Development of a Self-Powered Pipe Flow Metering System

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Abstract: Flow metering devices are one of the most important apparatus to measure/control fluid flows in pipelines, including industries such as chemical/petroleum plants, as well as residential/municipal facilities. In recent years, the systems have advanced into digital era with the development of science and technology. However, batteries and wired electricity are still the major operating power.

In this proposed “Self-Powered Pipe Flow Metering System (SPPFM)”, the pipe flow drives the rotor of a generator to power the measuring unit itself. Thanks to the system, only small part of the flow power is converted into electric power to obsolete the replacement of batteries or to eliminate the lengthy electric supply wires all together.

Major parameters including power needed and power generated under different flow rate are investigated. Based on the results of the experiments, feasibilities of the system are discussed. A commercial flow meter was used to calibrate this SPPFM system and the results of such a calibration are presented in the paper. A technique to achieve both goals using single generator hardware is explained. It was seen from the experiment that the SPPFM system would produce more electric power than the basic needs for an embedded digital measuring unit, leaving rooms for growing features such as wireless communication, graphic display and data storage.

Key Words: Pipe Flow, Generator, Flow Metering, Self Power

1. Introduction

Flow metering devices are one of the most important apparatus to measure/control fluid flows in pipelines, including industries such as chemical/petroleum plants, as well as residential/municipal facilities. For example, water loss is an extremely important issue for human beings. The control of water losses has been an activity associated with water distribution as early as the earliest systems were built [1]. Since Roman times many advances have been made but even in the newest distribution system, leakage occurs and today leakage engineers require a variety of equipment and techniques to measure, control and reduce leakage on water supply networks[2]. In recent years, the monitoring systems have advanced into digital era with the development of science and technology. However, at some sites it is troublesome to accomplish the task of maintain continue power supply to flow metering systems at either local or remote areas. The use of solar panels to power a regular flow meter is inefficient due to the lack of security and limited, if any, accessibility for maintenance of the equipment. Here is where SPPFM comes in handy, allowing the communication system to power itself with enough power to send signals using wire/wireless communication technology. Some examples of remote areas where SPPFM could be used are water pipes at mountains where the water is collected and extracted for domestic use or at water bodies where water is pumped through pipes for land irrigation or other usages.

In urban areas**,** flow meters do not face the same issues as in remote areas. Electricity is available almost everywhere and communications networks are well spread out. However, as the cities grow so the needs for more flow meters. Two main sources power these flow meters, electricity from the power grid or batteries. By using SPPFM there will be no need to connect to the power grid anymore. Since SPPFM is powered by itself, it could be installed in pipes underneath the streets, and not only use them as flow meters but also as sensors to detect leakages in the pipelines. The usage of SPPFM goes beyond remote areas and cities. It can also be used at hazardous places where chemicals or liquids at extreme temperature are being handled (Fig. 1).

Fig. 1 Pipelines in remote area; Underground pipelines at urban area and A Hazardous place

Oil pipelines at the desert and geothermal pipelines systems are among the numerous dangerous sites which can be beneficiated by the use of SPPFM. High temperature water, going above 160ºC in geothermal plants, and crude oil are some of the substances human being can not be exposed to, still flow of these substances need to be controlled.

One of the most commonly used device in the industry are the vortex flow meters [3] which can work on extreme environment and with low or free maintenance. However, they still require an input power ranging from 13 to 32 VDC [3] to operate. Powering these devices is troublesome in most of the cases. Therefore, SPPFM is an advantageous device in these types of environments. The application of the SPPFM does not end here. A more futuristic application would be that after miniaturization, this invention can even be integrated into embedded medical device in human body to power itself. This would enable physician to monitor/control the micro device and constantly analyzing and communicating the results. Use it for long period of time without taking out from human body to change batteries.

The Self-Powered Pipe Flow Metering System or SPPFM was created to minimize the maintenance needs and still have an accurate water flow measurement. This study was made practically and the measurements were compared with an accredited commercial flow meter, the Mini-wheel flow meter W-116, by TOKYO KEISO CO., LTD.

2. Mechanism of SPPFM Water Turbine

This SPPFM uses Pelton Wheel design for its water turbine, the geometry and the quantity of impellers was analyzed and optimized with the help of CFD software and Rapid Prototyping technology [4, 5].
Some of the prototypes of SPPFM are shown in Figure 2. For small pipes as show at the left hand side in Fig.2, there is an impeller, a data acquisition/analyzing unit and a power/pulse generator connected to the water/liquid pipe. For large pipes, the impeller and the generator can be inserted into the mainstream flow (right hand side of Fig. 2)

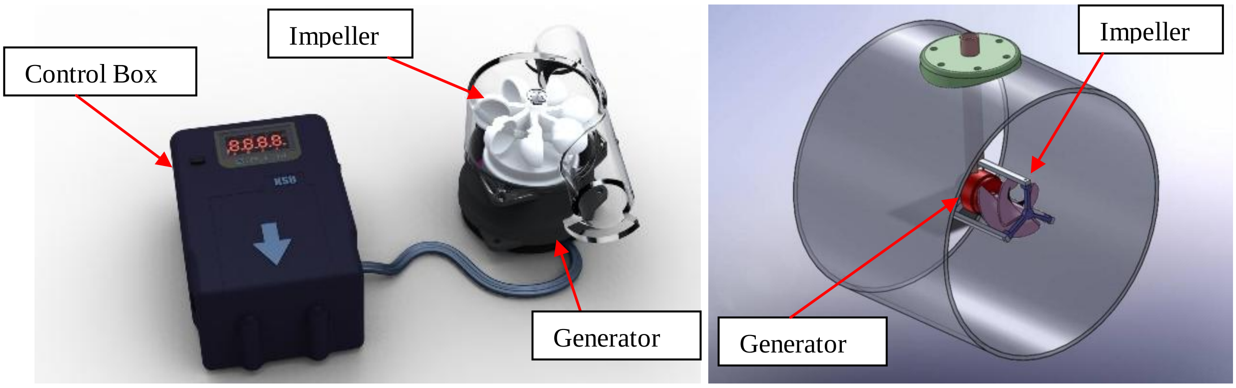


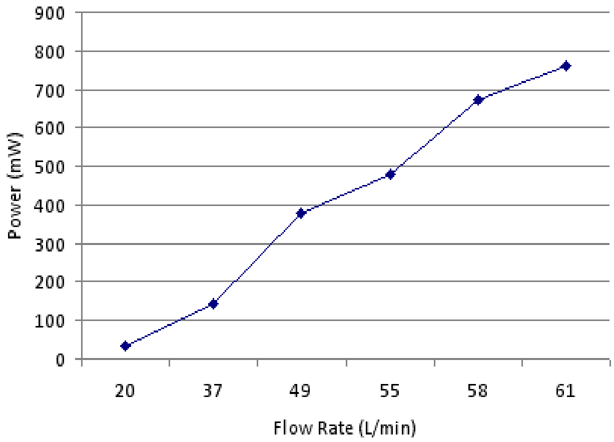
Fig. 2 A prototype of SPPFM for small and big pipes

In addition to the functionality, the generator itself also has a unique design. Firstly, the impeller is the only moving part, making the SPPFM very reliable and requiring very low maintenance. The second important advantage is the leakage proof. Parts that will suffer from corrosion are completely isolated from the liquid flow. The turbine and impeller material would have to be studied and chosen according to the exposed conditions. At geothermal plans, for example, where the fluid is very corrosive and the temperature might go up to 180ºC a study of material must be conducted. The SmCo permanent magnet would be the best choice since it “has a better thermal characteristic” [6].

The waterproof design is also useful at high volume liquid flow where the diameter of pipe line exceeds 0.5 meter. At geothermal plants, for example, where the fluid goes from 10 m^3/hr to 2000 m^3/hr, with right material, SPPFM can be used effectively. Since the SPPFM is leaking proof, it can be used underwater. Figure 5 presents two of the possible arrangements for large pipe lines, where the maximum flow speed occurs at the centerline portion under laminar flow condition.

3. Experimental Setups

The SPPFM has a small generator which converts the mechanical force of the flow into electrical energy. In this experiment, the inside diameter of the flow pipe is 18mm. Under constant conditions (load Ω), the relationship between DC voltage and flow rate is shown in Figure 3. The reading of flow rate is obtained from a commercial flow meter, "Mini-Wheel W-116" from TOKYO KEISO Co. LTD.



Power Generated				
L/min	VDC(Volts)	ADC(mA)	Wg(mW)	Wg/Wr
19.90	4.20	7.59	31.88	32.20%
36.50	6.57	21.51	141.32	142.75%
48.80	8.21	45.90	376.84	380.65%
54.50	9.35	51.50	481.53	486.39%
57.90	10.24	65.90	674.82	681.63%
61.20	11.22	68.00	762.96	770.67%
Wr=99 (mW)				

Fig. 3 Power generated vs. Flow Rate and Power required

The table at right presents the relationship between flow rate and the rate of power **Wg/Wr**, where Wg is the generated power and Wr is the power required by SPPFM measuring unit.

As an example, at 19.90 L/min this generator produces 4.20 VDC and 7.59mA, supplying a total power of 32mW. At this flow rate the generator is only supplying for 32 percent of the power required. However, at 36.50 L/min, this generator achieves 6.57 VDC, supplying a total power of 140mW. At this flow rate the generator is supplying 43% more than the total power required. A voltage regulator is needed to protect the circuit from burning out and keep a constant voltage of 3.3VDC [8]. This arrangement allows the SPPFM to use the power of the generator to operate safely without the need for batteries or any external power source.

In this study, the SPPFM measuring unit uses the ATMEL AVR Micro Controller Unit (MCU). This MCU uses from 2.7V to 5.5V, and in active mode it uses 3.6mA [9]. In contrary, most of the commercial system such as the Mini-Wheel W-116 uses 12V DC and 10mA to operate [10] making it very difficult to install them in areas where electric grid or other external source of energy is not present.

4. Electronic design for the measuring unit

The SPPFM system measures the frequency generated by a separated set of coil attached to the core of the generator. The measuring system uses the analog comparator feature of the Micro Controlling Unit (MCU) to get an accurate frequency measurement. As the speed of the rotor increases, the frequency of the second set of coil increases as well. This second set of coil produced a low voltage, high enough to enable the circuit to measure the rotor's speed and not higher than our reference voltage. Therefore, the system is able to accurately measure the whole range of frequency. The circuit that measures this frequency was simulated using PC simulation software from Proteus Company.

ISIS software was used to simulate the circuit as shown in figure 4. The upper part of the figure is a simulation of the seven-segment display that SPPFM measuring system uses and the bottom part is a Virtual Signal Generator (VSG). This allows the unit to simulate the frequency generated by SPPFM, and so giving evidence of the accuracy of the measurement. In this study, the SPPFM is configured to update its value every five second.

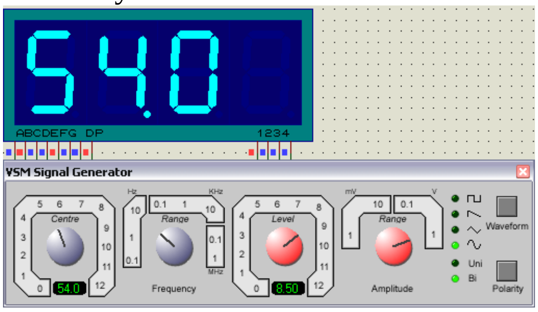


Fig. 4 ISIS software simulation for SPPFM measuring system(Hz).

The unit of measurement shown on the display is in Hz. Therefore, this is 54Hz generated by the VSG and the same value is shown on the seven-segment display. The MCU that SPPFM uses has an accuracy of ± 3% of nominal frequency. This accuracy can only be achieved at voltage between 2.7 and 5.5 VDC and at temperatures near 25ºC. For application under higher or lower temperature, calibration could be executed to compensate and achieve higher precision.

Contrary to Mini-Wheel W-116, which according to its data-sheet, has ± 5% [10] of the nominal frequency. In order to calibrate SPPFM, data samples between SPPFM and W-116 were taken to obtain the relationship between Hz and the flow rate (L/min).

The output of the SPPFM shows a linear relationship between the speed of the flow and the frequency of the signal. Similar conclusion was drawn between the speed of the flow and the flow rate, for Mini-Wheel W-116. The relationships are shown in Figure 7. Such direct linear relationship between the two systems allowed the SPPFM to be calibrated to give a very close approximation to the Mini-Wheel W-116 unit of measurement.

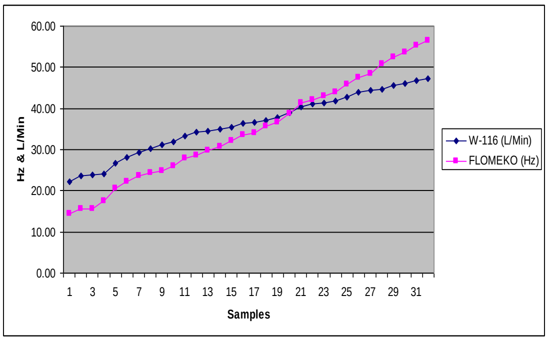


Fig. 5 SPPFM & W-116 flow measurements hand at different flow rates (Not calibrated) calibrated

Fig. 6 Left hand side W-116 L/Min Right side SPPFM measuring system L/Min,

In order to get a precise calibration, it was decided to use three different section of the graph. As shown on table 2, the first part comes from 33 L/Min to 34 L/Min. This portion would give us a correlation of 0.99 with respect to the frequency of SPPFM, being 1.00 a perfect correlation. The middle section of the graph goes from 34 L/Min up to 44 L/Min, giving a 1.00 of correlation.

Finally, the last part of the graph goes from 44.01 L/Min to our maximum that is 49.00 L/Min giving a correlation of 0.98. Therefore, the software for the SPPFM was written using these three different flow rates to calibrate from Hz to flow rate, finally giving a value that is in the range of Mini-Wheel W-116. All of these were done with the whole purpose of proving that SPPFM measurement, frequency, can be calibrated to provide a very precise flow measurement, liters per minutes. After calibration, the comparison between the SPPFM screen and W-116 can be appreciated in figure 6.

There are two sets of comparisons shown in above figure. In each set, the left hand side is the screen output from the Mini-Wheel W-116 while the left hand side is from the SPPFM. The fluctuations of Mini-Wheel W-116 range from 5-10 L/Min while the SPPFM only varies between 1-2 L/min.

5. Conclusions and outlook

The feasibility of the SPPFM concept has been proved through the study, achieving self powering and measurement accuracy. Under most flow conditions, only small amount of energy in the flowing fluid is to be extracted and transformed into electricity to power the measuring unit. In this study, the electronic unit requires 100mW to operate while the system reaches self-power at flow rate of 30L/min. Although this is a stand alone system, there are alternatives for applications. It could also be a combination of the pipe flow generator with other existing metering methodologies such as ultrasonic or pressure based metering.

For further study, a Permanent Magnet Generator (PMG) for low flow speed is under development. Moreover, the work of reducing power consumption of electronic unit is also underway.

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