REMOTE MEASUREMENT OF FLUID VELOCITY "IN POINT"

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Abstract - *In this paper the method for remote measuring and reconstructing a signal from an electromagnetic probe, dedicated to the measurement of fluid velocity in the point, is proposed. The method is based on the principles of recently developed measurement over the interval method. It is concluded that the interferences are digitally removed, and the samples of measured signal are successfully transferred from the remote location and completely reconstructed on central server.*

1. INTRODUCTION

For a long time there is a real need for remote measurement of fluid velocity. Whether it is in a remote part of a factory, hydropower plant, or measuring point kilometers away from supervision and control center. Such a measurement system can monitor more than one measurement point at a time (e.g. water supply network nodes). If there is any feedback on fluid velocity, it is possible to make certain control (e.g. increase-decrease flow) from the control center. Remote measurement of the environment parameters are becoming more and more actual. Changes in the water level of rivers and changes in velocity of river flows could be used to indicate the possibility of water flooding from the river bed. The technology of nowadays makes it all possible, through various kinds of hardware and software.

There are a number of techniques and approaches to measurement of the fluid velocity. It can be measured using: Pitot tubes, Acoustic Doppler method, Laser Doppler method, Electromagnetic method and so on. This paper deals with the measurement of the velocity of conductive fluid "in point", and the electromagnetic method is one of the best approaches for this type of measurement.

2. ELECTROMAGNETIC MEASUREMENT METHOD

Electromagnetic method is based on the principle that a conducting fluid will generate an electromotive force (EMF) proportional to the flow velocity as it passes through the magnetic field created by the sensor (probe), [2] . For clarification, the EMF will actually be induced on the end of the electrodes which are in contact with fluid. This principle basically represents Faraday's law in its simplified form and it is graphically shown in Figure 1. In the real life scenario the magnetic field is not homogeneous, yet it is variable in space and time. The velocity of the flow through a pipe of a certain diameter is not constant, yet the velocity depends on the spatial velocity field and time.

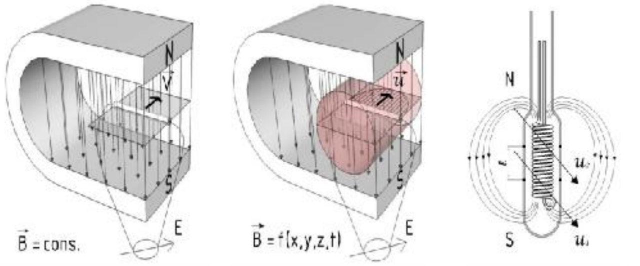

Figure 1 Electromagnetic induction principle (left), conductive fluid flow measurement using the electromagnetic induction principle (middle), conductive fluid velocity measurement "in point" (right) [3]

So induced EMF will be integral :

$$E = \int_D \vec{B} \times \vec{V} \cdot d\vec{L} \qquad (1)$$

In (1), E represents induced EMF, $\vec{B}$ represents magnetic field, $\vec{V}$ stands for fluid velocity and $\vec{L}$ is conductor length (in this case distance between electrodes submerged into a fluid).

Induced electromotive force E involves a number of parasitic components which are superimposed to the measured voltage [3].

$$E = E_V + E_C + E_L + E_{DC} + E_{DIST} \qquad (2)$$

In (2), E_V represents the signal due to measured velocity (within a target range of 0.1 microvolt to few microvolts), E_C and E_L are respectively capacitive and inductive disturbances, due to excitation signal. E_{DC} is a DC signal due to variable electrochemical water potential. The values of E_{DC} are often in range of a few volts. In the end E_{DIST} represents remaining disturbances (leakage currents, sudden changes in electric conductivity, etc.).

3. HARDWARE OF THE MEASUREMENT SYSTEM

Measuring system for remote measurement of fluid velocity consists of two major parts, which will be separately considered in this paper and analyzed in detail. The first unit group encompasses one part of hardware of the fluid velocity-meter and unit for sending the measured - raw data to the central server. The second group consists of: the rest of meter and the central server for processing of raw data and also acts as a WEB server. Users can access server via the client application (and/or the WEB browser).

3.1 MEASUREMENT DEVICE - REMOTE PART

Most of modern devices, commercially available on the market, using a standard method of discrete measuring, in other words measurement in point. In metrological slang, measurement in point is also known as sampling measurement method. The essence of the sampling method is: theoretically in infinitely short time interval, practically in a moment, the sample of analog measured value is taken, and in a time interval Δt , using analog to digital converter (ADC) is converted into a number.

There are two causes of systematic error in a sampling method: discretization in time and discretization by value. If sampling theorem conditions are satisfied, discretization in time can be eliminated as cause of systematic error. Discretization by value always causes systematic error, and it is impossible to eliminate it, but under certain conditions it is possible to reduce it to an acceptable level.

It is quite clear that equation :

$$\frac{1}{\Delta t} = f_s = 2 f_h , \qquad (4)$$

must be satisfied. In (4), f_h stands for the highest frequency of measured signal, or in the other words, upper limit of the signal's frequency range. It is therefore important for Δt to be as small as possible. The fastest are flash ADC's which have $\Delta t \approx 1ns$. The problem that occurs is flash ADC's small resolution. The resolution of ten bits is the maximum, in accordance with it, measurement uncertainty is large. It is well known that each additional bit of resolution doubles the hardware of flash ADCs, therefore the number of systematic error sources also doubles. From that point of view, it is much better that flash ADC has lower resolution.

Second problem of the measurement in point method is measurement of noisy signals. In the theory of discrete signals this is known as signal estimation among the noise, and theoretical approach does not take into account the quantization error (discretization by value). It is shown that a signal can be estimated better if sampling frequency is higher, and in this case fast ADCs become crucial.

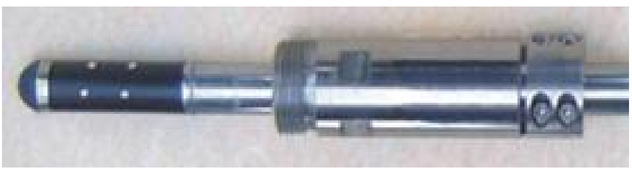

Figure 2 Two-component electromagnetic probe [1]

As an essential part of the measurement hardware is the two-component measuring probe, made by domestic manufacturer, "Svet instrumenata" from Belgrade. The probe uses pulse excitation with square waveform signal of $8.33 Hz$ frequency or $12.5 Hz$ frequency. The same signal is used for power supply. Excitation (power supply) signal is generated using a MOSFET, which is powered by batteries and works in inverter mode.

In this paper, we discuss a method of measuring different from the conventional, so-called "Measurement over an interval". It has been shown in a number of simulations, experiments, and practical application, this measurement method successfully eliminates almost all limitations of a "sampling method", but keeping all of its good features. Advantages of measurement over an interval come particularly to the fore with: measurement at high frequencies, noisy signal measurement, and it is characterized by high accuracy and linearity of the measurements.

In this method, ADCs with small resolution are used – flash ADCs, so the sampling frequency is practically maximal allowed by technology. For quantization error influence elimination, which is in this case significant, uniform random noise with mean value 0 is added to an input signal, in range of one quantum of applied flash ADC.

Figure 3 shows a block-diagram of a device for measuring one harmonic of noisy signal. At the input of the first ADC is the measured signal (uniform noise is previously added) plus dither signal h_1. If, however, at the second channel input is basis function from an orthonormalized set of functions, such as Fourier's, accumulator's mean represents the value of corresponding coefficient of signal expansion in orthonormalized set, so it is clear that the coefficients can be measured very accurately in this way. It is shown that a integer arithmetic is sufficient, and there is no need to use floating-point arithmetic, which further complicates the measurement hardware. In a prototype device for measuring the Fourier coefficients (harmonics) a 6x8 bit integer multiplier-accumulator is used, and other instrument of the same purposes uses 8x10 integer multiplier-accumulator [4],[5],[6].

It is clear that for the measurement of both coefficients (sine and cosine) of one harmonic, another identical measurement unit (shown in Figure 3) is required.

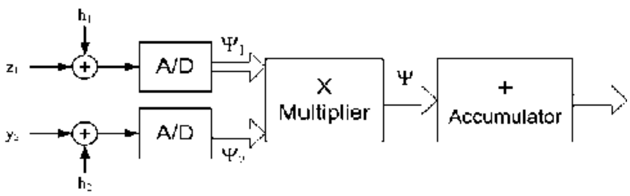

Figure 3 Block-diagram of the instrument for measurement of one harmonic of the noisy signal

Since the general idea is that the measurement is done remotely, already developed measuring hardware requires some modifications. In order to achieve good performance with the maximum utilization of battery power, the measurement unit can be separated into two parts. The first part consists of a measuring probe (Figure 2), the random noise generator and the dither signal and certain number of flash ADCs, depending on how many signal harmonics we want to measure. Samples of the measured signal - ψ_1 are sent via GPRS module to the central server. The entire process of measurement is controlled by the PIC microprocessor (MCU) series 18F. Figure 4 shows the block diagram of the remote part of the measurement system.

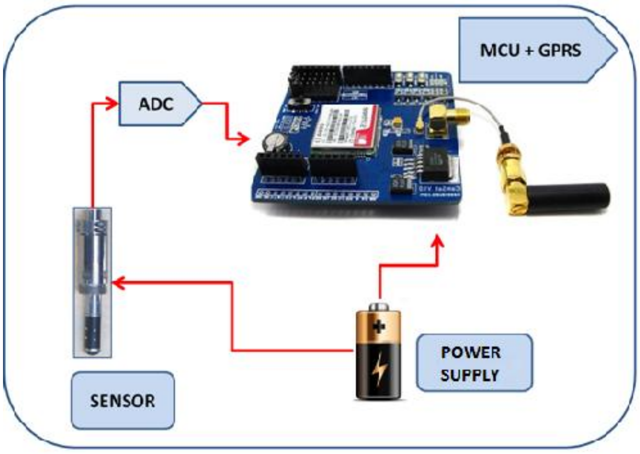

Figure 4 Block diagram of the remote part of the measurement system

3.2 MEASUREMENT DEVICE - CENTRALIZED PART

As mentioned in the previous section, hardware of the second part consists of a central server and the rest of the fluid velocity-meter. Samples of the measured signal $\psi 1$, which are sent over the GPRS module to the central server, are stored in the database. Since the function on second channel is known, and noise is also known ADC can be easily simulated, samples of a basis function on the interval could be prepared and stored in computer memory or database. Figure 5 is showing a simplified diagram of the central part of the measuring system.

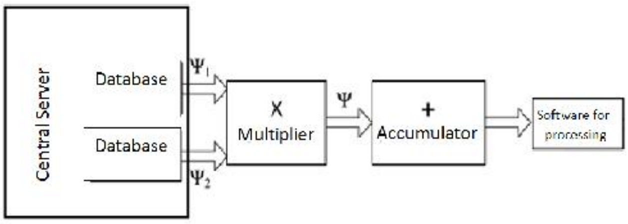

Figure 5 Modified diagram of the system

Samples of the measured signal ψ_1 and samples of the corresponding basis functions (sine or cosine) ψ_2, are brought directly to the block multiplier-accumulator from database on the server. As previously mentioned, the mean value of the contents of the accumulator represents the corresponding coefficients (sine or cosine) of signal expansion in orthonormalized set. For further processing and obtaining the final result of measurement dedicated software - PC applications is used.

4. SOFTWARE OF THE MEASURING SYSTEM

In this chapter we will discuss about the server side of the measuring system, operating system, software applications of general-purpose and special-purpose software written for this measurement. As well as in previous section, the software part can be considered in two, so to say, independent modules: an application for data processing and presentation of results, and web application that provides an insight into the results of measurements over the Internet. Both applications use a SQL database to store intermediate results of data processing, as well as the end results of velocity measurements.

4.1 OPERATING SYSTEM

In terms of feasibility, one can use any commercially available operating system (OS), but regarding functionality and reliability, the best answer is a Linux OS. Besides the fact that Linux is "open source" operating system, it does not require the payment of a license to use, Linux OS has a number of functional advantages that will be briefly mentioned:

- The ability to control the CPU interrupt priority (far better than other OS)
- It has a built-in apps to work with the database (MySQL server)
- Built-in Web server,
- Free graphical development environment - Lazarus, based on the Pascal programming language ...

4.2 APPLICATION FOR PROCESSING AND DISPLAYING RESULTS

This software module is a custom program written in Lazarus development environment, which, as mentioned above is based on the syntax of the PASCAL programming language. As seen from the title implies, this application has a dual role. The first role is in the processing of measurement data, mathematical calculations to get the results of measurements, which are then stored in a database. The second task (role) is to present the results to the end user, whether they are numeric values given in tables or graphical representation of the waveform of the reconstructed signal.

This application has a very useful feature, which is reflected in setting of a criteria for database searching by time and location of the measurement, so it provides the ability to track velocity "trends" of a specific fluid flow. Another very useful feature of this application is to provide a graphic presentation of the "harmonic analysis" of the measured signal. In this way, except the waveform, software gives insight into the values of the individual components on different frequencies, which participate in the signal construction. Figure 6 gives a graphical representation of a reconstructed the measured signal, and the signal components at different frequencies. Graph was generated using the software for processing and displaying the measurement results.

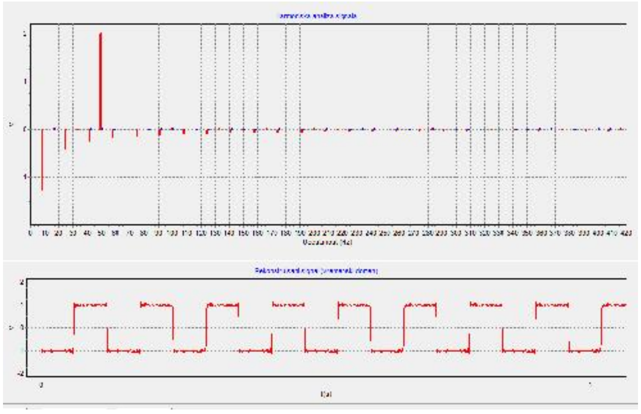

Figure 6 Harmonic analysis – top, reconstructed measured signal - down

4.3 WEB APPLICATION

For the purposes of remote measurement of fluid velocity, a web application is written, that provides end users with very fast access and insight into the measurement results via the internet and any commercially available web browser. The goal of making this application is the ability to access the results of measurements from any location in the world where there is internet connection.

The application is written using standard technique of making Web pages. Tools that were used in the development the application were: PHP and Java script languages, and MySQL data bases. It is important to mention that Web application, and application written in Lazarus, use the same database from which they read the measurement results.

For now the Web application can display tables with the results of the measurements, with the option to search the results by the location and by the time of measurement, and the plan is an upgrade module for the graphical representation of the signal waveform.

It is well known that Internet traffic can be very unsafe way to transfer data if not contempt. With this in mind, additional measures were taken for data protection. Applications are only accessible via HTTP Secure (HTTPS) protocol, so that the data traveling from the server to the user are encrypted. There is another level of protection - access control.The standard method of using a unique user name and password. And for additional authentication, randomly generated code (PIN) is sent to the user via SMS, which the user has to enter. It should be noted that this is a fully automated system for generating and sending messages, implemented under the Linux OS.

5. CONCLUSION

From the story described in the paper it can be concluded that modern technology, both in hardware and software domain plays a major role in the development of measurement, methods of measurement and Metrology itself as a scientific discipline. Hardware and software tools are at the peak of development, the only limit for their application in solving the existing problems is the imagination of individuals. The developed measurement system for remote measuring of conductive fluid velocity is just one of the many domains of application of modern technology. It is concluded that the project task has been successfully accomplished. The interferences are digitally removed (Figure 6), and the samples of measured signal are successfully transferred from the remote location and completely reconstructed on central server.

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