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Design and Fabrication of a Turbine Flow Meter

Mohammed Liaket Ali[1], Riaduzzaman Ridoy[2], Utsha Barua[3], and Mohammed Badsha Alamgir[4]

In the modern age of industrialization measuring the flow of fluid in an industry is a major issue for controlling the production process. Along with the flow of fluid, temperature is also a matter of concern for quality maintenance of the product. Keeping those things in mind this project is so designed and fabricated to record the flow rate and temperature of either a liquid (such as oil or water) or a gas (such as natural gas) simultaneously and precisely. And the output is shown in a liquid Crystal Display (LCD). Here a fluid (liquid) is passed through a turbine and rotated it at a rate that is proportional to the rate of flow of the fluid. An opto-sensor will then pick up the turbine rotation and send a pulse signal to the Arduino. A temperature sensor is also used to measure the temperature of the flowing fluid. We calibrated the Sensors with great care that's why a highly precise results of not more than 3% error were recorded and our data was measured several times. Every time this instrumental setup gave us same stable data with negligible fluctuations.

Keywords: Fluid mechanics, Renewable Energy, Industrial Measurement.

1. Introduction

Measuring the flow of fluid is a basic need in many industrial plants. In some operations, the ability to conduct accurate flow measurements is so important that it can make a difference between making a profit and taking a loss. In other cases, inaccurate flow measurements or failure to take measurements can cause severe (or even disastrous) results. In our undergraduate study, we did an experiment by measuring the flow and temperature manually, which gave us various data. As a result, desired output varied on a large scale. After that experiment, we planned to design a system that would lead us to a fixed output every time and we also planned an automated system with a simple design. The turbine flow meter has many benefits. One example would be the oil industry. If anyone gets a clear idea of exactly how much oil are processing per hour he can estimate the productivity of the plant. That is not the only benefit of this meter. It is also an effective way to keep industrial piping system safe. If the meters are kept calibrated and checked frequently, the authority will be notified before something goes wrong with system, possibly blowing a pipe. In industry, it is common to have a piping system for more than one fluids, for example, natural gas and crude oil. This flow meter could easily be inserted into the system and can be monitored very efficiently. Turbine flow

[1]Mohammed Liaket Ali, Department of Mechanical Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh, Email: mohammedliaketcuet10@gmail.com
[2]Riaduzzaman Ridoy, Department of Mechanical Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh, Email: hridoybd33@gmail.com
[3]Utsha Barua, Department of Mechanical Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh, Email: utshabarua10@gmail.com
[4]Mohammed Badsha Alamgir, Department of Computer Science and Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh,
Email: Badsha.bdmap@gmail.com

meters have been used to measure fluid flow for a wide variety of applications. One type of conventional flow meter utilizes an axial flow turbine that is disposed within a cylindrical bore. As fluid passes through the bore, it impinges upon the vanes of the turbine and causes rotation which is proportional to the rates fluid flow. But in this project a Z axis turbine will be used, which also exhibit similar kind of operation during water impinges.

When a liquid moving through the flow meter at moderate rate, the rate of rotation is a fairly linear function of the fluid flow rate. Some conventional flow meters can be operated over a limited or narrow range exhibit one percent or better accuracy. Many electrical hydraulic system applications, product packaging applications involving the dispensing of predetermined amounts of liquid such as the filling of beverage bottles, petroleum distribution such as retail sales of gasoline and scientific instrument applications would greatly benefit from turbine flow meter which exhibit a high degree of accuracy over a broad fluid range of two or more orders of magnitude. Normally the problem of inaccuracy is most acute in the extremely low flow portions of fluid portions of fluid flow range of the flow meter. Fluid flow measurement can be divided into several types; each type requires specific considerations of such factors as accuracy requirements, cost considerations, and use of the flow information to obtain the required end results. Normally the flow meter is measure flow indirectly by measuring a related property such as a differential pressure across a flow restriction or a fluid velocity in a pipe.

In this research**,** we tried to fabricate a turbine flow meter so as to get digital readings along with a temperature readings. Some previous studies were conducted in which the flow and temperature were measured manually**.** So, in this respect, our design is not relevant to others.

The paper is organized as follows. Section 1 presents the introductory thought and motivation for this experiment. Section 2 describes the literature review on this topic of flow measuring devices. Section 3 explains the methodology for this experiment and basic outlines. Section 4 presents the step by step outlooks of the experiment about how it works. Section 5 describes physically how the mechanical and Electrical setup has been built and how they have been interfaced. Section 6 comprises of series of calibration and the measuring demonstration. Section 7 shows a series of experimental results that demonstrates the effectiveness of this experimental device and the simulated results. Section 8 describes the final findings, limitation and the future aspects of this experiment.

2. Literature Review

In the beginning of 5000 BC measurement of flow was introduced to control water distribution through the ancient aqueducts of the early Sumerian civilization from the Tigris and Euphrates rivers. Such systems were based on volume per time operated by diverting flow in a single direction from dawn to noon and diverted it in another way from noon to dusk. Bernoulli (1738), he outlined the basic principles of the conservation of energy for flow, In Hydrodynamics. He focused on the reciprocal relation of kinetic energy and static energy which is the basis of differential pressure flow measurement. Woltman (1790), a German engineer developed the first vane type turbine meter to measure flow velocity in river and canals. But those meters were not available in industrial market until World War 2. Emergence of this war created a desire need for equipment of higher accuracy, greater versatility and quicker response under critical conditions. Faraday (1831) who tried to use his electromagnetic induction laws to measure flow. To measure the water flow of river Thames, Faraday used two metal electrodes connected to a galvanometer from Waterloo Bridge. Later, Thurlemann (1941) worked on the method of electrical velocity measurement for liquid and after that Shercliff (1962) established firm principles of magnetic flow meters in his book “The theory of electromagnetic flow measurement”. Just after three years of Faraday’s original experiment, Coriolis (1835) made the discovery of coriolis effect which helped to construct the highly accurate direct measurement mass flow coriolis meter later. In 1963 ultrasonic flow meters were first used in commercial application. Before that positive displacement flow meters were common in form. But due to misuse they gained bad reputation until further improvements which help them to become world’s best. Now the market of ultrasonic flow meter is the quickest growing among all flow meter. Yokogawa (1970) developed vortex flow meter which was first introduced by Eastech (1969). Those flowmeters depend on the creation of vortices generated by a bulk object placed inside flow stream. Although vortex meter are especially for steam measurement but for gas and liquid measurement they can also be used. These have higher accuracy than positive displacement based flow meter. Sierra (1997) Instruments introduced new multivariable vortex flow meter which was capable to measure more than one process variable and these meters were designed specially including pressure transmitter and a temperature sensor. Zierke et al (1993) introduced a high capacity, low noise slip ring in a rotating frame to measure flow where an optical shaft encoder provided rotor angular position and speed. Kolhare and Thorat (2013) used magnet on one arm of turbine and a Hall Effect device on the outer side of the pipe to measure flow of water in solar water heater. Garmabdari et al (2014) used Hall Effect sensor based rotary encoder to measure algorithm and for monitoring water flow rate. They computed the flowrate by dividing the number of counted pulses (C. P.) over the actual time (Ta) converted to minute which give an output in round per minute (RPM).

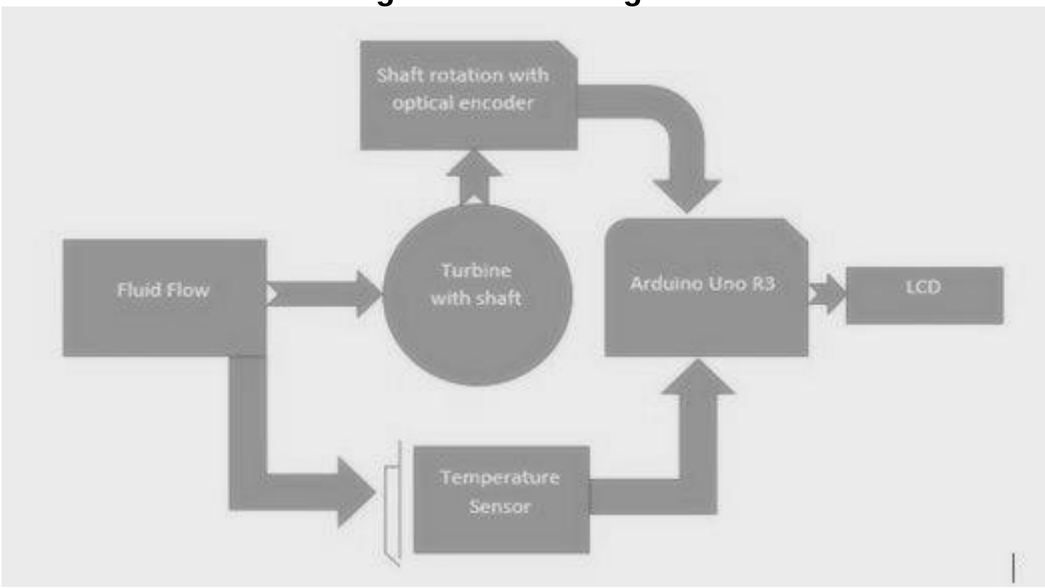
3. Methodology

For this project, a standard ARDUINO is used for programming. From various options ARDUINO is chosen for it’s simple design and lower power requirement to function properly. A turbine with a stainless steel shaft is mounted in a rectangular box. A wheel encoder will be attached with the shaft to count the rotation. The sensor pulses are then sent to the ARDUINO to calculate and store data. The temperature sensor will also take a stream of data that will be sent to the ARDUINO and displayed. The ARDUINO will then use the measurements to calculate the rate of flow & temperature of the material. A digital display will be used as the user interface, showing the data along with simple buttons.

4. Flow Diagram

Fluid or water will flow from the inlet at a high velocity. The high velocity of water will impact on the turbine. According to the jet principle it will rotate for its shape. As the shaft rotates, the turbine encoder will also rotate as it is attached with the shaft. Then the optical sensor will pick up its output & send signal to the Arduino. Temperature sensor will also send data to the Arduino. The microcontroller will process those data and show the flow rate and the temperature of the flowing fluid.

Figure 1: Flow Diagram



5. Structural Design

First of all a rotor is made just like a turbine that involves cutting sheet metal with a proper design for bending and a compatible shape for better use. A mild steel rod serves the purpose of the shaft of the turbine. The bearing setup will be such that, the shaft can rotates freely along its axis.

There are two basic parts in the overall structure:

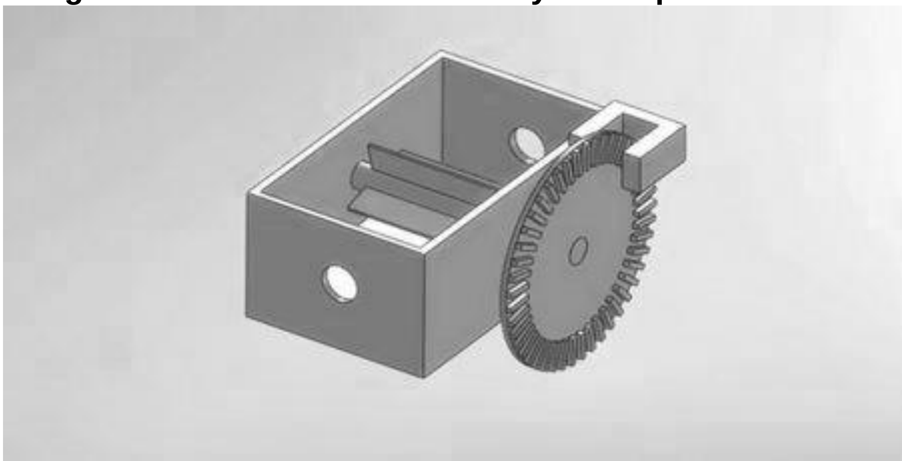
A. Mechanical setup
B. Electrical setup

A. Mechanical set up

Mechanical set up for this flow meter is based on some of the separate parts

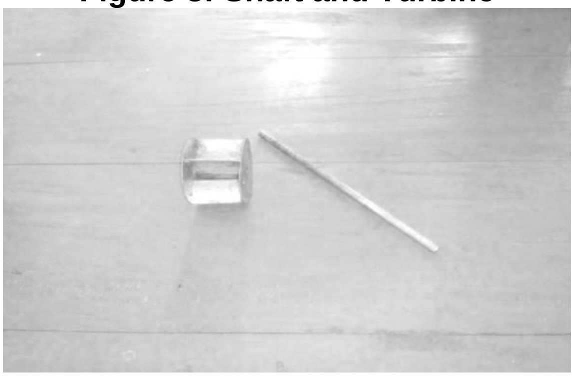
1. Rotors
2. Shafts
3. Bearing
4. Reducer & socket

Figure 2: Blade & Shaft Assembly with Optical Encoder



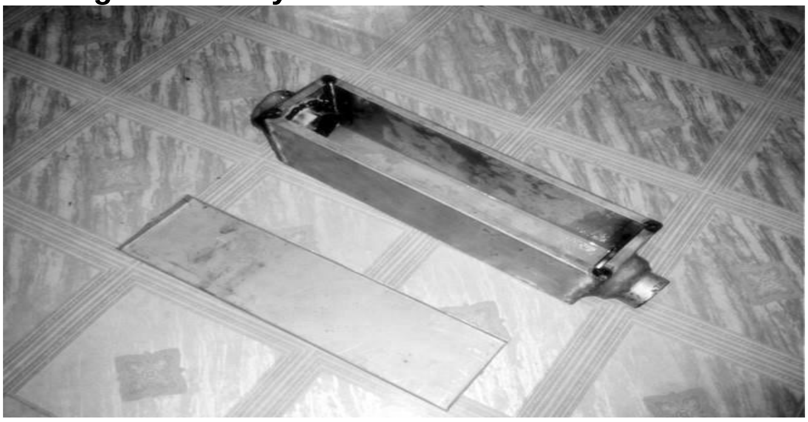
The rotor shaft assembly or the turbine will be then placed in a box. The box will be made with sufficient dimension to make no trouble for the turbine to rotate and to make the fluid flow imping on the turbine blades effectively. The making of the turbine involves cutting of sheet metal with proper design for bending and give it a twist. Four twisted blades are used. Each blade is having a height of 1.5 inches. Two circular disks having a diameter of 3 inches are used to attach the blades in equal spacing. A mild steel rod is taken as the shaft of the turbine. As the bearing is with inner diameter of 1cm, the shaft is designed to meet the requirement by turning operation. The assembly of rotor and shaft is given in fig 03. The rotor shaft assembly or the turbine is now placed in a box. The box is made with sufficient dimension to make no trouble for the turbine to rotate and to make sure the water flow can impinging on the turbine blades effectively. The dimension of the rectangular box is 3.7 inch by 3 inch.

Figure 3: Shaft and Turbine



Whereas the diameter and height of the turbine are 3 inches and 2 inch respectively. The length of the rectangular box is 12 inches. A reducer is used at the incoming side of the meter just to ensure the convenient flow from the supply line. The meter is facilitated with the option of being attached in a line of piping system via a incoming reducer and outgoing socket. Two bearing is provided for confirming the free movement or rotation of the shaft. Inner diameter of the bearing is 1cm. To hold the bearing, two bearing cap is provided so that bearing can be attached with rectangular. The bearing caps are attached with the rectangular box by drilling and providing bolt and nut system.

Figure 4: Body Structure of the Meter



B. Electrical Set Up

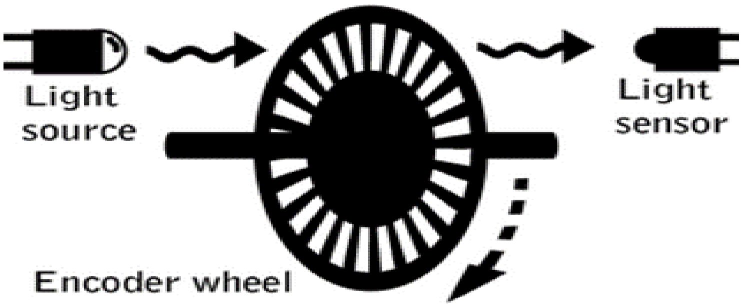
The main parts of the electrical setup are-Optical encoder, ARDUINO, Data and display Cable.

Among them worth mentioning is the optical Encoder.

Optical Encoder

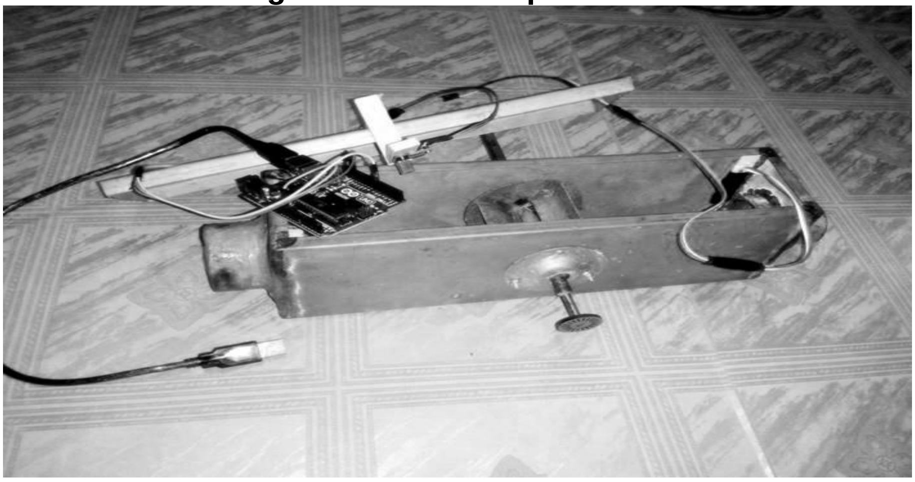
Encoders can electronically monitor the position of a rotating shaft. Our Absolute Encoders are electro-mechanical devices that are useful feedback elements in closed-loop control systems [in fig 3.7]. They provide position control in packaging, robotics, pick and place, lead/ball screw, rotary table positioning and component insertion applications. Our Incremental Optical Encoders provide low cost, smaller physical size, high frequency and high resolution. Our accessories help you easily install and efficiently use our encoders. The two main parts are the encoder wheel and the opto-sensor. The encoder wheel has evenly spaced holes around the diameter and in this case is made from etched brass sheet. The opto-sensor is a dual channel TCUT1200. As the encoder wheel passes over the opto-sensor.

Figure 5: Optical Encoder



the transitions from a gap to a non-gap are detected. The signals from the sensor can be decoded to produce a count of the number of transitions. The count increments for one direction and decrements for the other. Overall test setup is shown in the Figure 5.

Figure 6: Test Setup



6. Calibration and Measurement

For getting accurate data it is very important to calibrate the sensors. The success of the whole project depends on calibration. There are several calibration techniques.

a. Positive displacement
b. Time weight
c. Field power
d. Old stand by
e. Bucket and stop watch

Among the prescribed methods we preferred bucket and stop watch technique for our convenience.

Bucket and Stopwatch Calibration

The simplest way to measure the volumetric flow is to measure how long it takes to fill up a bucket of known weight. Converting the mass into volume using the density of the water volumetric flow can be measured. A bucket is taken for the purpose. The stopwatch is started when the flow goes to the output with a constant rpm of the shaft and stops after the bucket is filled up. The bucket weight is then measured by the weight measuring device which can be converted into cubic inches. With the help of the dimension, one can know the volumetric flow rate by dividing the volume and the time taken to reach that volume. Here the calibration and reading of rpm from the encoder is taken simultaneously. For a given rpm, the device is attached with the hose and a bucket is positioned underneath the device. So we can have the measured flow. LCD or laptop display gives us the flow rate for a constant rpm of the shaft and stop watch gives us time reading. Rpm can be calculated from the encoder disc dimension and structure.

7. Tests and Results

Our flow meter exhibits a satisfactory degree of accuracy over a broad fluid range of magnitude. Normally, the problem of inaccuracy is most acute in the extreme high and low flow portion of the flow range. The recorded data are presented below.

Table 1: Flow Rate & Rpm Reading

Observation	Time of observation (min)	Mass flow rate(kg/sec)	Measured flow rate(in^3/sec)	Rpm of the corresponding flow rate	Actual flow rate from the calibration meter(in^3/sec)
1.	5.02	1.46	120.51	81	123.33
2.	5.32	1.50	123.81	83	127.11
3.	5.14	1.52	125.46	87	129.2
4.	5.19	1.55	127.94	90	128.53
5.	5.24	1.56	128.76	96	130.1
6.	5.09	1.57	129.59	98	130.5

Table 2: Temperature Reading and Error Estimation

Observation	Measured Temperature(°C)	Actual Temperature(°C)	Error (%)
01	38	38.9	2.31
02	36	36.5	1.37
03	41	41.8	1.91
04	40	40.7	1.72

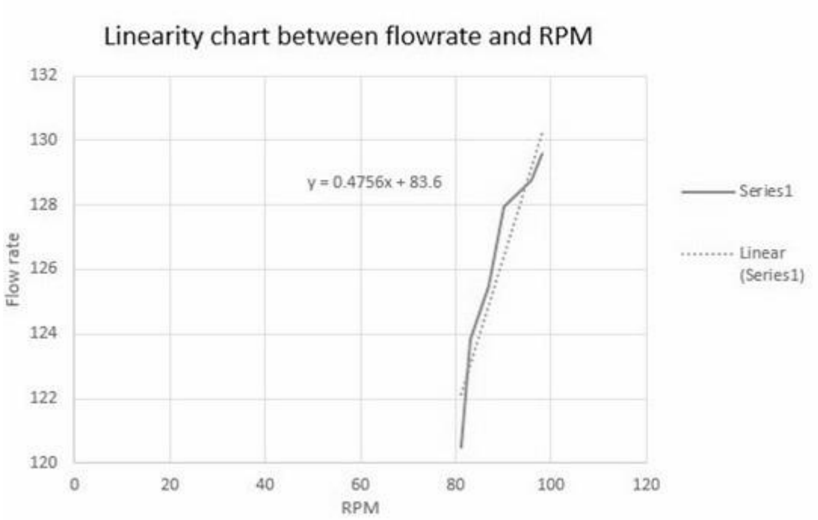
Table 3: Error Estimation of Flow rate

Measured flow rate(cubic inches per second)	Actual flow rate from calibration meter(cubic inches per second)	% Error
120.51	123.33	2.29
123.81	127.11	2.60
125.46	129.2	2.89
127.94	128.53	0.46
128.76	130.1	1.03
129.59	130.5	0.68

7.1 Linearity Test

As the flow rate is proportional to the rpm of the shaft that's why their graph is linear. In the graph below we also plotted the measured flow rate versus rpm and compared it with the actual linear one. Here we see that the experimental graph is almost linear and very close to the actual graph.

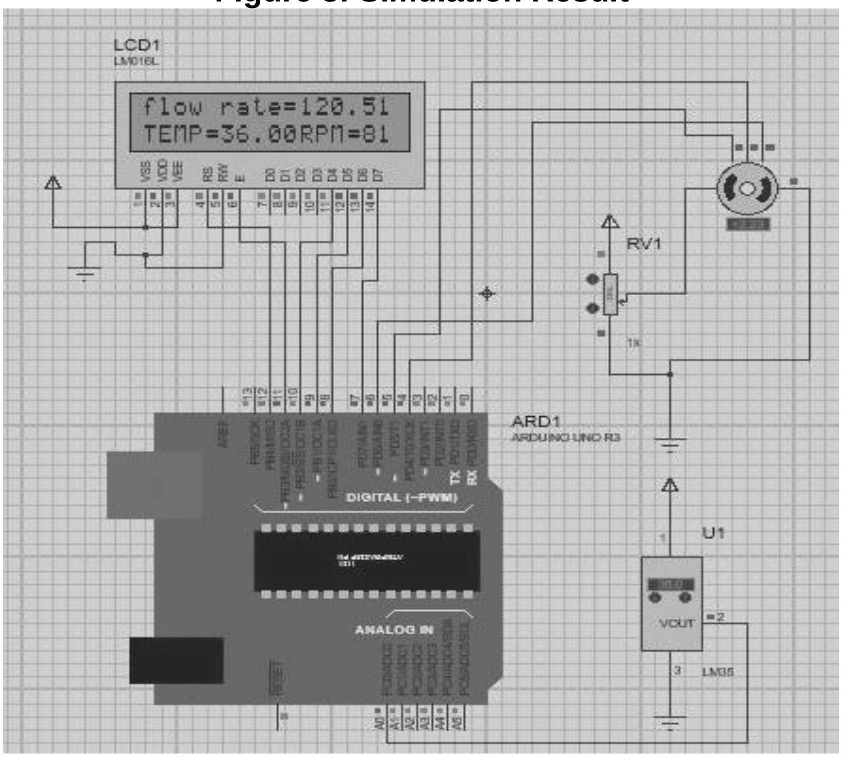
Figure 7: Linearity Graph



7.2 Software Simulation

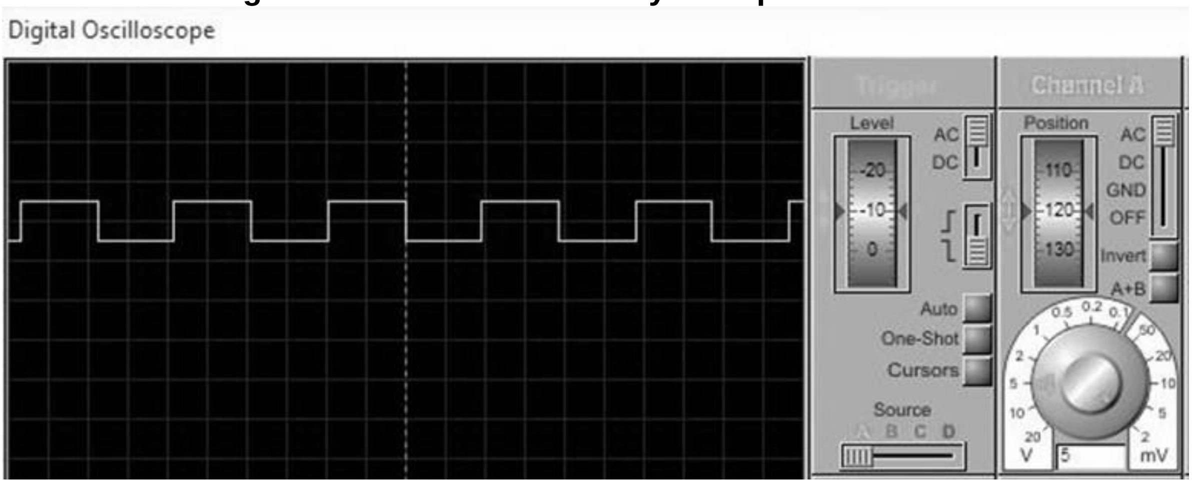
The circuitry portion is simulated with Proteus 8 professional. The codes that we developed in the Arduino IDM works fine. It is compiled without any warning. We also debugged the code. Every parts of the circuit acts as we expected. Here is the simulated result of the whole system.

Figure 8: Simulation Result



During the simulation, the optical encoder continuously generated a pulse signal as the encoder wheel rotates. We used a digital oscilloscope to detect the pulse signal. Here is the simulated pulse signal result.

Figure 9: Pulse Generated by the Optical Encoder



8. Conclusion

From the result, we can see that the relationship between the measured rpm and measured flow is almost linear. There is some error in the measured data comparing with the actual data. It's due to the water leakage from the bearing joint. There is some energy loss to overcome the friction. Another major problem is that fluid could not impact the turbine with the same accurate position. As we calculated flow rate and temperature from this simple setup and no other design have not invented yet, this setup can be used universally. There are some limitations in this project. The incoming fluid should have enough speed to rotate the turbine. So this flow meter can only be used in a high-speed fluid supply line. Moreover, the sensor that we used is rated for -55°C to 150°C range. That's why this meter is not compatible with extreme condition.

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