Extended Measurement Range of Vortex Flow Meter in High Turbulent Range

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Abstract: It is known that a vortex signal is fundamentally related to the fluid flow velocity. When, a vortex flow meter operates at a low flow velocity, the vortex signal is weak, which has been discussed by several researchers in recent years. Subsequently, when a flow meter operates at a high flow velocity, the vortex signal is superimposed on additional signals, making it difficult to extract the true vortex signal. Both problems directly influence the measurement range of a vortex flow meter. The investigation of the vortex signal in high turbulent range is rarely mentioned in literature, and is the focus of this work. A typical vortex flow meter has been optimized and its measuring range has been extended up to 55%.

Keywords: Vortex flow meter, Signal processing, Kalman filter

1. Introduction

Vortex flow meters are used in many industrial fields, e.g. petroleum, chemical and food industries. They are popular due to their low price and high accuracy. The particular advantages of the vortex flow meters are the linear relationship between flow rate and frequency as well as the independence of the measurement of pressure, temperature and density of the fluid. These characteristics are valid for measurements of conductive and non-conductive fluids [1]. The measurement principle of vortex flow meter is based on the phenomenon of Kármán vortex Street, where a bluff body is placed perpendicular to a flow stream inside a pipe. As a liquid or gas passes a bluff body in a pipe, the localized velocity distortion around the bluff body will cause an unstable wake behind the obstruction. Eddy currents will be created which grow into vortices and are shed from each side of the bluff body in a repeatable and oscillatory manner [2]. The basic concept of a typical vortex flow meter illustrates in figure 1 and consists of three parts, which are described as follows:
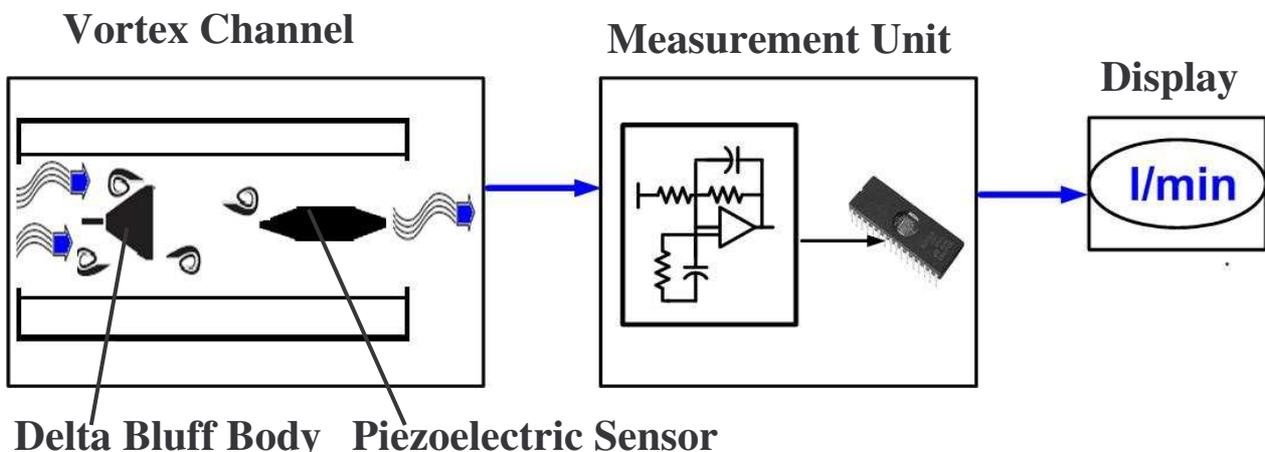

Fig. 1: Block diagram of a basic concept of a typical vortex flow meter

1. Vortex channel; where the Kármán vortex is generated on the bluff body. These generated vortices are detected by a sensor, e.g. piezoelectric sensor.

2. Measurement Unit. It consists of an analog filter circuit and microcontroller.

3. Digital display. For output the flow rate

The piezoelectric sensor converts the variation of the pressure in the Kármán vortex street into an alternating voltage signal. This signal passes through the analog filter circuit system to pre-process the signal before sending it to the microcontroller. The pre-processed signal is applied as an input to the microcontroller for computing the flow rate. Subsequently, the flow rate is shown by a digital display.

1.2 Problems and Objective

When, a vortex flow meter operates at a high flow velocity, the vortex signal is superimposed by turbulent noise. Thus the flow detection of the true vortex signal is difficult to extract. The investigation of the vortex signal in high turbulent range is rarely mentioned in literature, and is the focus of this work. In order to solve this problem; a commercial vortex flow meter DUT (device under test) has investigated outside of its measurement range. The commercial vortex flow metre DUT has the following specification:

- Measurement range: 0.5 – 4.5 l/min

- Bluff body: Delta-Form

- Detection method sensor: piezo-electric sensor

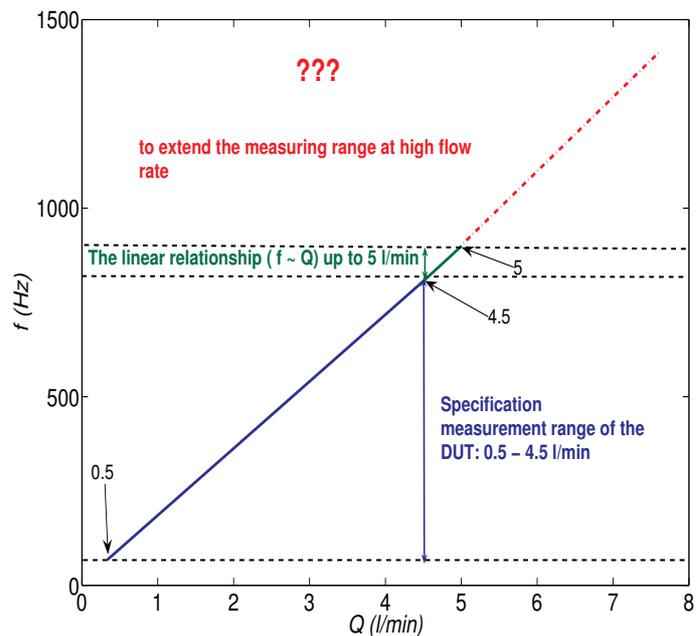- Compact electronic with digital display

Fig. 2: The relationship between the flow rate and the frequency of vortex

The DUT shows in a measurement range of 0.5 to 4.5 l/min a linear relationship between flow rate and frequency of vortex. If the flow rate is greater than of 5 l/min, then the relationship will not be applicable, as shown in figure 2.

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2. Experimental Measurement

The measurement setup is composed of three parts, the flow rig, an oscilloscope and a PC, as shown in figure 3. The main part is the flow rig which consists of an automatic controller, the DUT, a reference flow meter and a pump. All the measurements were made by applying water as a flowing medium to DUT.
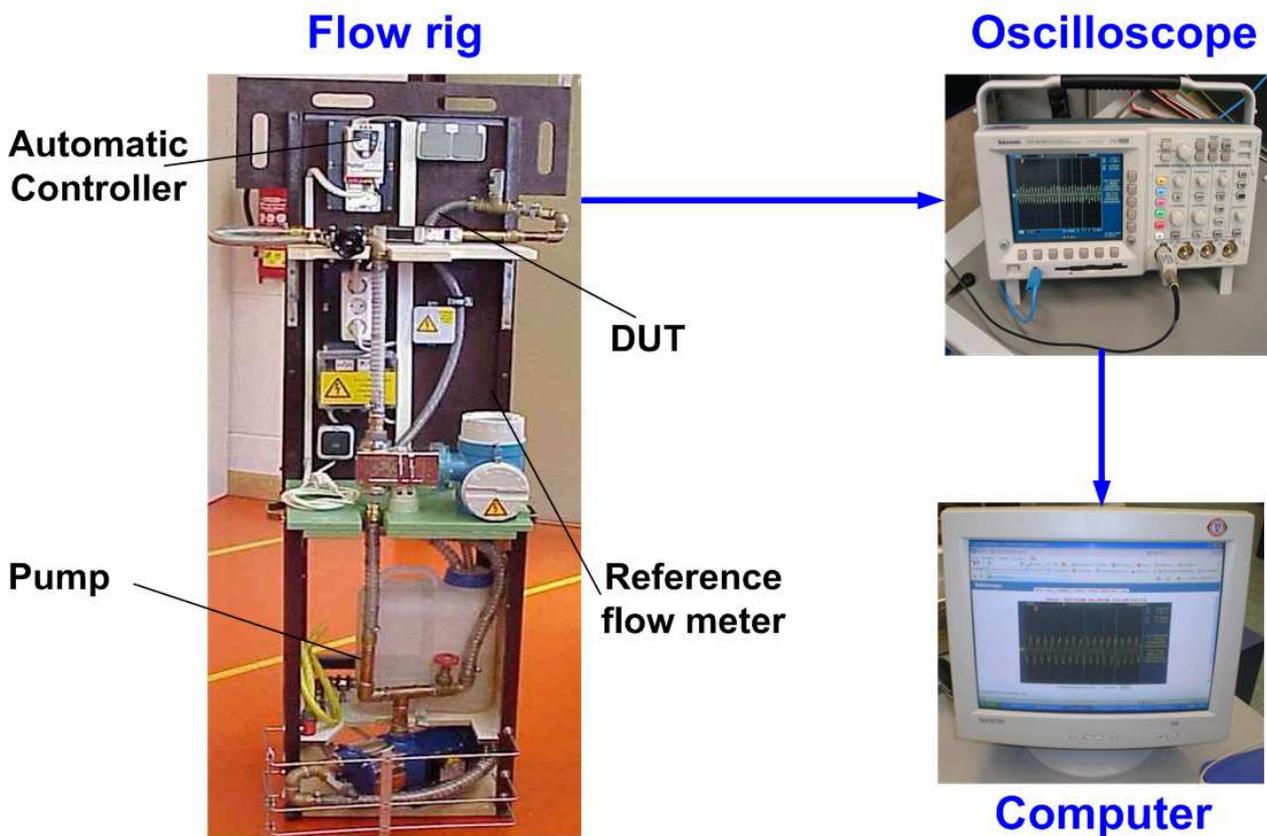
Fig. 3: The measurement setup composed of a flow rig, where the DUT is installed for investigation. The measurements were sampled with an oscilloscope and analyzed on the PC.

The sampled data are taken directly from the piezoelectric sensor at various flow rates with an oscilloscope, using a sampling frequency of 10 kHz and saved on a PC. The Data were collected for 1 second, generating 10,000 points. As a first attempt to analyze the sampled data, it is plotted in the time domain, as shown in figure 4.
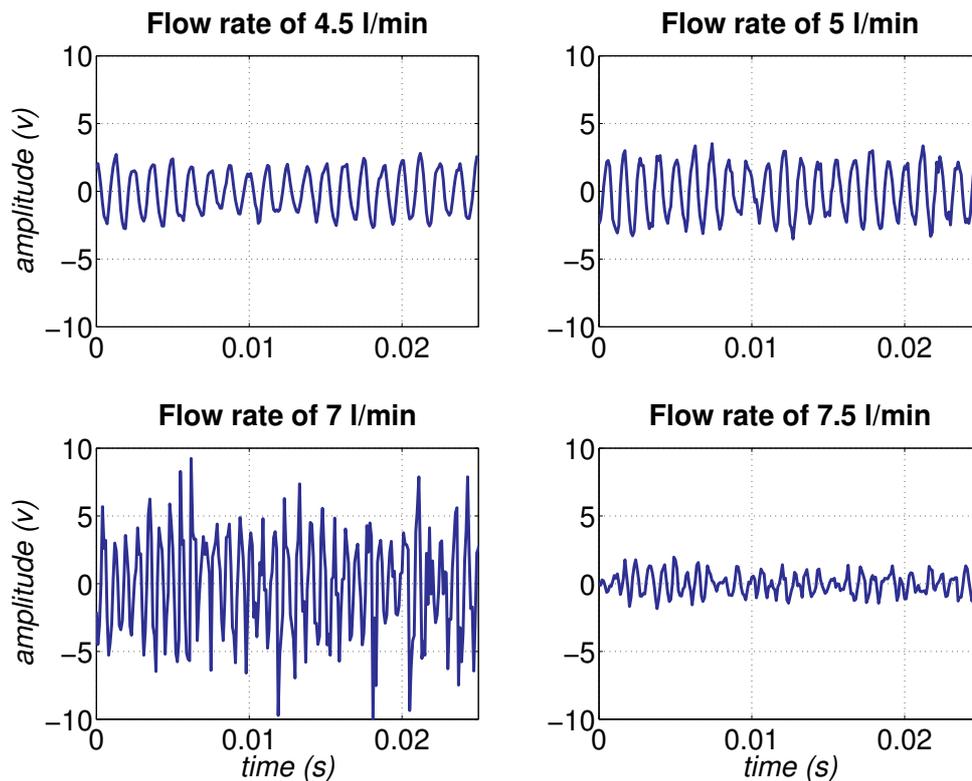
Fig. 4: Vortex signals at different flow rates plotted in time domain. With flow rate of 4.5 l/min the measured signal is like-sinusoidal. The sinusoidal of the measured signals of flow rate outside the specification 5 to 7 l/min are still identified. At flow rate 7.5 l/min; it is not possible to identify the sinusoidal of the measured signal.

Figure 4 shows the measured signal with flow rate of 4.5 l/min, which is inside the specified range of the DUT and three measured signals taken by flow rate outside the specification, with flow rate 5, 7 and 7.5 l/min, in order to find out whether the vortex signal could be detected at high flow rate from piezoelectric sensor. From these results, it is clearly depicted that the measured signal is getting worse by increasing the flow rate. The results from these measurements show that piezoelectric sensor can detected the vortex signal outside the specified DUT measurement range up to 7 l/min. Beyond 7 l/min the amplitude decreases drastically and the oscillation stops.

3. Design of Analog Circuit System

The aim of this circuit is to preprocess and digitalize the measured signal before sending it to a microcontroller. The measured signal is composed of two parts: the signal vortex shedding signal and the noise signals from interference. The measurements in the section 2 have helped us to understand the measured signal, where at low flow rate (0.5 to 1.0 l/min) the signal amplitude is too less (under 1.0V) and must be amplified. Above flow rate of 2.0 l/min the measured signal has sufficient amplitude, so that no amplification is needed. The second task of the circuit is to filter out the measured signal from undesired frequencies which do not correspond to frequency of vortex. In low flow rate electromagnetic noise could be available, and in high flow rate is observed interference noise due to flow turbulence.

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3.1 The stage of the analog circuit system
The block diagram for the designed analog circuit system is shown in figure 5. It consists of four stages, Voltage Limitation, Band-Pass Amplifier, Low- Pass Filter and Comparator.
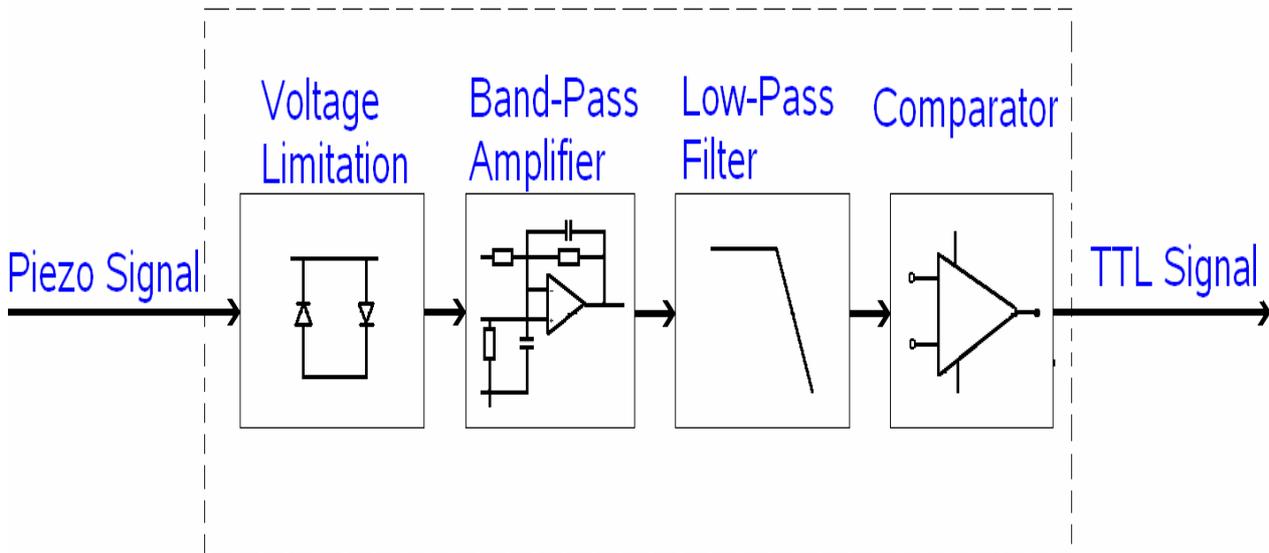

Fig. 5: A block diagram of the designed analog circuit for pre-processing the measured signal to a microcontroller

The piezoelectric sensor produces a measured signal. First the measured signal is processed by the voltage limiter stage. This stage limits the amplitude of the signal to ± 0.7 V. The next step is the signal amplification using a Band-Pass-Amplifier, which only signals with small amplitude are amplified. After amplification; the measured signal is still contains high frequency components, which are filtered out using low pass filter. In the last stage, the comparator digitalizes the measured signal which is applied as an input to the microcontroller. The analog filter circuit system has been described in details in [3]. The quality of the output signal of the new analog circuit system has been observed that the measuring range can be extended to measure flow up to 7.0 l/min.

4. Computation Algorithm

A DSP algorithm is designed based on a zero-cross technique and Kalman filter. The algorithm is implemented in a microcontroller to determine the shedding frequency of vortex in the specified and extended measuring range. In the first part of the algorithm; a zero-cross technique is used to estimate the frequency of the TLL signal, which is obtained from the analog circuit system. The second part of the algorithm is a Kalman filter, which filters out the noise from the estimated frequency. The Kalman filter basically consists of two blocks, the prediction step and the correction step, which both run recursively. A block diagram of the principle function of the overall signal processing algorithm is shown in figure 6.
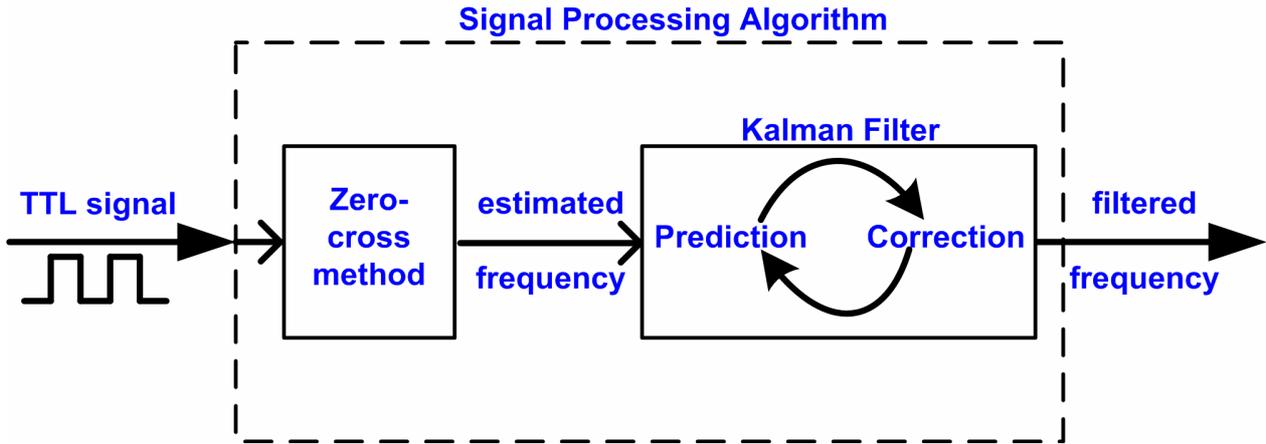
Signal Processing Algorithm

Fig. 6: A bolck diagram of the DSP algorithm

In the prediction step, the filter estimates the evolution of the predicted frequency and its covariance. And in the correction step, Kamlan filter corrects the estimated frequency as well as the estimated covariance by incorporating the actual measurement. The details of the signal processing algorithm have been discussed in [4]. The implementation of the algorithm is employed in PIC-microcontroller.

5. Results

The new analog filter circuit was analysed outside their specified measuring range. Figure 7 compare the performance of the analog circuit of a typical flow meter to the new one presented in the section three. Up to =5 l/min the signal quality of a standard analog circuit is not as good as the new analog circuit. In addition it has been observed that the measuring range of the new analog circuit can be extended to measure flows up to 7 l/min.
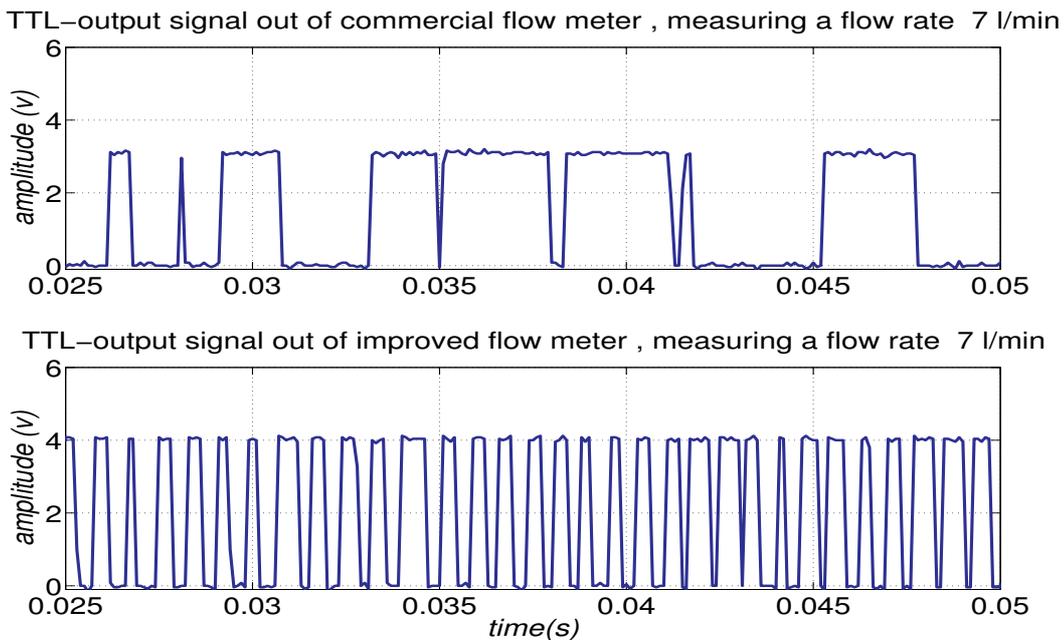

Fig. 7: Comparision of TTl-output signals of the commercial and improved flow meter, flow rate of 7 l/min

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A new signal processing algorithm has been implemented in a microcontroller, and the TTL signal from the designed analog circuit is applied as an input to this microcontroller. Figure 8 compares the performance of a commercial to the improved flow meter. It can be seen that the measurement range of the improved flow meter is extended to measure flows up to 7 l/min.
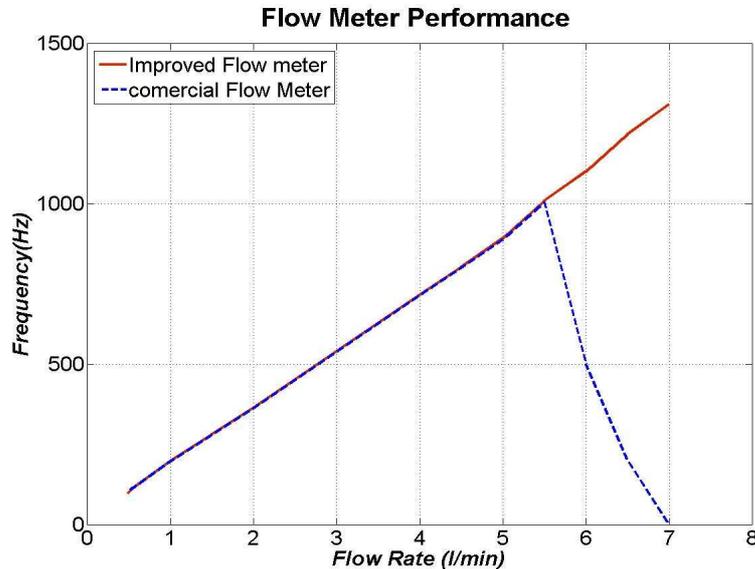

Fig. 8: Performance comparison the improved and commercial flow meter

6. Conclusion

When a vortex flow meter operates at a high flow rate, the vortex shedding frequency signal is superimposed with additional signal and therefore it is difficult to measure the flow rate. The measured vortexes signals are taken directly form a piezoelectric sensor in high turbulent flow rate and investigated. Based on measurement, a new analog filter circuit system has been designed, which is able to extend its measuring rang about 55%. In additional a new signal processing algorithm based Kalman filter has been implemented in microcontroller, which allows an estimation of the frequency signal in the extended measuring rang. Furthermore, linearity of this vortex flow meter is achievement at a high flow rate.

References

[1] K.W. Bonfig, Technische Durchflussmessung, 2.Auflage, Vulkan-Verlag, Essen 1987, 196-198.
[2] J.E. Hardy, J.O. Hylton, T.E Mckght, C.J. Remenyik and E.R Ruppel, Flow Measurement Methods and Applications, 1999, 13-14.
[3] M. Akresh, L. Reindl, W.D. Walker. Improved Vortex Flow Meter Using Pre-Filter, SCS'08-IEEE International Conference on signals. Circuit & Systems, Tunisia, 2008, 98
[4] M. Akresh, L. Reindl, W.D. Walker, Flow Measurement Using Kalman Filter for Smoothing Vortex Shedding Frequency, Proc. I2MTC2010-IEEE, Austin, 2010, pp.234~237.
[5] Volker Hans, Ernst von Lavante and W. Merzkirch, Fluid Mechanics of Flow Metering, 2005.