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Using the Coriolis Acceleration to Design a Digital Mass Flow Meter

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ABSTRACT

There are several ways to measure fluid flow can be generally divided into three groups: analyzed, volumetric and the mass. In this project, the design and construction of a mass flow meter using the Coriolis acceleration is analyzed. In this design, measurement of the mass of the fluid is done without the involvement of other physical properties by an appropriate theory and design. So this flow meter is able to measure the mass flow with less error than other flow meters. Also one can measure the various fluids flow rates by using various valves. It will be cost affordable. The springs are used on sensor to change the measuring range can be changed. Using a spring with larger k, the measuring range increases.

Keywords: Coriolis acceleration, mass flow meter.

INTRODUCTION

When the mass flow meter is based on Coriolis force, it is named Coriolis flow meter. Many industrial processes require accurate measurement of mass flow. Commonly used flow meters often measure volume of flow. Then, using the volume and density, mass of fluid can be calculated by equation 1.

Mass=Volume*Density Eq. 1

When density is constant, volume of fluid can be converted to mass easily. But changes in temperature, pressure and viscosity can be effect on the density and would conclude lower accuracy at the mass measurement. For example, in areas where temperatures are high in summer, amount of mass of fuel that is showed by car screen, is more than what it imports fuel tank.

So the difference between the amount of fuel indicated by the fuel station and the amount of fuel in the vehicle fuel tank is the reduction in the density of the fuel by the temperature decrement. We need measure mass directly to fix this problem.

By using Coriolis mass flow meter, mass of fluid is calculated by pipe harmonic movement. Changes in the direction of flow by the tube vibration are caused the Coriolis force.

Coriolis force that the tube is inserted in the y direction is calculated by designed sensor, then the mass is measured using this force.

Advantages of this flow meter can be as follows:

- Providing advanced diagnostic tools to measure fluid conditions
- The ability to measure mass, volume, temperature and velocity of the fluid as well as the different conditions in a single device
- Accurate and repeatable data delivery in a wide range of flow rates in different situations

2- History

Review of Coriolis flow meters that has been made clear that the building of these flow meters consist of two tubes with vibrating properties and the torsion of tube is measured by the detector system.

Twin-tube design that fluid flows in two parallel pipes to remove the effects of vibration effectively. Tube of flow meter is the only part of Coriolis flow meter that is in contact with the liquid and typically is made of stainless steel.

Vibration caused by pipe is recorded using chart of recorder devices. This process was done manually previously. With the advancement of technology, this process is done using the software is no longer necessary to use paper. This deices have an important memory and all changes resulting from inputs are kept in this memory. These devices have a screen that can be customized for each operator to observe the quantity [1].

3- Methods of Measurement

Methods for measuring fluid flow can be divided into three groups:

A) Inferential flow meter method

B) Volumetric flow meter method

C) Mass flow meter method

(A) Inductive flow meter

This method is used in most fluid flow measurements. In this method, flow rate of the fluid can be calculated by measuring the different properties that have are in the fluid.

Analytical methods for measuring flow con be used as follows:

1) The liquid column (inferred by measuring the pressure difference created by the barrier fluid path)

2) Target flow meter (inferred by measuring the force)

3) Variable area flow meter (inferred by measuring the position of the float)

4) Magnetic flow meter (inferred by measuring the resulting voltage of the working fluid passes through a magnetic field)

5) Turbine flow meter (inferred by a factor proportional to the velocity)

6) Vortex flow meter (perception of vibration, pressure or temperature)

7) Ultrasonic flow meter (perception of sound intensity)

(B) Volumetric flow meter

If the device is able to measure the volume of fluid filled and emptied regularly provided that the remaining fluid volume is constant and the number of full and empty container can be measured, the flow rate can be determined.

One of the most common methods is positive displacement flow meter that is used to measure the products they are buying or selling.

(C) Mass flow meter

The Coriolis devices are used in many factories. Although this device has a high price, but because it can measure the mass of the fluid directly, used in some operations.

Also in some units, this type of flow meter can be used to measure the fluid to turn with integrated valves. The operation of this device is measuring the mass of fluid without the involvement of other physical properties [1].

4- Building of Flow Meter

In order to design accurate flow meter building and prevent the creation of problems and also saving time, at first a simple model of flow meter was made. With the help of this model, the exact location and dimensions of the flow meter sensors was estimated. This model is made of a bracket and a mechanism for generating oscillating motion, as shown in Figure 1.

In this simple model oscillating motion have done manually. But at the original design, an engine with adjustable angular velocity is used to provide constant oscillating motion in order to increase measurement accuracy.

Figure 1. Simple model

After several tests and check the results, the size and exact location of the flow meter gauge force sensor and the maximum measurable flow rate was estimated as follows:
Maximum of flow rate: 2.260 kg/s
Dimensions: 320*185*200 mm^3

Then, final modified plan was drawn using Solid Works software. The overall building of this Coriolis flow meter is shown in figure 2. As can be seen in the figure 2, construction of the flow meter is as follows:
1) A vibrating tube that can be said is a major component of the flow meter
2) Small engine leading to swing tube by adjustable angular velocity
3) Mechanism for transmission oscillating motion of the motor to the tube
4) Sensor of measuring the Coriolis force
5) Screen
6) The main body that the other components are installed on it

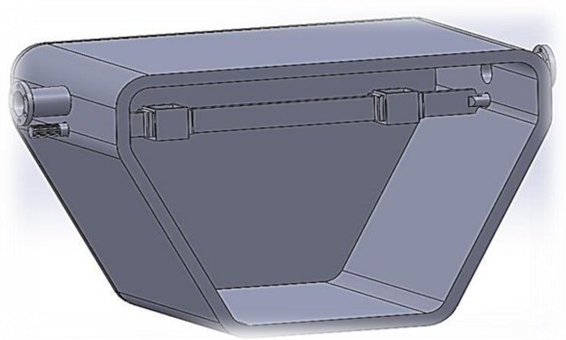

Figure 2. Building of final Corilis flow meter

In Figure 3, the location of the vibrating tube is shown by the blue line which is swing using designed mechanism.

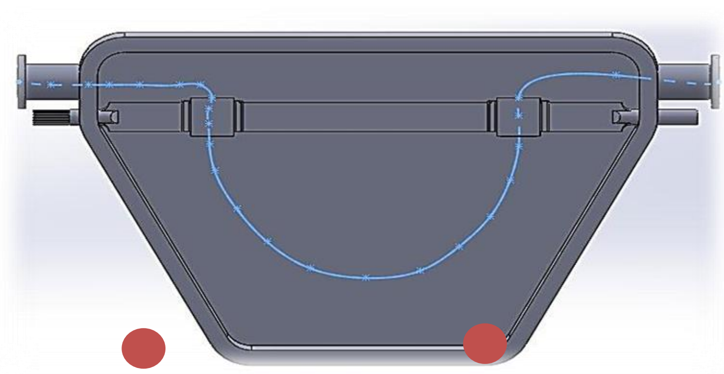

Figure 3. The Location of Vibrating Tube

Oscillation motion does by an external force which is funded by a small engine. This engine is installed on the outside of building of flow meter. Axes of mechanisms is connected to engine by a belt, thus oscillating motion of the motor is transmitted to axes.

5- The creation of the Coriolis force

Coriolis effect is a force overnight Coriolis force which distorts moving objects out of the straight line, from the perspective of an observer in a rotating device. As shown in Figure 4, it is visible that the flow meter has a vibrating pipe which has the adjustable swing speed.

If fluid be at rest, two points A and B shown in the figure 4 oscillate in a swing phase and its period is proportion to the angular velocity of engine.

If fluid is at moving state, difference phase occurs between the sensor A and B. The cause of this difference phase is the Coriolis force. This force is shown at figures 4 and 5 for counter clockwise and clockwise rotations respectively.

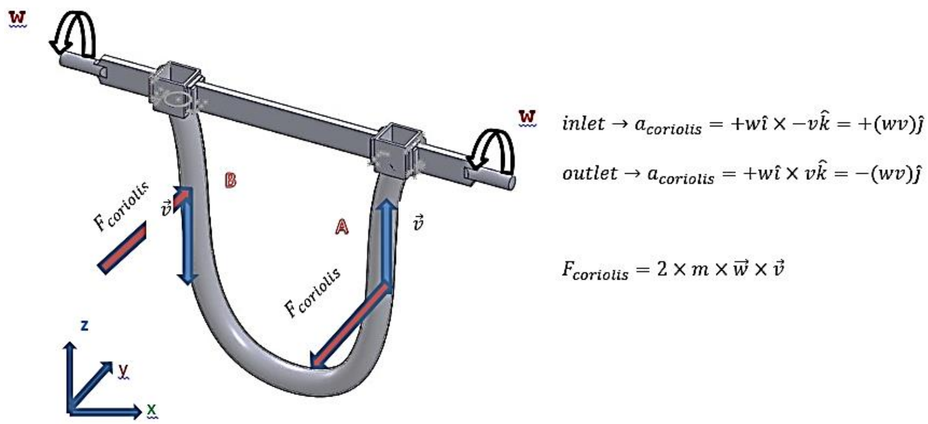

Figure 4. Corilis force at counter clockwise rotation

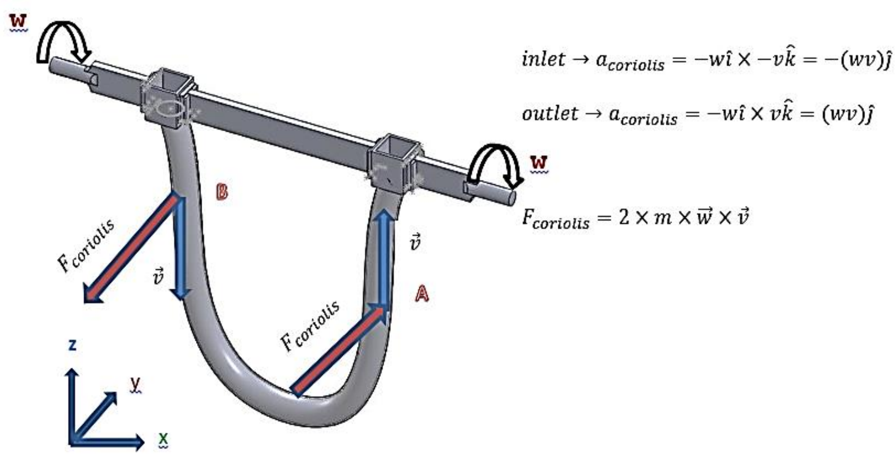

Figure 5. Corilis force at clockwise rotation

6- The effect of the Coriolis force on the mass of flow

The Coriolis force leading to the creation of a phase shift in two part of tube as shown at figure 6.

A fixed amount of mass is passes between signals A and B signal. If a bubble is firmed in path of fluid, amount of mass reduces and therefore Coriolis force reduces and distracting of pipe is reduced.

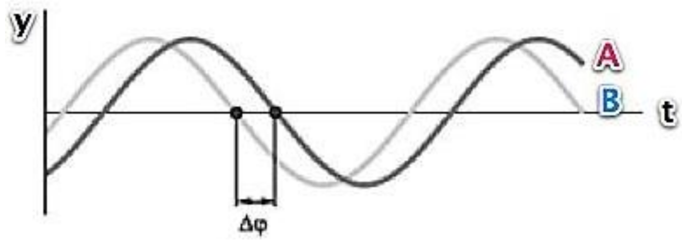

Figure 6. The phase difference between points A and B

The mass of flow is proportional to the phase difference between two points A, B. The phase difference can be obtained over the time by equation 2 where Δθ id the phase difference between two points and w is the angular velocity.

$$\Delta t = \frac{\Delta\theta}{w} \quad \text{Eq. 2}$$

The amount of fluid mass flow is proportional to the distance between the sensors 1 and 2 as equation 3 where the calibration factor (k) can be calculated according to boundary conditions.

$$\dot{m} = k\Delta t \quad \text{Eq. 3}$$

Considering the tube as a volume control as shown at figure 7, mass of flow can be calculated using Coriolis force by equation 4.

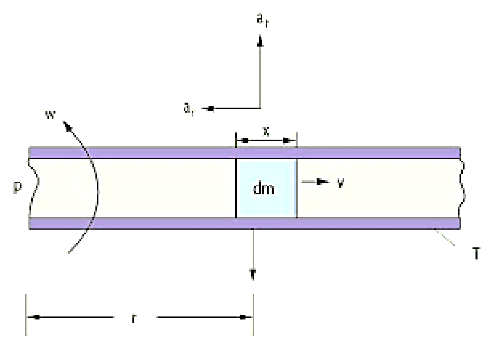

Figure 7. Considering Tube as a Volume Control

$$a_r = r \times w^2 \qquad a_t = 2 \times w \times v \qquad \text{Eq. 4}$$
$$dm = \rho V = \rho A x \qquad F_{coriolis} = \rho A x \times 2wv \qquad mass\ flow = \frac{F_{coriolis}}{2 \times w \times x}$$

The components of the measurement system are as follows:
(A) Atoniks Sensor
(B) AVR
(C) Screen

In this method, proximity sensor of Atoniks is used for measuring the flow rate. Number of oscillation sent to the AVR by this sensor. The heart of a measurement system is AVR that all calculations are done in it. An example of AVR (ATMEGA16) is shown in figure 8. The output mass can be shown in screen using programming.

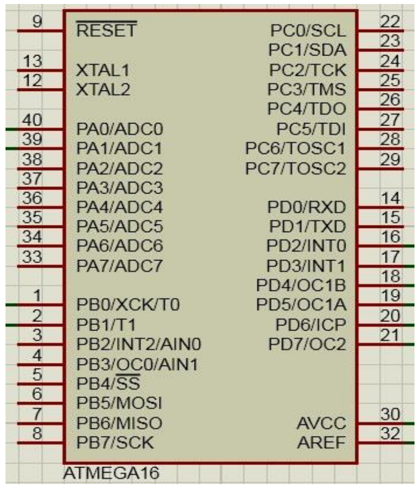

Figure 8. ATMEGA16

The sensor that is used in this flow meter is composed of a variable resistor and a spring as shown in figure 9. This sensor measure the Coriolis force and so mass of flow can be determined using equation 4.

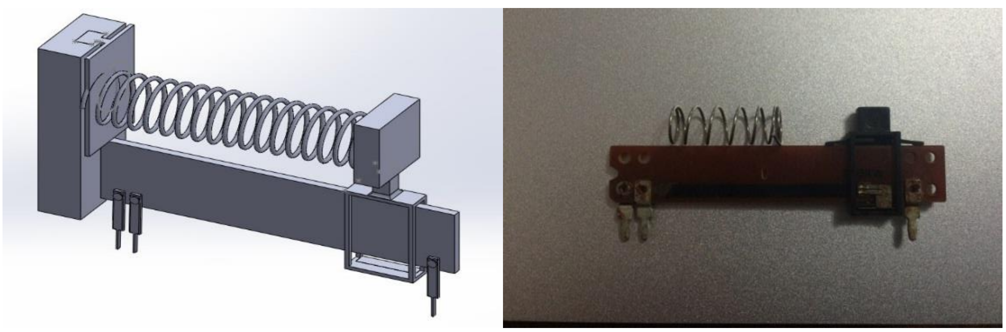
Figure 9. Sensor for measuring the force

7- Discussion and conclusion

Finally, after assembly the components of flow meter as shown in Figure 10, the designed flow meter is tested. Results of test are shown in table 1.

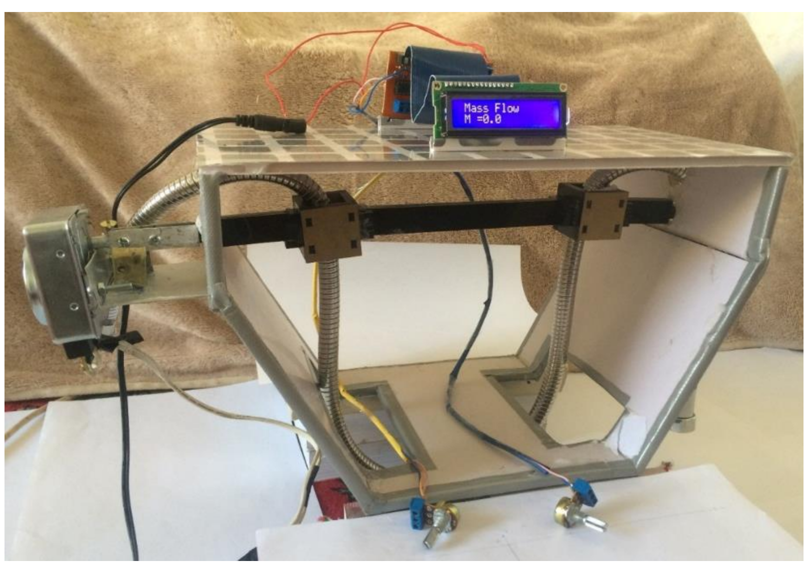

Figure 10. Final Designed Flow Meter

Table 1. Results of tests

Row	The measured Mass	The Actual Mass	Percentage of error
1	3.7 kg	5 kg	26%
2	9.2 kg	8 kg	15%
3	16 kg	10 kg	60%

The measured mass at row 3 has high difference from actual mass. This difference is because of decrease in the measurement accuracy of rheostat that is because the rheostat became hot. Using rheostat by high quality can be solve this problem.

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