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Full length Research Paper

Development of a Low Cost Digital Turbine Water Flow Meter for Irrigation Farm

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Abstract

Low cost digital turbine water flow meter was developed in the instrumentation laboratory unit of the national center for agricultural mechanization-ilorin. System testing which comprises the component test, integration test, functional test and extreme case test were carried out during the developmental stage. The used of Hall Effect switch was considered to reduce mechanical contact bounds while measuring the water flow. The flow meter was calibrated using a standard global water flow probe under a controlled flow rate range from 0.5 to 5.0 m³/s. The corresponding frequency of flow, measure voltage and calculated voltage to every giving flow rate was measured. The result shows r squared values for the flow rate/frequency and flow rate/measured voltage relationship of 0.998 and 0.984 respectively. The result shows that the developed water flow meter is a system equipped with capability to measure water flow rate from closed irrigation pipe. Development of other type's flow meter other than turbine flow meter is highly recommended.

Keyword: *Turbine, Flow meter, Hall effect, Irrigation pipe, Calibration.*

Introduction

Effective irrigation water management begins with accurate water flow measurement. Development of a digital water flow meter is an essential problem in water management that has been surprisingly little investigated. Flow measurement technology has grew speedily in recent decades. Physical phenomena discovered in last decades have been the starting point for many variable flow measuring devices. In recent year's technical development in other fields such as optics, acoustics and electromagnetism have resulted not only in improved sensitive designs but also in new flow measuring concepts Wang and Ronald (2014).

Recently, flow meters have proven to be an excellent device for measuring flow in any water application domain. In irrigation fields flow meters are required for measuring the water needed to supplement the insufficient rainfall. Flow meters also serves as an indicator to know whether irrigation pump needs repair or there are leakages along the pipelines. Flow can be measured with contact type or non-contact type of sensor, accurate flow measurement is an essential step both in the terms of qualitative and economic points of view. The measurement of water flow is required for water management purposes in the area of water resources planning, pollution prevention and flood controls (Thandaveswara, 2014). Shapes, size, price ranges and accuracy are factors that affect choice of flow meters as some have comparative advantages over others. Previously, technique known as ultrasonic flow measurement a non-invasive type of measurement is widely used to calculate flow, because of its capability to avoid noise interferences in its output (Ria et. al., 2013). Now a days due to its non-linear characteristics its use is been restricted. Various types of flow meters that are available in the market are shown in Figure 1.1.

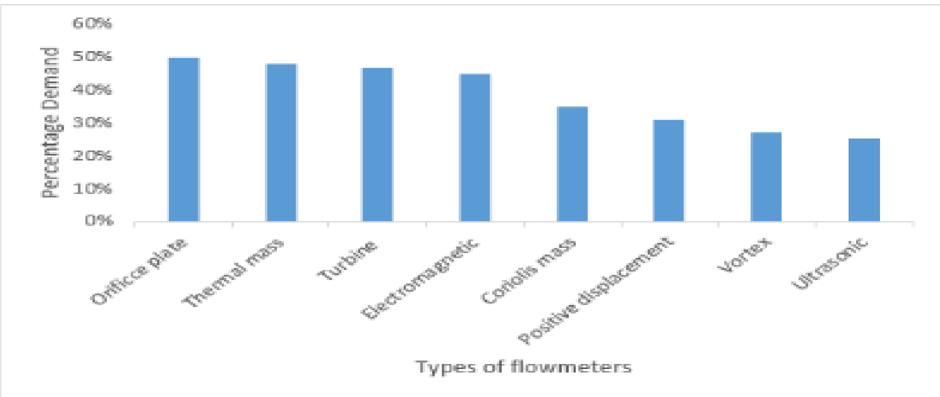

Figure 1.1: Industrial flow meter usage (Source: Ria et. al., 2013)

Flow meters with turbine or rotor is the third highest used because of its measurement accuracy, durable, reliable, easy to install, economical to purchase. The working principles of turbine water flow meter is that water when passes through the rotor cause the rotor to rotate at the speed equivalent to velocity of water. Rotor's speed changes with different rate of flow of water. As each blade passes through the magnet, a magnetic field is created at the base of the Hall sensor and thus pulses are generated. These pulses produce an output frequency proportional to the volumetric flow.
Literature studies shows that lot of research work has been carried out for evolving different water flow measurement techniques but knowledge regarding the development of a low cost water flow meter using locally sourced materials remains indispensable. Luis et al. (1997) design and fabrication of a low cost water flow meter which can measure up to 9 litre/minute, avoiding direct contact of flow with silicon sensors. Katie et al. (2009) studied the flow conditioning for irrigation propeller meters. Recently, the accuracy of monitoring irrigation flow meters have been vastly improved by collateral developments in electronics and computer technology (Replogle, 2002).

The objective of this study is to develop a low cost digital turbine water flow meter using locally sourced materials that is highly adaptive to liquid density and temperature to measure irrigation pipe water flows. The developed flow meter will guide in decision making as to when to change a leakage irrigation pipe.

Materials and Methods

Study Area

The study was carried out at instrumentation laboratory unit of the National Centre for Agricultural Mechanization (NCAM), Ilorin. NCAM is about 20 km to Ilorin metropolis, Kwara State, Nigeria. Also, is abou 370m above sea level and lies on Longitudes $4^o30'$ East and Latitude $8^o26'$N (Awu et al., 2016). NCAM climate is influenced by the Inter-tropical Convergence Zone (TCZ), which results in wet and dry seasons. The rainfall usually starts from April and lasts till late October, with the peak rainfall occurring both in June and September and the dry season lasts between November and March. The mean annual rainfall of the area is about 1700mm, while the mean monthly maximum and minimum temperatures in the basin are 31^0C and 29^0C, respectively, with the highest temperatures recorded in the months of February, March and April. The potential evapotranspiration of the area is between 1500 – 1700mm per annum (Awu et al., 2016).

Development of the Flowmeter

The development of low cost digital flowmeter in this study is by the integration of instruments such as hall-effect water sensor, buffer (voltage gain amplifier), frequency to voltage converter and read out meter as shown in the block diagram in figure 2.1.

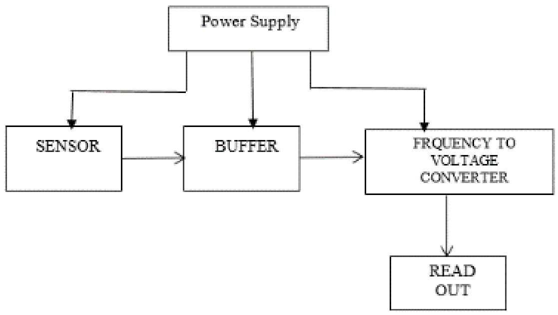

Figure 2.1: Circuit block diagram

The design considered on the selection of right components and materials as it plays a very important role to meet the need of the system. The component materials used in the development were locally sourced.

Hall Effect Sensor: The hall-effect sensor by seeed studio was chosen for this study because of its design compactness, high sealing performance, high quality hall-effect sensor and RoHS compliant. The flow sensor consists of a plastic valve body, a water rotor and a hall-effect switch as shown if figure 2.2. The sensor was design such a way that when water flows through it the rotor rolls. Its speed changes with different rate of flow. The hall-effect sensor outputs the corresponding pulse signal.


Figure 2.2: internal structure of the hall-effect water flow sensor

The flow meter basically works with the output of the flow sensor. The rotor is surrounded by a magnet along with the Hall Effect sensor, as water flows through the rotor, its blades rotates and a magnetic field is produced. An alternating current (AC) pulse is generated which is then converted into digital output. The number of pulses generated per litre produces an output frequency which is directly proportional to the volumetric flow rate/total flow rate through the meter. The output frequency were read with the help of frequency meter. The flow sensor has a working voltage, maximum current, flow rate and operating pressure of 5V, 15mA, 30l/min and 1.2Mpa respectively. The sensor was tested with oscilloscope to see the type of sine wave is producing and it was confirmed to be a perfect square sine wave as shown in figure 2.3 below.

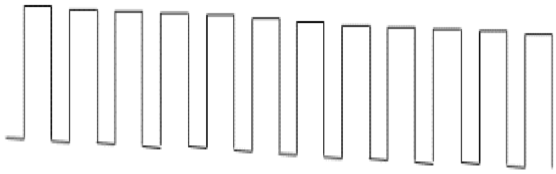

Figure 2.3: Perfect square sine wave from oscilloscope during sensor testing

The Voltage Buffer: The buffer otherwise known as unity gain amplifier was designed and developed essentially to make a copy of the output voltage V_{out} from the input voltage V_{in} for the flow meter. The buffer does that without drawing any current from wherever the input voltage is attached such that at the output terminal it will get the desired amplified operational current of 5 volts. The voltage buffer was realized using operational amplifier and bipolar junction transistor (BJT). The voltage follower using BJT also known as emitter follower is shown in figure 2.4.

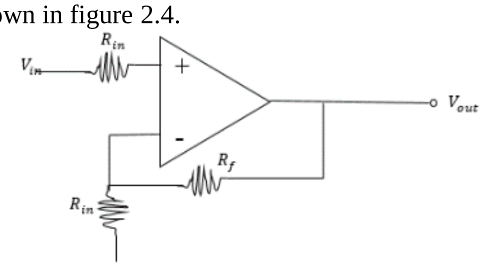

Figure 2.4: Buffer circuit diagram used

The voltage gain is designed using the equation 1.

$$A_v = 1 = \frac{V_{out}}{V_{in}} = \frac{R_f}{R_{in}} \quad (1)$$

Giving that $R_f = 1$

$$A_v = 1 = \frac{1}{R_{in}} \quad (2)$$

Therefore, $R_{in} = 1$

Where

$A_v = voltage\ gain$, $V_{out} = voltage\ output$, $V_{in} = voltage\ input$, $R_{in} = input\ resistor$ and $R_f = feedback\ resistor$

Frequency to voltage converter: The design of the frequency to voltage converter was to converts the sensor input frequency into a proportional voltage which is extremely linear to the input frequency. The frequency to voltage conversion is attained by differentiating the input frequency by using C_3 and resistor R_7 and feeding the resultant pulse train to the threshold of the LM331 IC. The negative going edge of the resultant pulse train at V_{out} makes the built-in comparator circuit to trigger the timer circuit. At any instant, the current flowing out of the current output pin (V_{out}) will be proportional to the input frequency and value of the timing components (R_1 and C_1). The result of the voltage (V_{out}) proportional to the input frequency (F_{in}) will be available across the load resistor R_4 as shown in figure 2.5.

The relationship between R_3 and V_s is expressed mathematically in equation 3 and 4:

$$R_3 = V_s - 2V \quad (3)$$

And

$$\left({R_4}/{(R_5 + R_6)}\right)\ x\ R_1C_1\ x\ 2.09V\ x\ F_{in} \quad (4)$$

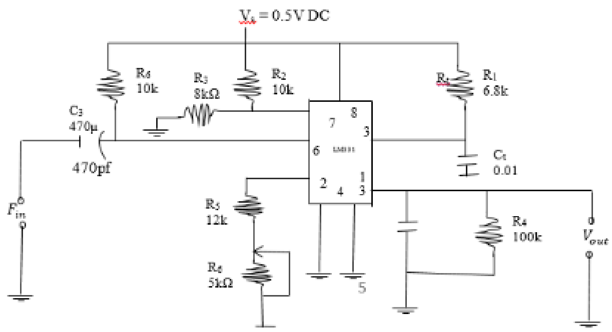

Figure 2.5: frequency to voltage converter circuit

Output voltage, V_{out} is estimated using equation 5.

$$V_{out} = F_{in}\ x\ 2.09V\ x\ \frac{R_4}{R_5}\ x\ R_t C_t \quad (5)$$

Power Supply: the power supply circuit was constructed with the following components: 7805 regulator IC, 100µf electrolytic capacitor of 25v voltage rating, 10 µf electrolytic capacitor of 6v voltage raring and 100µf ceramic capacitor. The power supply was designed to give out well regulated +5v output, output current capability of 100mA (Figure 2.6).

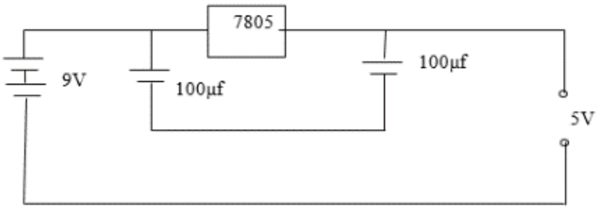

Figure2.6: 5 volt power supply circuit diagram

Volumetric Calibration of the Developed Flow meter

The developed flowmeter measures the rate of water that passes through it. After development, it is important to calibrate the flow meter to meet the application needs. The developed flowmeter was calibrated using secondary standard method with calibration traceability to the U.S. National Institute of standards and technology (NIST, www.nist.gov).

Global Water Flow Probe was the standard used to calibrate the developed flow meter, the global water flow probe is a highly accurate water velocity instrument for measuring flows in open channels and partially filled pipes. The water velocity probe consists of a protected water turbo prop positive displacement sensor coupled with an expandable probe handle ending in a digital readout display. The calibration was based on the facts that the standard employed for the calibration was accurate enough to perform the calibration, the rate of flow between the developed flowmeter and the calibration standard were under a steady state, care was taken to ensured that the was no leak and significant temperature change in intermediary volumes that will affect the measurement.

Results and discussion

The results are in two faces, the development of the low cost water flow meter, the evaluation and calibration of the developed flow meter. The developed water flow meter measures water by rotating the rotor at the speed equivalent to velocity of water that passes through it. The rotor's speed changes with different rate of flow of water. As each blade passes through the magnet, a magnetic field is created at the base of the Hall sensor and pulses are generated. These pulses produce an output frequency proportional to the volumetric flow which is then read out with the help of a frequency meter. As shown in Figure 3.1.

Figure 3.1: Pictorial diagram of the developed flow meter

Accuracy is a qualitative term that is used to express expectation and general specification for flowmeter. The calibration was carried out to estimate the uncertainty associated with measurements from the meter in its final application. The calibration uncertainty provides confidence that the determination of the value lies within coverage factor of k = 2 pulses per m^3, which is approximately 95% confidence level according to Guide to Measurement of Uncertainty (GUM) and ISO 5168.

Meter factor and Relative error was also estimated for the developed flow meter. The meter factor is the ratio of the meter output to value determined by the standard as shown in equation 6 and 7 below.

$$F = \frac{Q_s}{Q_i} = \frac{V_s}{V_i} \quad (6)$$

$$E = \frac{Q_i - Q_s}{Q_s}\ x\ 100\% \quad (7)$$

The result of the calibration and evaluation of the developed water flow meter is shown in Table 3. The calibration was conducted under a controlled flow rate range from 0.5 to 5.0 m^3/s which is within the range of the flow sensor. The corresponding frequency of flow, measure voltage and calculated voltage to every giving flow rate was measured is shown in Table 3.1

Table 3.1: Results for the developed flow meter calibration

m^3/s	Frequency (Hz)	Measured Voltage (V)	Calculated Voltage (V)
0	0.00	0.00	0.00
0.5	500	0	0.49
1.0	1000	0.38	0.98
1.5	1501	0.93	1.47
2.0	2005	1.45	1.96
2.5	2500	2.21	2.45
3.0	3001	2.58	2.94
3.5	3500	3.24	3.43
4.0	4000	4.01	3.92
4.5	4500	4.50	4.41
5.0	5000	5.0	4.90

The relationship of the flow rate to the frequency and measured voltage are shown in figure 3.3 and 3.4 respectively. The calibration result shows that the R squared values for the flow rate/frequency and flow rate/measured voltage relationship are 0.998 and 0.984 respectively

Figure 3.2: Pictorial view of the locally developed water flow meter and the standard used the calibration

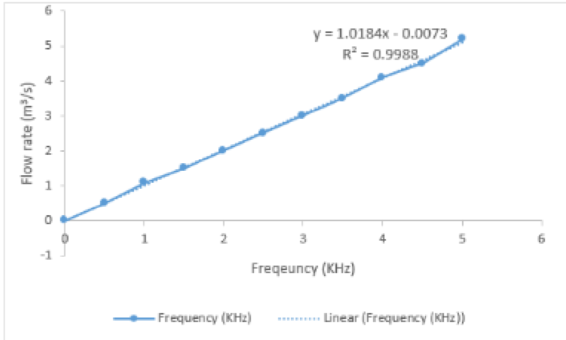

Figure 3.2: Calibrated flow rate/Frequency relationship

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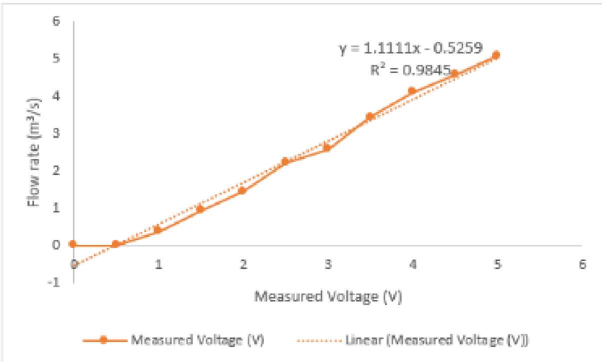

Figure 3.2: Calibrated flow rate/measured voltage relationship

Conclusion and Recommendation

Turbine meters have found widespread use for accurate water measurement applications. The unit consists of a multiple-bladed rotor mounted with a pipe, perpendicular to the liquid flow. The rotor spins as the liquid passes through the blades. The rotational speed is a direct function of flow rate and can be sensed by magnetic pick-up (Hall Effect). Electrical pulses is be counted and totalized. The number of electrical pulses counted for a given period of time is directly proportional to flow volume. The developed digital low cost water flow meter is a system equipped with the capability to measure water flow rate from a ½″ closed pipe especially in irrigation pipe. This is of particular importance because water flow meters are not always readily available for research works in some part of Nigeria and hence buying them is very expensive. Development of other low cost flowmeters other than turbine flow meter is highly recommended.

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