Combined Processing of Electronic Signal of Vortex Flowmeter

***M. Music, M. Ahic – Djokic**
Electrical Engineering Faculty, Sarajevo, Bosnia and Herzegovina
Zmaja od Bosne 1, 71000 Sarajevo, Bosnia and Herzegovina
tel.038733659338, e - mail: mustafamusic888@hotmail.com

Abstract: Passing through the vortex street, behind the bluff body, amplitude and phase modulation of ultrasonic wave happen at the same time. Level and form of modulating signal depend of mean flow velocity and shape and size of vortices. In this paper, one combined method of signal processing, converted ultrasonic to electronic signal, using amplitude or phase demodulation, has been presented. Choice of processing depends on the mean flow velocity. Also, experimental results, using prototype ultrasonic vortex flowmeter PVMP50, based on noticed method have been presented.

1. Introduction

Principle of working of ultrasonic vortex flowmeter is based on detection of separated vortices, behind the bluff body in the Karman vortex street, fig.1. Mean flow velocity is directly proportional to frequency of vortices in range of Reynolds number, $10^4 < Re < 5*10^5$, and depends on characteristic dimension of bluff body and value of Strouhal number.

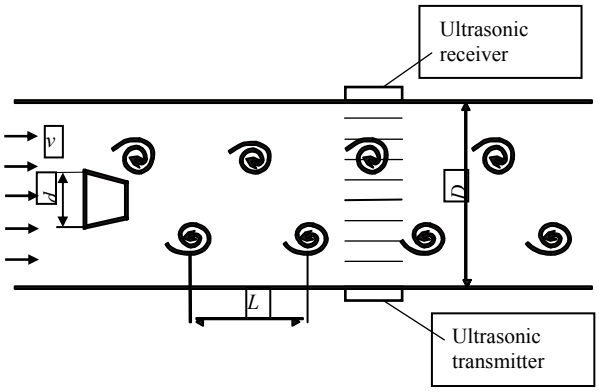

Fig.1. Scheme of vortex street

It proved experimentally that Strouhal number is constant in noticed flow range. For ideal Karman vortex street: flow is laminar in the street, vortices are in the shape of cylinder, and vortex street is unlimited. In this case, ultrasonic wave, which passes orthogonal through the vortex street is modulated by vortices, and on the received side could be written as follows:

$$u(t) = \left[U_1 \ (1 \pm m_a \cos \omega t)\right] \cos(\omega_0 t + m_p \cos \omega t) \qquad (1)$$

where are: $U_1 = U_0 \ e^{-mD}$, amplitude of ultrasonic wave on the received side without the vortices in the flow,

ω_0, frequency of the ultrasonic wave,

ω, frequency of the vortices,

m_a, m_p, coefficient of amplitude and phase modulation respectively,

D, diameter of vortex flow meter,

U_0, amplitude of transmitted ultrasonic beam.

2. Signal processing

Amplitude and phase modulated ultrasonic wave is converted to electronic signal by the ultrasonic transducers based on piezo –electric effect. For ideal vortex street and ideal shape of vortices, it is possible to make

mathematical model of modulation of ultrasonic signal in the vortex street (1). Coefficient of amplitude and phase modulation, according to relation (1) depends on the : ultrasonic frequency (f_0), diameter of vortex flow meter (D), mean flow velocity (v) and ultrasonic velocity in the fluid (c). (1). According to that mathematical model, [1], [2] amplitude and phase coefficient of modulation could be written as fallows:

$$m_a \approx \frac{m\ D\ V_\theta}{c}, \quad \text{coefficient of amplitude modulation,} \tag{2}$$

$$m_p \approx \frac{4\pi f_0\ D\ V_\theta}{c^2} \quad \text{coefficient of phase modulation,} \tag{3}$$

m - coefficient of ultrasonic absorption in liquid fluid,

V_θ - angle velocity of vortices,

c - ultrasonic velocity in the fluid.

For small flow rate coefficient of amplitude modulation, according to relation (2), is less then 1% of modulated signal. Level of the modulating signal is in the range of the noise signal caused by the disturbance in fluid flow, or by vibration of flow installation. In that flow rate it is practically impossible to use amplitude modulated ultrasonic wave for processing and detection of vortices. Adventage of phase modulation provides flow measurement at range of low flow rate without affect of noise signal, using chip, static, active filters and comparators of electronic signal.

For high flow rate, more then 50% of full flow range and small size of vortex flowmeter, according to relation (3), angle of phase modulated signal is higher then 90^0. It affects incorrectly to the process of measurement. At the same time, in this case level of amplitude modulation is sufficient for electronic processing (higher then 10% of modulated signal), and it is possible to use amplitude-modulated signal for detection of vortices.
Fact that amplitude and phase modulation of ultrasonic wave happen at the same time in vortex street, provides the use of phase and amplitude modulated signal for detection of vortices, (flow measurement by ultrasonic vortex flow meter) at low and high flow rate respectively.
Modulated and demodulated signal and designed electronic network, based on microcontroler for processing signal, are presented in the fig. 2., fig. 3. and fig.4. respectively.
Suitable flow was 200 l/min., and frequency of separated vortices was 38Hz. Cylindrical shape of bluff body which characteristic dimension is 11mm, has been used.
Principle of measurement and signal processing is based on next procedure:
It orders virtual flow, by microcontroler, less then flow rate which corresponds to angle 90^0 at PLL processing signal.
If real flow is less or as same as virtual flow, it uses phase modulated ultrasonic wave for signal processing Phase demodulation of signal is realized by PLL structure. If actual flow is higher then virtual, amplitude modulated ultrasonic signal is processing. Classical detector or simple hold element makes amplitude demodulation of signal. Every new start of vortex flow meter includes processing of phase-modulated signal.
Input operational amplifiers, and band pass filters are based on high broad band and low noise FET transistors. Designed electronic unit for signal processing is based on microcontroler INTEL 8051
Ultrasonic transducers are developed on piezo – crystal PIC 255 whose resonant frequency is 2 MHz.
It is important to notice that virtual flow is different for different size of vortex flow meter, and must be defined for each size of vortex flow meter by programming microcontroler.

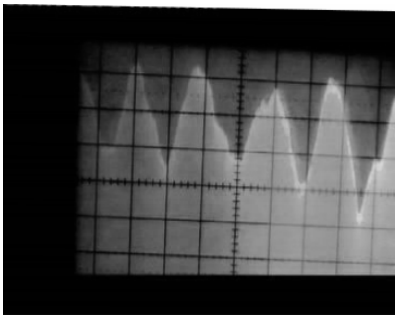

Fig.2 modulated signal

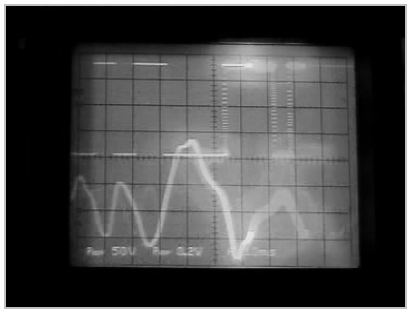

Fig.3 demodulated signal

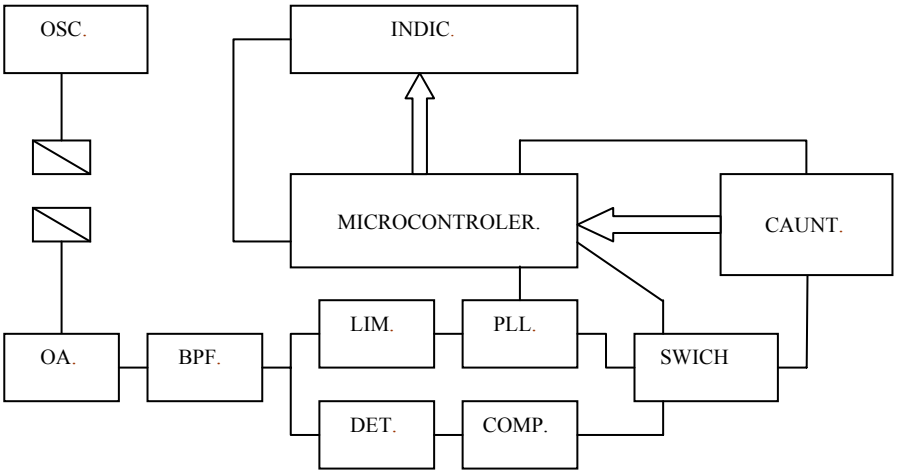

Fig.4 Electronic structure for processing signal

3. Experimental results

Testing and calibration prototype vortex flowmeter, PVMP50 DN50, based on the presented method has been realized by Calibration station « Delta Petrol» certificated from State Institute for Accreditation of Bosnia and Herzegovina. Water was used as working fluid which temperature was 15^0C, and turbine flowmeter DN50 has been used as standard flowmeter which uncertainty was $\pm 0.15\%$. Calibration characteristic is presented in the fig. 5. It was not possible to reach full flow rate because power of the pump and capacity of water tank have been limited.
That limitation does not reduce general conclusions, because linearity of Strouhal number is good at high flow rate.

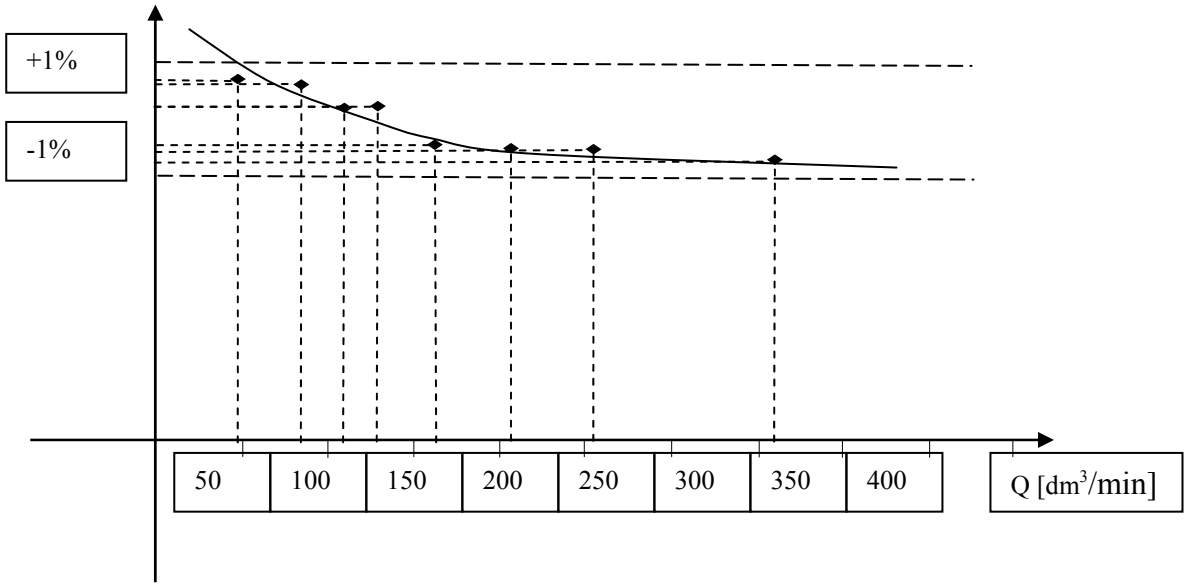

fig.5. Characteristic curve of prototype vortex flow meter PVMP50

4.Conclusion

In this paper, method of combined processing of amplitude and phase modulated signal at vortex flow meter (by microcontroler) has been presented. That is possible to realize, because amplitude and phase modulation of ultrasonic beam in vortex street happen at the same time. This method offers correct measurement at low flow rate

(less then 50% of full flow range) using phase modulated signal and using amplitude signal for processing modulated at high flow rate.

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