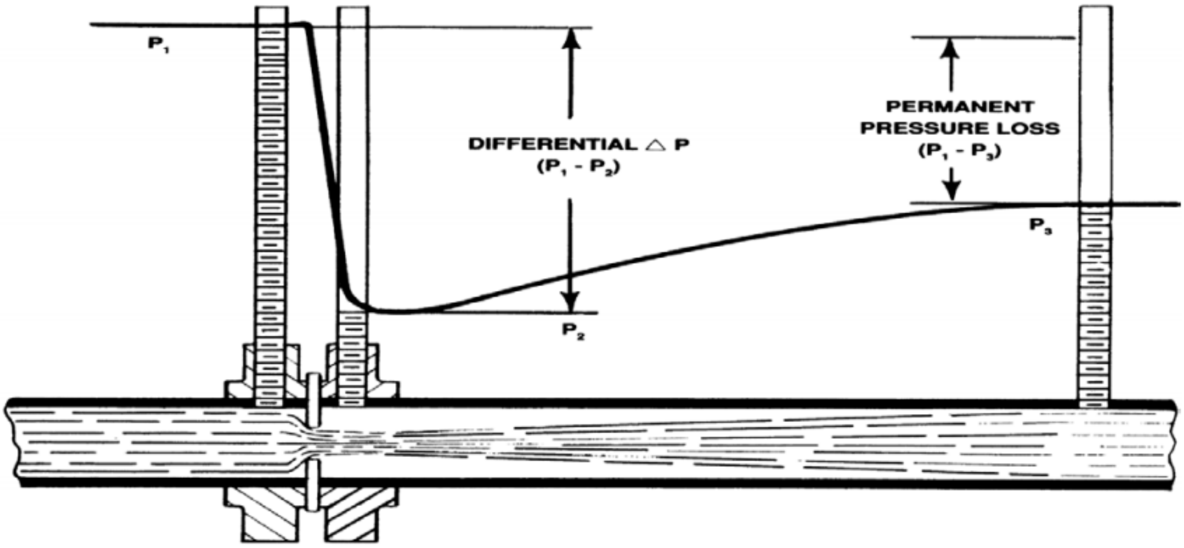


Figure 2.3: Orifice plate flow meter [7]

2.5 Calorimetric flow meter

The calorimetric principle for fluid flow measurement is based on two temperature sensors in close contact with the fluid but thermal insulated from each other. One of the two sensors is constantly heated and the cooling effect of the flowing fluid is used to monitor the flowrate. In a stationary (no flow) fluid condition there is a constant temperature difference between the two temperature sensors. When the fluid flow increases, heat energy is drawn from the heated sensor and the temperature difference between the sensors are reduced. The reduction is proportional to the flow rate of the fluid.

Response times will vary due the thermal conductivity of the fluid. In general lower thermal conductivity require higher velocity for proper measurement.

The calorimetric flow meter can achieve relatively high accuracy at low flow rates[9].

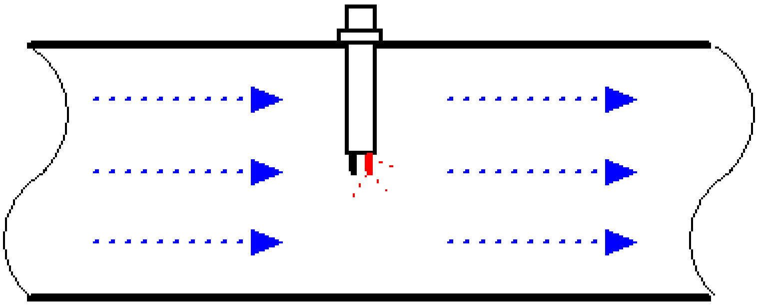


Figure 2.4: Calorimetric flow meter [9]

2.6 Pitot tube

The principle of flow measurement by Pitot tube was adopted first by a French Scientist Henri Pitot in 1732 for measuring velocities in the river. A right angled glass tube, large enough for capillary effects to be negligible, is used for the purpose. One end of the tube faces the flow while the other end is open to the atmosphere.

The liquid flows up the tube and when equilibrium is attained, the liquid reaches a height above the free surface of the water stream. Since the static pressure, under this situation, is equal to the hydrostatic pressure due to its depth below the free surface, the difference in level between the liquid in the glass tube and the free surface becomes the measure of dynamic pressure. Therefore, we can write, neglecting friction (equation 2.2) :

$$p_0 - p = \frac{\rho v^2}{2} = \rho g h \tag{2.2}$$

where p_0, p and v are the stagnation pressure, static pressure and velocity respectively at point A (figure 2.5) [2].

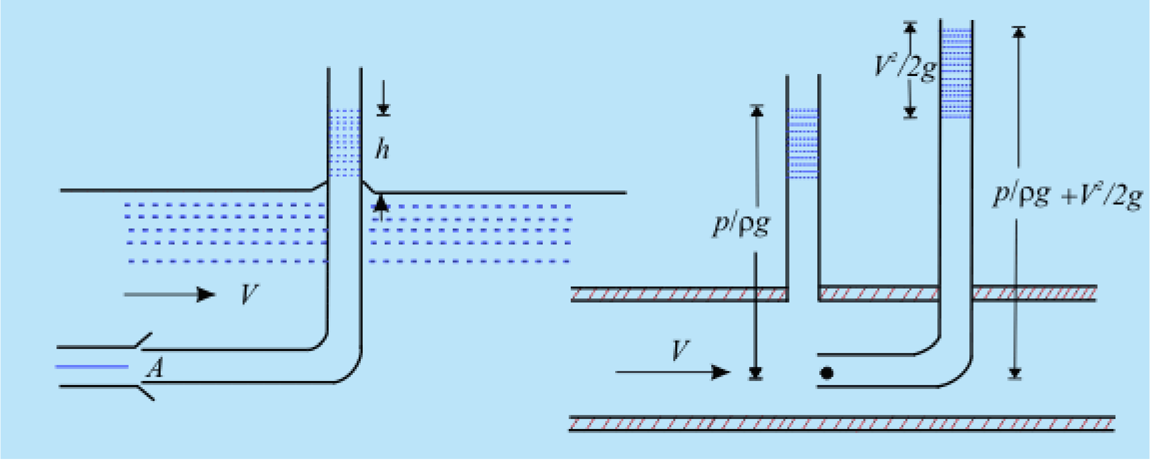


Figure 2.5: Pitot tube [2]

Chapter 3

Experiments and results

3.1 System presentation

The proposed hydraulic system is a test prototype of an airlift pump that needs compressed air flow measurement and water flow measurement at the same time in order to determine the relation between them. The water flow measurement is done while water flows into a big tank dedicated for liquids' flow measurement. As the water level increases, an ultrasonic transceiver detects the level, knowing the tank's dimensions, the average flow rate is calculated with simple mathematical equation.

This thesis will focus on the air flow rate which is more complicated to measure. As seen before, many methods of flow measurement exist, but when considering the compressed air characteristics such as density and physical state (gas), we can conclude that the most suitable method of air flow rate measurement for this case is Pitot tube 3.1.

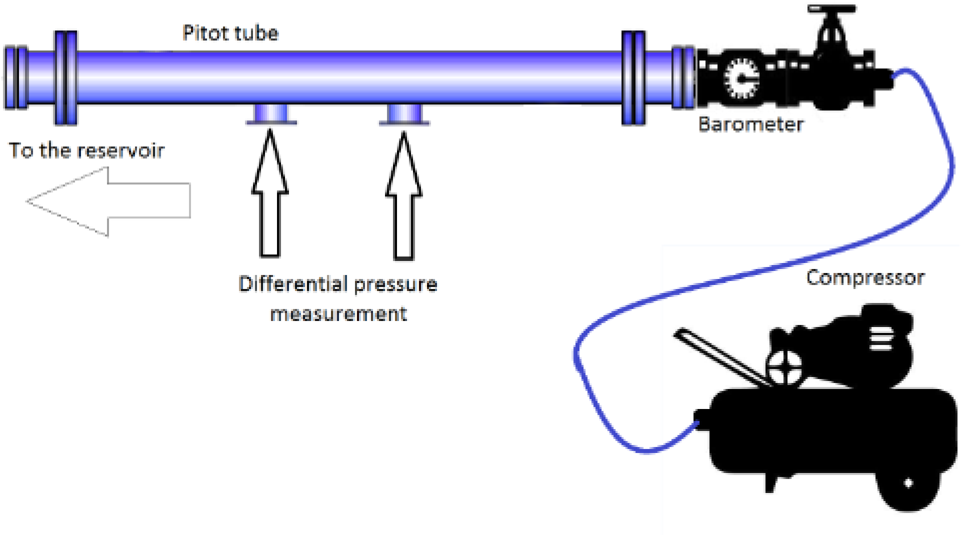


Figure 3.1: System schema

Hence, with the use of Pitot tube whose principle is explained above, the flow measurement problem is reduced to differential pressure measurement. That means that simple pressure measurement method would be sufficient, but we have to verify its efficiency.

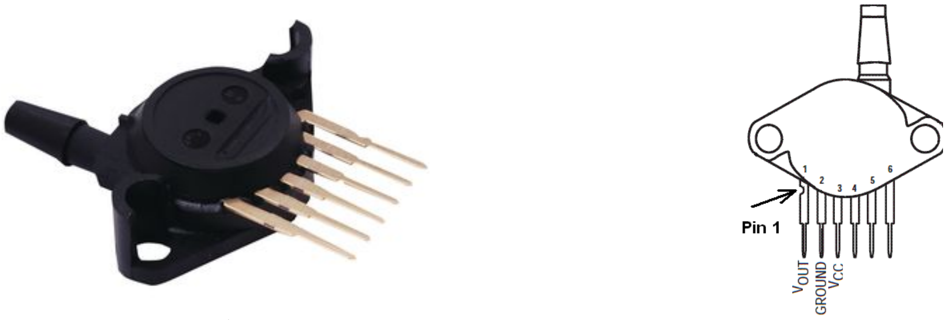
3.2 First method: using MPX4250AP pressure sensors

Firstly, I will briefly introduce the pressure sensor and some of its characteristics.

The pressure sensor MPX4250AP

The MPX4250 series sensor integrates on–chip, bipolar op-amp circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. The small form factor and reliability of on–chip integration make the Motorola MAP sensor a logical and economical choice for automotive system designers[1].

This sensor's working principle is very simple: when it is put to a pressure it directly gives an equivalent voltage that can be received from V_{out} PIN.



MPX4250AP picture

MPX4250AP PINs

Figure 3.3: Motorola MPX4250AP pressure sensor.

In fact, this sensor works on the absolute pressure principle which is referred to the vacuum of free space (zero pressure). In practice, absolute piezoresistive pressure sensors measure the pressure relative to a high vacuum reference sealed behind its sensing diaphragm. The vacuum has to be negligible compared to the pressure to be measured. First Sensor's absolute pressure sensors offer ranges from 1 bar or even 700 mbar as well as barometric pressure ranges (see figure 3.4).

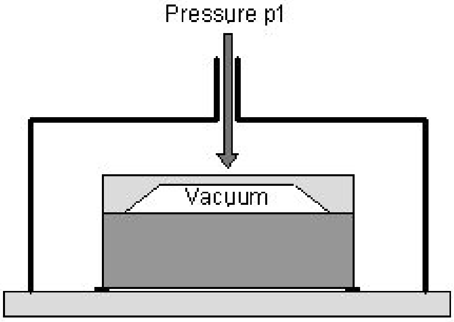


Figure 3.4: Principle of an absolute pressure sensor (piezoresistive technology)

Its transfer function is given by:

$$V_{out} = V_s(P0.004 - 0.04) \tag{3.1}$$

with $V_s = 5.1 \pm 0.25V$.

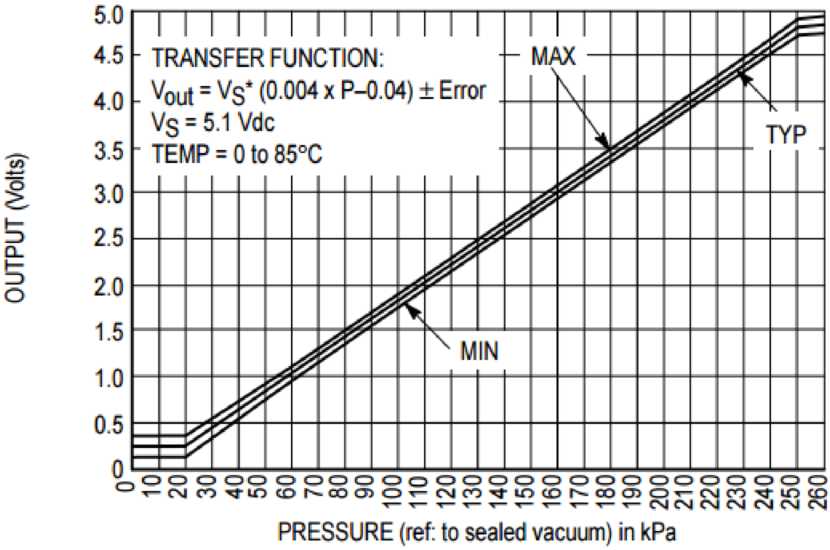


Figure 3.5: Output voltage in function of absolute pressure [1].

Differential pressure measurement

As said before, Pitot tube reduces the flow measurement problem into differential pressure measurement. Using two MPX4250 pressure sensors, one for static pressure and the other for dynamic pressure measurement on the Pitot tube we can measure flow as shown in figures 3.6 and 3.7.

Figure 3.6: Flow measurement with two pressure sensors

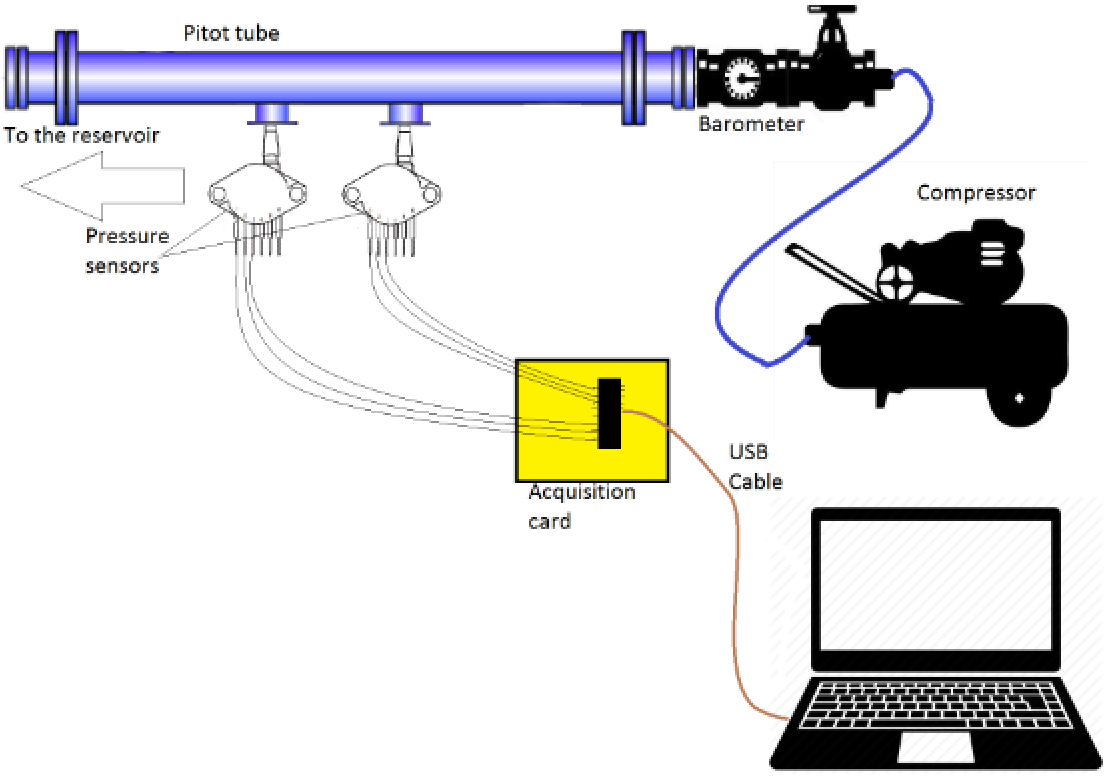


Figure 3.7: Flow measurement with two pressure sensors (schema)

These sensors send data to an acquisition card (figure 3.8) where a microcontroller process it and send it to computer through USB cable in order to display it, plot it and store it.

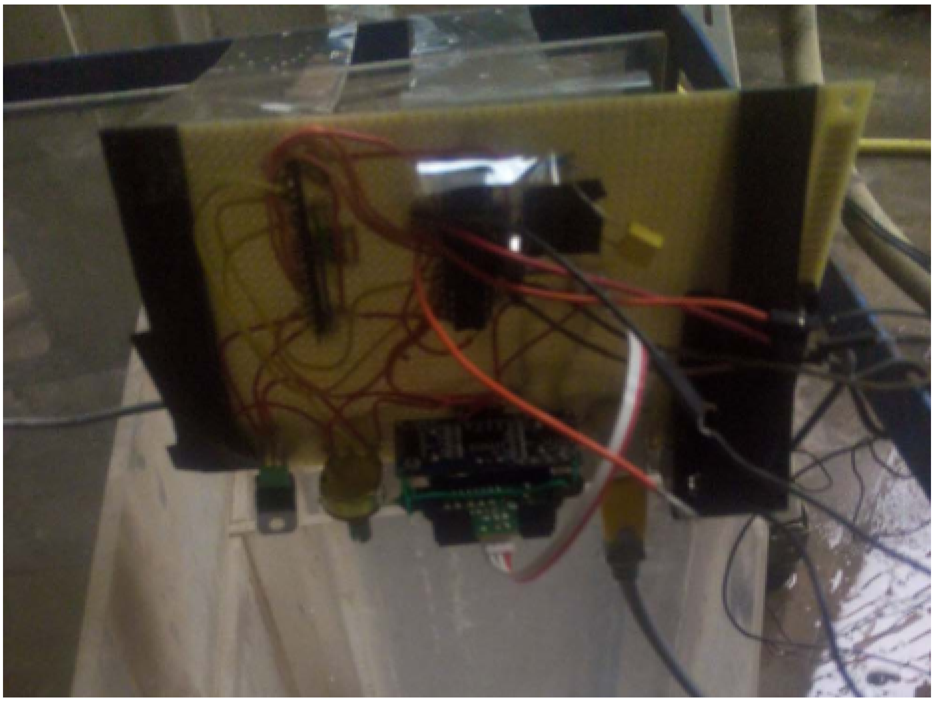


Figure 3.8: Acquisition card

Microcontroller program

The data processing is done by the microcontroller PIC18F2550. The data is then sent to computer in order to visualise it, plot it and store it by a graphical interface. The program of the microcontroller is given below.

```
// LCD module connections
sbit LCD_RS at RB4_bit;
sbit LCD_EN at RB5_bit;
sbit LCD_D4 at RB0_bit;
sbit LCD_D5 at RB1_bit;
sbit LCD_D6 at RB2_bit;
sbit LCD_D7 at RB3_bit;
sbit LCD_RS_Direction at TRISB4_bit;
sbit LCD_EN_Direction at TRISB5_bit;
sbit LCD_D4_Direction at TRISB0_bit;
sbit LCD_D5_Direction at TRISB1_bit;
sbit LCD_D6_Direction at TRISB2_bit;
sbit LCD_D7_Direction at TRISB3_bit;
// End LCD module connections

//-----------------------------------------------------
unsigned char readbuff[64] absolute 0x500;
// We create two buffers: one for sending data to USB
unsigned char writebuff[64] absolute 0x540;
// and one for receiving data from USB.
//-----------------------------------------------------


void interrupt()
{
   USB_Interrupt_Proc(); // Activating USB servicing inside the interrupt
}


int cnt=0;                                //global variable declaration

void main()

{

//Variable declaration

unsigned long d1;
    unsigned long d2;
   float d,da,db;
int a,m,n,l;
   char txt1[8];
   char txt2[10];




ADC_Init();                        // Initialize Analog Digital Converters

   ADCON1=0x0E;             // Analog PINs specification


Lcd_Init();       /initialization of LCD
   Lcd_Cmd(_LCD_CLEAR);          // Clear display
   Lcd_Cmd(_LCD_CURSOR_OFF);     // Cursor off
```

```
   HID_Enable(&readbuff,&writebuff);      // Enable HID communication



Lcd_Out(1,1,"Developed By");      //writing on LCD
   Lcd_Out(2,1,"PolyTech");

   Delay_ms(3000);
   Lcd_Cmd(_LCD_CLEAR);



while(1)

{
//First pressure sensor

     d1=ADC_Read(1); //Reading the index from the analog digital converter
     da=d1;
     da=da*5/1023; //Calculating the voltage equivalent to the index

//Sensor calibration
     da=((da/5.1)+0.04)/0.004;
     da=da+5;

       FloatToStr(da, txt1);            // Convert voltage to string
       Ltrim(txt1);
       Lcd_Out(1,1,"Pres1 = ");
       Lcd_Out(1,9,txt1);
       Lcd_Out(1,15,"cm");



//Copying data to USB write buffer
if(da<100) m=7;
     else m=8;
       for(cnt=l+1;cnt<l+m+1;cnt++)
       writebuff[cnt]=txt1[cnt-l-1];
       writebuff[l+m+1]=’;’;


            //Second pressure sensor

d2= ADC_Get_Sample(0);
     d2=ADC_Read(0);
     db=d2;
     db=db*5/1023;
     db=((db/5.1)+0.04)/0.004;
     db=db+3;

      FloatToStr(db, txt2);
       Ltrim(txt2);
       Lcd_Out(2,1,"Pres2 = ");
       Lcd_Out(2,9,txt2);
       for(cnt=l+m+2;cnt<l+m+12;cnt++)
       writebuff[cnt]=txt2[cnt-l-m-2];


      hid_write(&writebuff,64); //sending the USB write buffer to USB data PINs
```

```
    Delay_ms(1000);
    }
}
```

Results

The result of the pressure measurement is given in the table 3.1 where P1 and P2 are the pressure values coming from the two pressure sensors implemented on Pitot tube and the last column is the differential pressure. The graph plotted in figure 3.9 represents the differential pressure (P1-P2) in kPa in function of time (s).

Time (s)	P1 (kPa)	P2 (kPa)	P1-P2 (kPa)
1	194,5656	191,2947	3,2709
2	195,0448	192,7322	2,3126
3	194,0864	192,0134	2,073
4	194,5656	191,5343	3,0313
5	194,0864	192,7322	1,3542
6	194,5656	193,2114	1,3542
7	194,0864	192,7322	1,3542
8	194,8052	192,0134	2,7917
9	194,0864	192,0134	2,073
10	194,8052	192,0134	2,7918
11	193,8468	192,4926	1,3542
12	194,0864	192,0134	2,073
13	195,7635	192,0134	3,7501
14	194,5656	192,7322	1,8334
15	194,5656	192,0134	2,5522
16	194,0864	192,0134	2,073
17	194,0864	192,9718	1,1146
18	194,5656	192,4926	2,073
19	195,0448	192,9718	2,073
20	194,5656	192,7322	1,8334
21	194,0864	192,0134	2,073
22	194,5656	192,7322	1,8334
23	194,0864	192,4926	1,5938
24	194,8052	192,7322	2,073
25	195,0448	192,4926	2,5522
26	194,5656	192,7322	1,8334
27	186,4196	192,0134	2,594
28	194,0864	192,0134	2,073
29	194,0864	192,9718	1,1146
30	194,8052	192,4926	2,3126
31	194,8052	192,7322	2,073
32	195,2844	192,9718	2,3126
33	194,0864	192,7322	1,3542
34	194,5656	192,0134	2,5522
35	195,0448	192,0134	3,0313
36	194,0864	192,0134	2,073
37	194,8052	192,9718	1,8334
38	194,0864	191,7739	2,3126

Table 3.1: First method: table of values

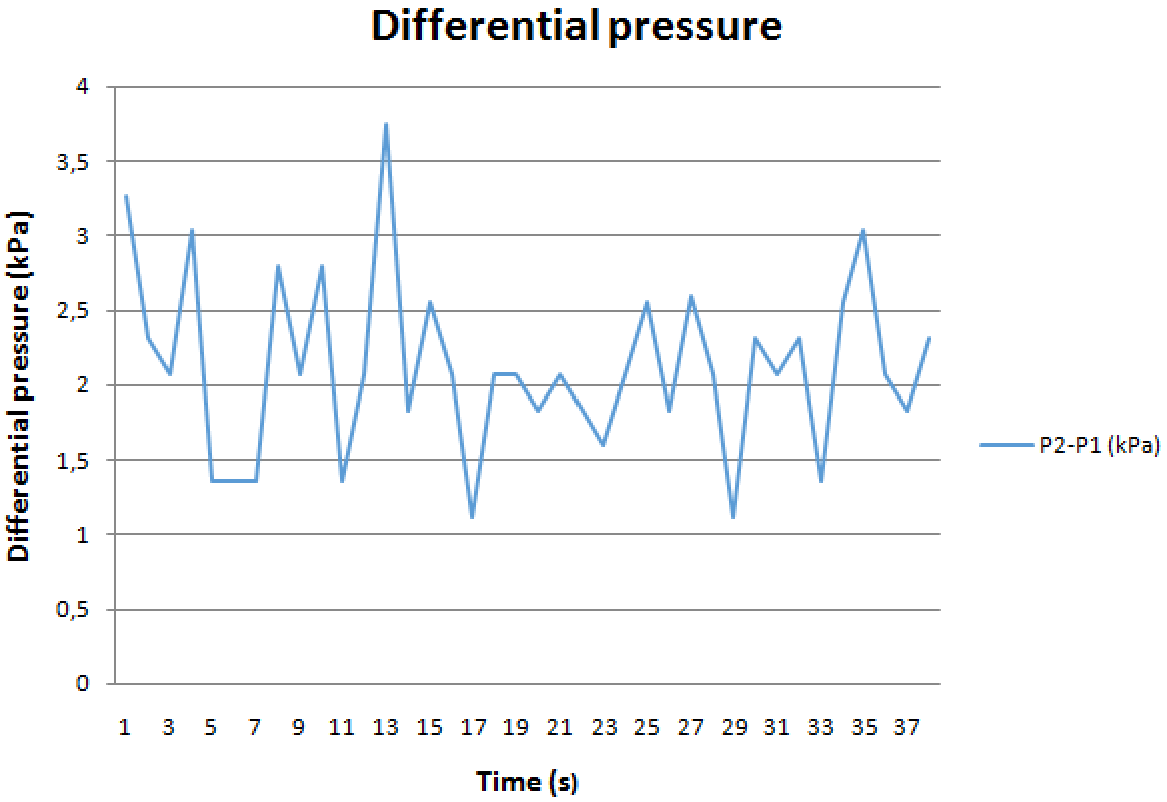


Figure 3.9: Differential pressure (P1-P2) in kPa

We notice that the pressure from the first sensor was around 194 kPa and the pressure from the second sensor was around 192 kPa. The differential pressure is between 1 and 3 kPa which is a very low value.

Knowing that the maximum error value for the pressure sensor MPX4250AP is 3.45 kPa (given by the constructor Motorola [1]), we notice that the differential pressure calculated from the pressure values measured by sensors didn't exceed the maximum error value given by the constructor. This leads us to consider the precision of the sensors insufficient for this application. In order to measure the differential pressure correctly, we need a more precised method.

3.3 second method: using the ultrasonic transceivers HC-SR04

The previous method has shown an insufficient precision in measuring the differential pressure, this leads to false values in calculating the air flow rate.

Many pressure sensors with better precision than MPX4250AP exist in markets, but they remain very expensive due to the sensitive technology used in their construction. However, a mechanical solution exits with a good and sufficient precision that response to our problem and can replace the sensors. This method is the water U tube manometer. With a density of $1g/cm^3$, the water makes the manometer 13 times better in precision than mercury.

Moreover, the water is not dangerous contrary to the mercury that is poisoned and should be treated carefully. In the other hand, this method still has the disadvantages of all mechanical methods that are the impossibility of electronic processing and real time visualisation.

Since the differential pressure is transformed into a level difference by the manometer, reading level will be sufficient to calculate the flow rate using the Pitot tube. Therefore, two ultrasonic transceivers placed at both legs of the manometer can combine the mechanical method's precision with the electronic measurement advantages.

Ultrasonic transceiver HC-SR04

Here are some general notions about the ultrasonic transceiver HC-SR04.

Ultrasonic transducers operate based on both converse and direct effects of piezoelectric materials in which the vibration would be produced upon the application of a potential difference across the electrodes and then the signal would be generated when receiving an echo. Consequently, piezoelectric elements play a very important role in transducer technology. For specific applications, proper piezoelectric materials are chosen according to a number of factors such as their piezoelectric performance, dielectric properties, elastic properties and stability. A transducer rings at its natural frequency once it is excited by an electrical source. Since the piezoelectric material itself exhibits much higher acoustic impedance (30 MRayl) than that of biological tissue or water (1.5 MRayl), a substantial part of the acoustic energy would be lost at the rear interface and not directed into the forward direction, resulting in poor resolution and sensitivity, if not properly matched acoustically. The transducer is usually treated as a three–port network including two mechanical ports and one electrical port as shown in figure 3.10 [12].

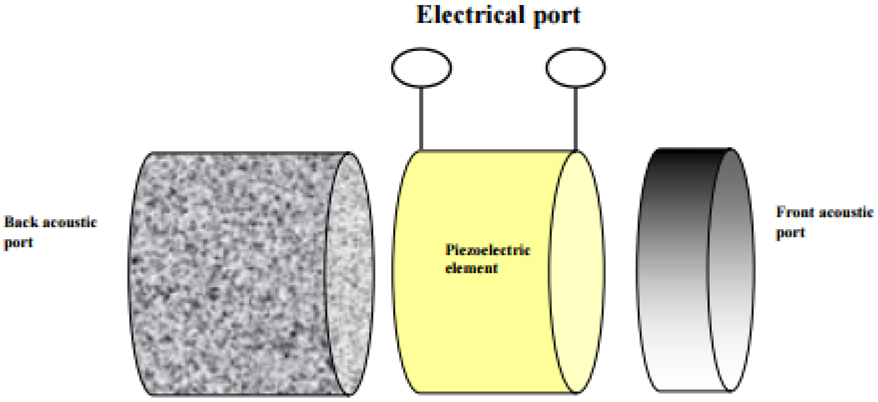


Figure 3.10: A three–port network of the transducer [12]

The mechanical ports represent the front and back surfaces of the piezoelectric element and the electrical port represents the electrical connection of the piezoelectric element to the electrical source. The front layer is known as an acoustic matching layer, which can improve the transducer performance significantly (Theoretical 100%). Transmission is shown to occur for a sinusoidal acoustic wave when the matching layer thickness approaches $\frac{\lambda_m}{4}$ and acoustic impedance of the matching layer material Z_m is :

$$Z_m = (Z_p Z_l)^{1/2} \tag{3.2}$$

where λ_m is the wavelength in the matching layer material, Z_p and Z_l are the acoustic impedances of piezoelectric material and the loading medium, respectively. For wide-band signal, the acoustic impedance of the single matching layer should be modified to be :

$$Z_m = (Z_p Z_l^2)^{1/3} \tag{3.3}$$

In fact, 100% transmission is impossible for only considering the front matching layer. Due to the acoustic mismatch between the air and the piezoelectric material, the reflected wave reverberates inside the transducer element. This would cause long ring–down of the ultrasonic pulse, which is the so–called ringing effect. For imaging applications, it is highly undesirable to have a pulse with long duration. Backing layer can be used to damp out the ringing by absorbing part of the energy from the vibration of the back face. Besides minimizing the acoustic impedance mismatch, the backing layer can also act as a supporting layer of the fragile transducer element because of its relative rigid nature of the piezoelectric layer.
The general schema of the ultrasonic level measurement is explaining in figure 3.11.

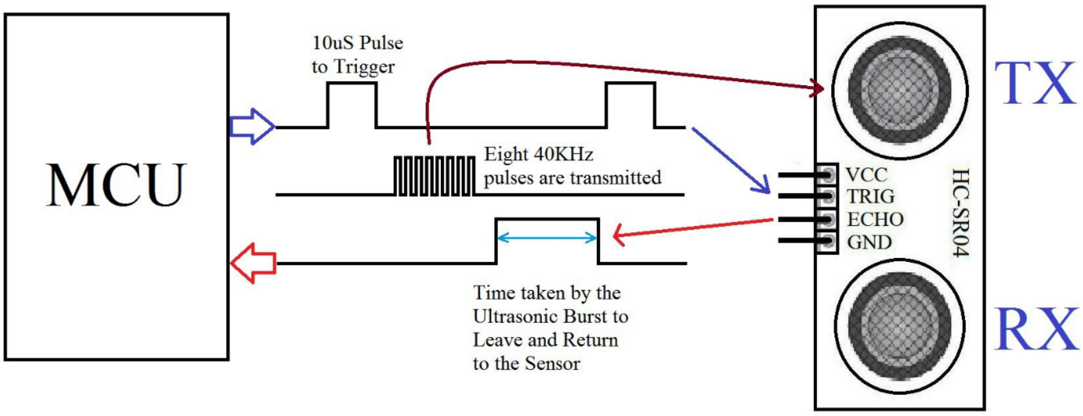


Figure 3.11: General schema of ultrasonic level measurement principle

Microcontroller program

```
// LCD module connections
sbit LCD_RS at RB4_bit;
sbit LCD_EN at RB5_bit;
sbit LCD_D4 at RB0_bit;
sbit LCD_D5 at RB1_bit;
sbit LCD_D6 at RB2_bit;
sbit LCD_D7 at RB3_bit;
sbit LCD_RS_Direction at TRISB4_bit;
sbit LCD_EN_Direction at TRISB5_bit;
sbit LCD_D4_Direction at TRISB0_bit;
sbit LCD_D5_Direction at TRISB1_bit;
sbit LCD_D6_Direction at TRISB2_bit;
sbit LCD_D7_Direction at TRISB3_bit;
// End LCD module connections

//---------------------------------------------------
unsigned char readbuff[64] absolute 0x500;
// We create two buffers: one for sending data to USB
unsigned char writebuff[64] absolute 0x540;
// and one for receiving data from USB.
//---------------------------------------------------


void interrupt()
{
   USB_Interrupt_Proc(); // Activating USB servicing inside the interrupt
}


int cnt=0;                                  //global variable declaration

void main()

{

//Variable declaration

unsigned long d1;
    unsigned long d2;
   float d,da,db;
int a,m,n,l;
   char txt[3];
```

```
Lcd_Init();       /initialization of LCD
   Lcd_Cmd(_LCD_CLEAR);          // Clear display
   Lcd_Cmd(_LCD_CURSOR_OFF);     // Cursor off




TRISB = 0b10000000;           //RB7 as Input PIN (ECHO for ultrasonic)

   HID_Enable(&readbuff,&writebuff);      // Enable HID communication



Lcd_Out(1,1,"Developed By");      //writing on LCD
   Lcd_Out(2,1,"PolyTech");

   Delay_ms(3000);
   Lcd_Cmd(_LCD_CLEAR);

   T1CON = 0x10;                 //Initialize Timer Module




while(1)

{

     TMR1H = 0;                  //Sets the Initial Value of Timer
    TMR1L = 0;                  //Sets the Initial Value of Timer


//Pulse generating
     PORTB.F6 = 1;               //TRIGGER HIGH (RB6 as an output
     for ultrasonic trigger)
     Delay_us(10);               //10uS Delay
     PORTB.F6 = 0;               //TRIGGER LOW




     while(!PORTB.F7);           //Waiting for Echo
     T1CON.F0 = 1;               //Timer Starts
     while(PORTB.F7);            //Waiting for Echo goes LOW
     T1CON.F0 = 0;               //Timer Stops

     a = (TMR1L | (TMR1H<<8));   //Reads Timer Value
     a = a/5.882;                //Converts Time to Distance




if(a>=20 && a<=24000)          //Check whether the result is valid or not
     { a=a/5.7; //distance calibration
         a = a + 1;
       IntToStr(a,txt); //Conversion of the value to character
```

```
       Ltrim(txt); // cutting the character string

//display the character on the LCD
Lcd_Cmd(_LCD_CLEAR);
       Lcd_Out(1,1,"Distance = ");
       Lcd_Out(1,12,txt);
       Lcd_Out(1,15,"mm");


//Copying data to the USB writing buffer
       if(a<100) l=2;
       else l=3;
       for(cnt=0;cnt<l;cnt++)
       writebuff[cnt]=txt[cnt];
       writebuff[l]=';';
       }


else
     {
       Lcd_Cmd(_LCD_CLEAR);
      Lcd_Out(1,1,"Out of Range");
     }

Delay_ms(1000); //waiting


      hid_write(&writebuff,64); //sending the USB write buffer to USB data PINs


   }

}
```

Level measurement

Thanks to the manometer, we can calculate differential pressure from the level difference between its legs with much more precision than the pressure sensors MPX4250AP. The implementation of two ultrasonic transceivers up on the manometer's legs (see figure 3.12) offers electronic measurement of level which means electronic processing and data acquisition in computer. This combination between the mechanical method and the electronic sensors gives the possibility of real-time visualisation of pressure on computer, graph plotting and storage.

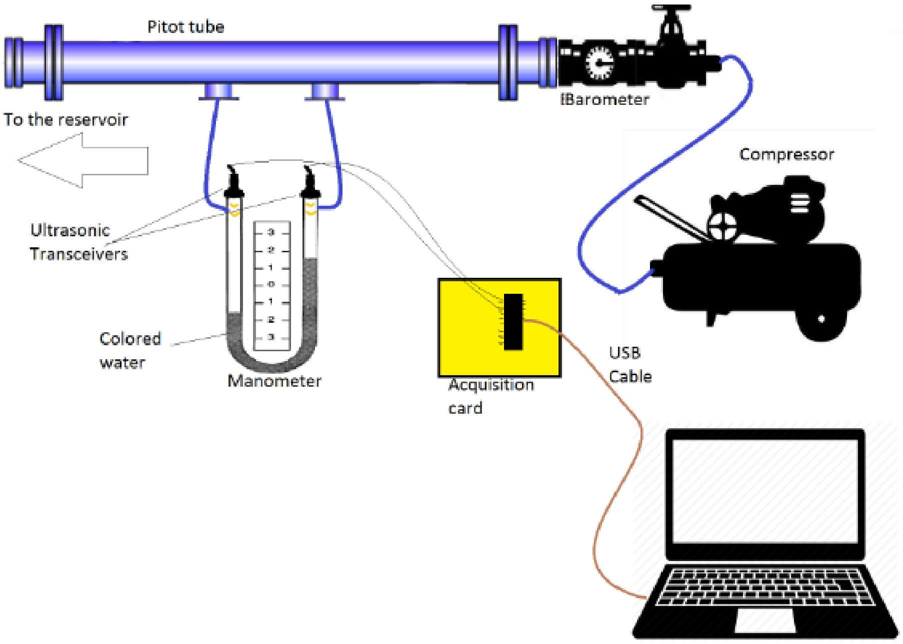


Figure 3.12: Flow measurement using ultrasonic transceiver

Due to dimension problem, it is impossible to implement the ultrasonic transceiver HC-SR04 on the manometer's leg, but since the air flow is related to the water flow, the implementation of the HC-SR04 on a flow-measuring tank can verify the method's results. These results compared to level difference between the manometer's legs while visualising both at the same time can confirm the method's functioning. The water-flow measuring tank offers the possibility to measure water flow through level (see figure 3.13).

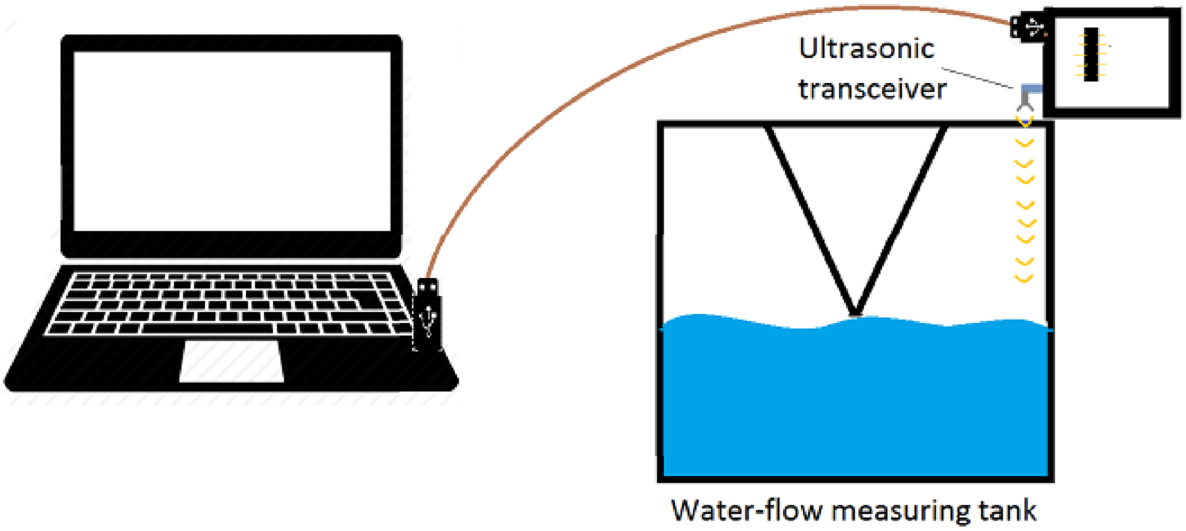


Figure 3.13: Water flow measurement using ultrasonic transceiver

The visualisation of water level values (expressed by distance sensor-water in table 3.2 and figure 3.14) while watching the level difference in manometer's legs 3.16 allows us to see the simultaneous increase in both water flow and compressed air flow.

Time (s)	Distance sensor-water (mm)
1	286
2	285
3	285
4	284
5	283
6	283
7	282
8	282
9	281
10	281
11	280
12	279
13	279
14	278
15	277
16	277
17	277
18	276
19	276
20	276
21	276
22	276
23	275

Table 3.2: Second method : table of values

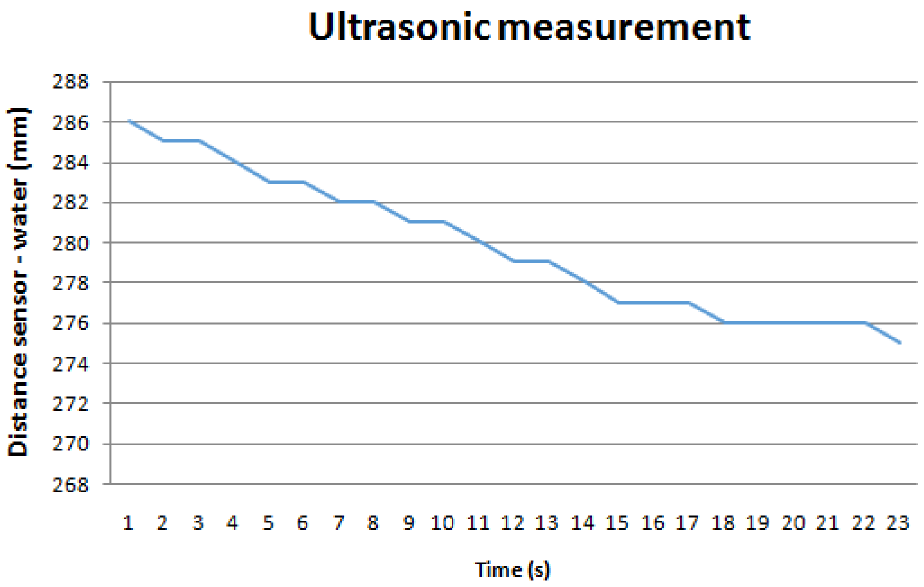


Figure 3.14: Sensor-water distance

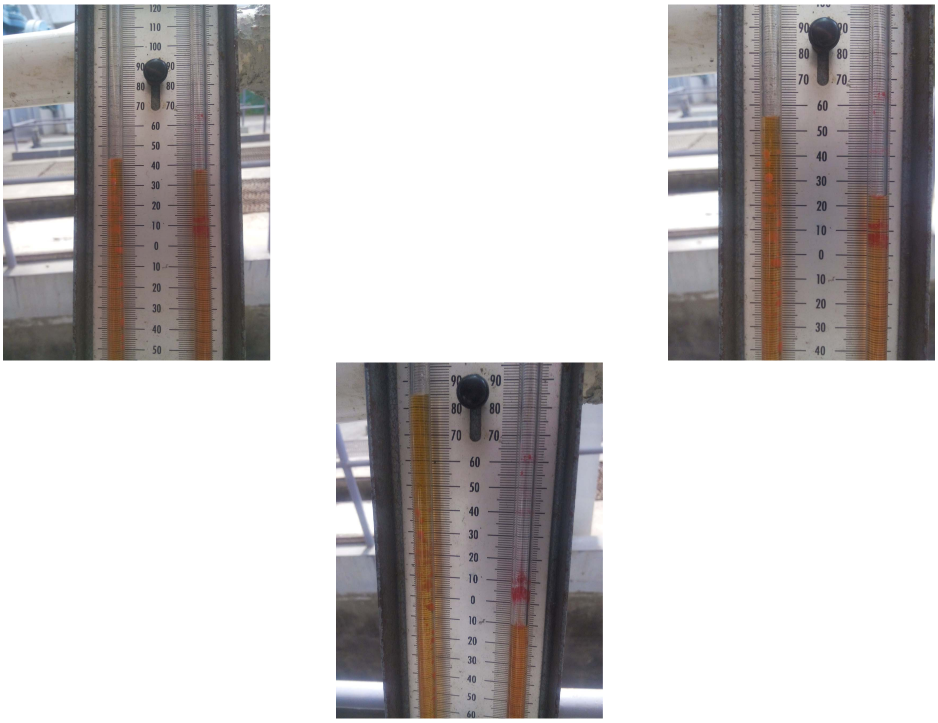


Figure 3.16: Differential pressure represented by level difference in manometer's legs

Both water level in the tank and the level difference in the manometer increase. This means that the ultrasonic transceiver is able to measure the compressed air flow rate using the level difference between manometer's legs.

With a resolution of 1mm and a maximum error of 3mm, the minimum differential pressure that can be measured $3mmH_2O$. Using equation 2.2 we can calculate the equivalent flow rate to $3mmH_2O$ in a 10cm diameter Pitot tube. So, the smallest flow rate value detected by ultrasonic transceiver is $1.905mm^3/s$ which means $11.43cm^3/min$.

This result is around 10 times better in precision than the MPX4250AP minimum value ($20.63mm^2/s$ which is $124cm^2/s$). In better conditions, two smaller ultrasonic transceivers (8 mm for example) would be able to perform the measurement and extract the flow rate in real time.

Conclusion

The combination of different measurement methods can lead to a new method regrouping the advantages from the classical ones. Ultrasonic transceiver is a simple electronic device that is relatively cheap and available in markets and the U tube manometers are simple mechanical instruments that can be found in all hydraulic laboratories. The implementation of ultrasonic transceivers on manometer's legs led us to a simple but efficient measurement method with both electronic and mechanical advantages.

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