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ULTRASONIC FLUID FLOW MEASUREMENT METHODS, AN OVERVIEW

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Abstract. Over the last decade, ultrasonic flowmeters have made measurable penetration in the flowmeters field, although the principles of the ultrasonic flow measurement have been known for a long time. This kind of flowmeters have numerous inner adventages over most of the traditional methods. In this paper, e review of the usable ultrasonic flow measuring methods for industrial purpose from the practical aspect in its realisation is presented. it is also shown that the pulse–phase bidirectionality ultrasonic flowmeter integrated in a microprocessor–based electronics package can achieve very good performances.

1. Introduction

In all ultrasonic methods intended for the fluid flow RATE measurements several processes are included: transmission, signal propagation, reception of the ultrasonic waves, signal conditioning and data processing. During that, an ultimate goal is to determine the ultrasonic velocity in a movable liquid. Mostly, the relative velocity is measured. It points to the ratio between the ultrasonic signal velocity through a calm in respect to the velocity of a movable liquid within the pipe.

The ultrasonic methods can be successfully implemented in a fluid flow measurement because they are non-contact, do not disturb the flow, have a fast response, good stability, a wide dynamic range, eliminate the influence of velocity profile variations, allow velocity measurement in electrical conductive and non-conductive fluids both in clean and impure liquids [1,2].

The basic problem in practical realization of the ultrasonic flowmeter relates to the fact of how to establish a correct and uniform dependence

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between the fluid flow velocity, v, and certain parameter of the ultrasonic wave through the fluid, i.e. suitable parameter of the ultrasonic electrical signal which is accepted by a receiving sensor.

This primarily relates to frequency variations, phase or ultrasonic time propagation in a function of the velocity, and other variable characteristics of the fluid (temperature, pressure, viscosity, density e.t.c.). Comparing some of the same parameters of the receiving and the transmiting signal it is possible to determine the fluid flow velocity.

Concerning the methods applied in fluid flow velocity measurements they can be divided into the following two groups: a) methods based on the ultrasonic time propagation measurement, b) methods based on the Doppler's effect [20].

From the practical point of view, in industrial applications, the former methods are preferred. They are characterized by time propagation measurement in upstream and downstream directions. But, their accuracy is not good enough, especially when low fluid flow velocities are estimated. Therefore, in practice, their modified versions known as the compensation methods are widely used. Among them the most distinguished are the time-frequency and phase-frequency methods [3].

The principles of ultrasonic flow rate measurement have been known for many years, but only within the last two decades have these meters made measurable penetration at the flowmeter field. In this paper, from the large number of these known methods, a review of the usable ultrasonic flowmeter's methods for industrial production is presented. Also, a practical aspects in realisation of the pulse phase two–way ultrasonic flowmeter integrated in a microprocessor–based electronics package to determine flow rate are given.

2. Fluid flow measurement based on estimation of time propagation

With these methods, as it is shown in Fig. 1, the difference in time propagation of the ultrasonic signals, transmitted in upstream and downstream direction is measured [2] and [20].

If the ultrasonic wave is transmitted at the angles of Θ and $(\pi - \Theta)$ with respect to fluid flow velocity vector $\vec{v}$, then the corresponding propagation times in upstream and downstream directions are defined as

$$t_d = \frac{D}{(c + v\cos\Theta)\sin\Theta} \tag{1}$$

$$t_u = \frac{D}{(c - v\cos\Theta)\sin\Theta} \tag{2}$$

where are: $t_d(t_u)$ – time propagation of the ultrasonic wave in a downstream (upstream) direction; D – pipe's diameter; c – velocity of the ultrasonic signal through liquid; and, v – average fluid flow velocity on the path from the transmitter to the receiver.

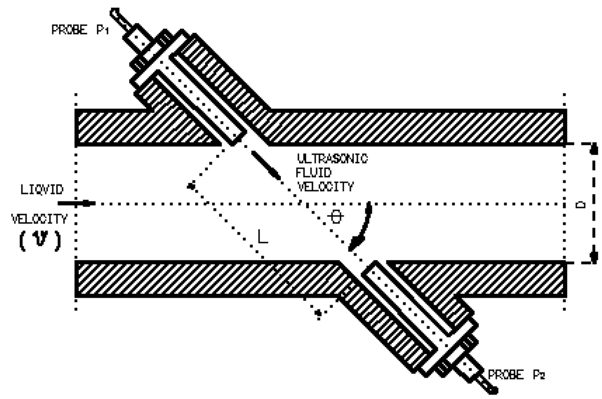

Fig. 1. Physical position of the flowmeter's ultrasonic probes

According to (1) and (2) we are going to define the following time-difference

$$\Delta t = t_u - t_d = \frac{2D \cot \Theta}{c^2} \cdot v \ , \tag{3}$$

$$v = \frac{D}{\sin(2\Theta)} \cdot \frac{t_u - t_d}{t_u t_d} \tag{4}$$

Relation (4) can be approximated in the following way

$$v \simeq \frac{c^2 \tan \Theta}{2D} \ (t_u - t_d) \tag{5}$$

A fluid flow volume, Q, for the given diameter of the pipe D is

$$Q = \frac{\pi D^2[m]}{4} v[m/s] \ 10^3 \ [l/s] \tag{6}$$

Diagrams which show, at first, the dependence of the function $Q(\Delta t)$, determined according to relations (4), $Q_a(\Delta t)$, and (5),$Q_b(\Delta t)$, and secondly, the error $\Delta Q = Q_a(\Delta t) - Q_b(\Delta t)$ as a consequence of approximation of (4) by (5), are given in Fig. 2.

Analyzing Fig. 2 it can be concluded that the error magnitude at a full scale range is of order 10^{-4} when the pipe's diameter D=0,1m, $\Theta = 45°$, $c = 1500\ m/s$ and the fluid flow velocity is up to 40 l/s.

According to this, when we want to achieve accuracy better than 1% during fluid flow measurement at a full scale range, it is necessary to determine the time-interval with a resolution less than $4ns$.

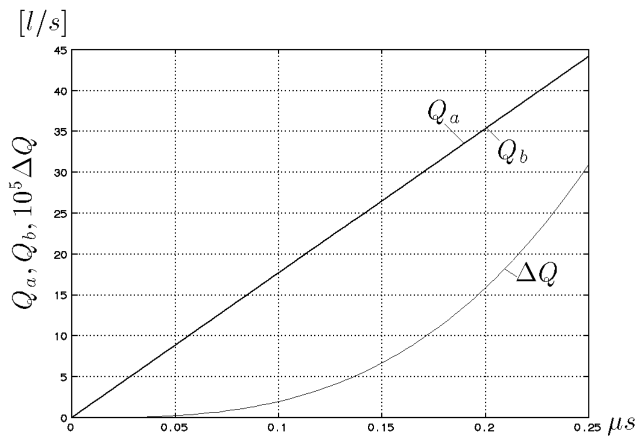

Fig. 2. Flow volume quantity Q and error approximation ΔQ in the function oftime–propagation Δt

Time resolution can be determined from the diagram shown in Fig. 3. The diagram in Fig. 3 is obtained according to (3) where the pipe's diameter taken as the parameter varies within the limits from 0,1 to $0,3m$. Having in mind the possibilities of nowdays technology, we conclude that this time-interval is order of magnitude as for the signal time propagation through standard digital CMOS and TTL ICs as well as through the comparator circuits. For that reason these methods are more suitable for fluid flow measurements in the pipes with a larger diameter and for larger velocities. At the pipes with smaller diameter this problem is solved by the transmission of an ultrasonic signal along the axe of the pipe or by using the multiple reflection. In this way, the time difference Δt is increased. However, in practical realization due to turbulent liquid movement in the vicinity of the transmitter/receiver, significant amplitude variations of the amplitude in the receiving signal will appear during the measurement. This problem can be overcome if automatic gain regulation is involved. Since these variations are fast, system's inertion has to be slow. But in this case a self oscillation mainly caused by random interferences must be avoided.

The fluid flow measurement methods based on time propagation measurement can be divided into three groups:

(i) Direct time propagation measurement of the ultrasonic signal,
(ii) Methods based on the phase-difference measurement,
(iii) Sing-around techniques

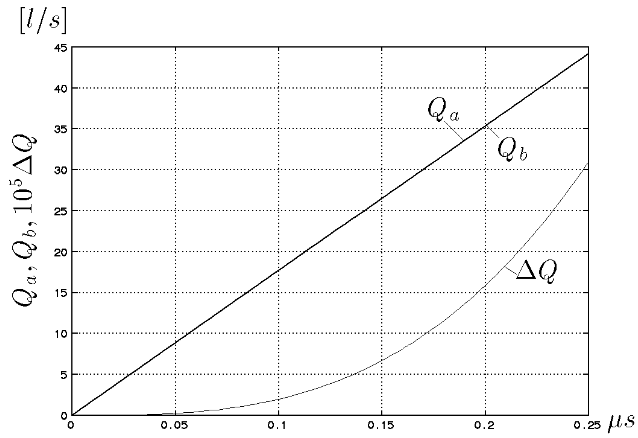

Fig. 3. Time propagation Δt in the function of flow volume quantity with D as a parameter

2.1. Direct time propagation measurement of the ultrasonic signal

This method can be realized either sequentially or simultaneously.

Principle of the sequential measurement is depicted in Fig. 4. This technique is based on switching roles between the transmiting and receiving transducer. At first, one of the transducers is used as the transmitter, and the second one as the receiver. After that by using the multiplexing technique a switching is performed. The probes are pulse-excitated, and the propagation times t_d and t_u, are measured sequentially. The time-intervals t_d and t_u are measured either by analogue integration or by counting the pulses of a high-frequency stable oscillator during the referent time-interval.

Integration/counting process is determined when the transmission process is started, and it terminates when the ultrasonic signal is received. In this case the time difference $t'_u - t'_d = \Delta t'$ is determined as

$$\Delta t' = \frac{2D \cot \Theta}{c^2}\, v + t_{e1} + \delta\tau \tag{7}$$

where are : t_{e1} – difference in propagation time of the signal through switching electronics and the pulse-shapers; $\delta\tau$ – jitter influence due to unstable comparator trigger-level.

The errors that occur as a consequence of t_{e1} can be eliminated through system's calibration at a zero-fluid flow.

The errors, involved by $\delta\tau$, can be reduced by multiple measurements, i.e. averaging of measured time propagation. Through this, the noise effect and variations in the pulse-shaping process are avoided.

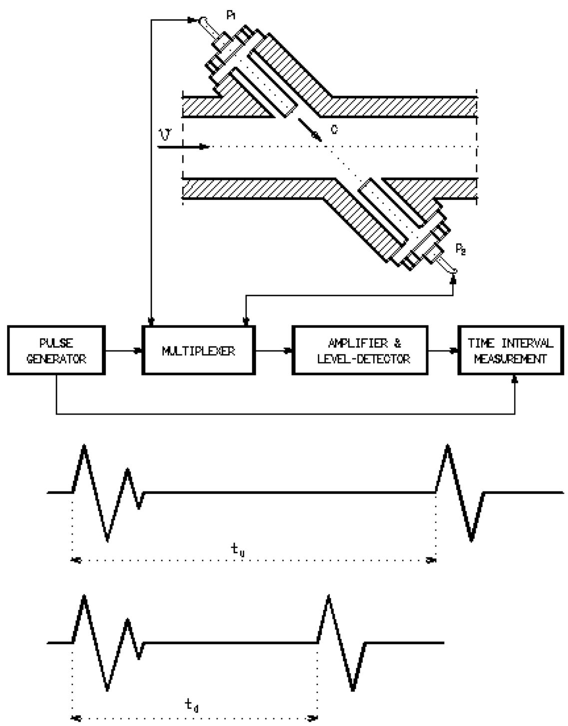

Fig. 4. Sequential direct time measurement

Principle of the simultaneous measurement is depicted in Fig. 5, [1]. In this method simultaneous pulse-transmissions, in both directions, are performed. After that, the received signals are detected and processed. As benefits, a shorter measurement period is evident. On the contrary, as a demerit duplicated electronic circuits for transmission, reception and data processing are used. This points to the fact that the differential delay through both channels can be hardly reduced to zero. This is especially critical for low fluid flow velocities. In both approaches (Fig. 4 and Fig. 5) narrow-pulses are generated. In order to achieve the specified accuracy, time durations of the leading and trailing edges of the pulses, at the transmiting and receiving side, should be as shorter as posible. This implies to the fact that the wide-band high frequency amplifiers with a linear phase characteristic should be installed.

According to (7) it is evident that $\Delta t'$ depends on $1/c^2$. For more accurate measurement, error compensation is required. In this case it is obligatory to compensate the velocity temperature dependence of the ultrasonic signal through liquid. For more details on this problem see [12].

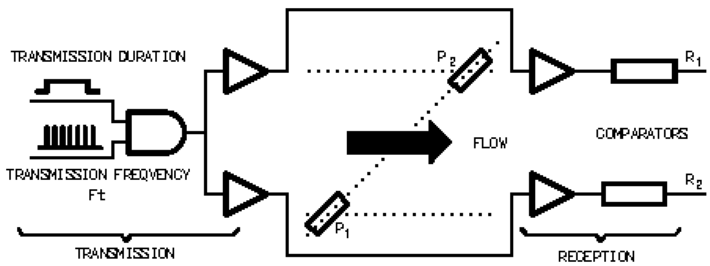

Fig. 5. Simultaneous fluid flow measurement

2.2. Methods based on the phase-difference measurement

In these methods the fluid flow velocity is determined by measuring the phase-difference between two sinewave signals transmitted in upstream and downstream directions. The phase-difference appears as a consequence of ultrasonic signal propagation through the movable liquid. These methods can be classified as the continual and the burst ones [20].

In the continual method the ultrasonic signal is transmitted and received permanently at the same time from both transducers which can operate at:

(i) two frequencies f_1 and f_2, where $f_1 \neq f_2$,

(ii) principle of frequency modulation

The method which uses two different frequencies is described in [16].

By this method, both the flow velocity, v, and the ultrasonic velocity, c, can be determined. After that c is used as a data to provide error compensation, because c is a function of temperature. The principle of operation, without practical realization of this type of the flowmeter, is described in [16].

The methods based on frequency modulation, are characterized by low accuracy especially for low fluid flow velocities and in pipes with small diameters. Due to a limited measurement range they are mostly used only for distance measurements. During practical flowmeter's realization, extension of the measurement range represents one of the main technical problems [21].

Principle of operation in burst methods is shown in Fig. 6, and is described in details in [1] and [20].

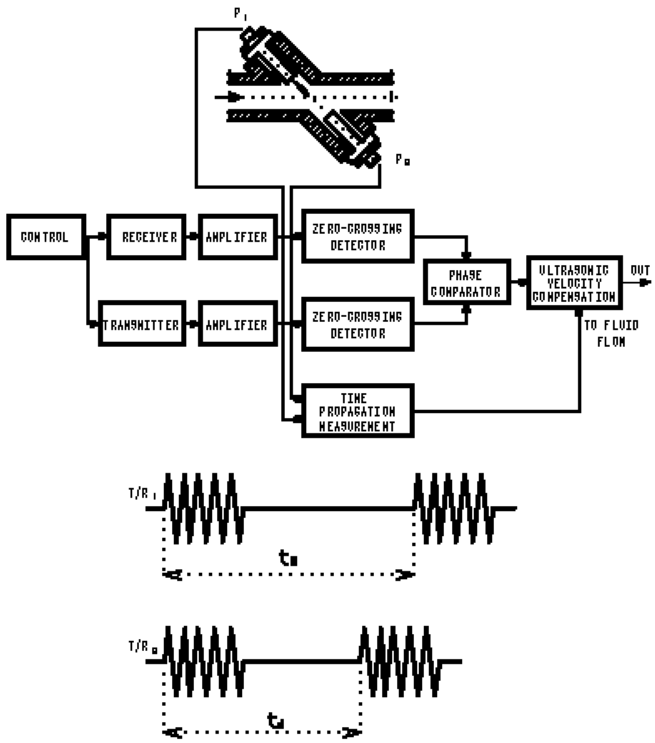

Fig. 6. Burst phase–difference method

Train of ultrasonic oscillations is transmitted simultaneously, and after that both transducers are used as the receivers. First, the input signals are amplified, and after that they are shaped by zero-crossing detectors. After shaping a phase compensation is performed. The phase angles of the receiving signals, in upstream and downstream directions, are given as

$$\Phi_d = 2\ \pi\ f_0\ t_d, \quad \Phi_u = 2\ \pi\ f_0\ t_u\ , \tag{8}$$

where: f_0 – basic frequency of the ultrasonic signal.

If the phase-difference $\Delta\Phi = \Phi_u - \Phi_d$, then according to (8) we obtain

$$\Delta t = t_u - t_d = \frac{\Delta\Phi}{2\pi f_0} \; . \tag{9}$$

Substituting (9) into (3) for the velocity v, we have

$$v = \frac{c^2 \; \tan\Theta}{4\pi \; D \; f_0} \cdot \Delta\Phi \tag{10}$$

According to (10) it can be seen that the difference $\Delta\Phi$ obtained at the output of the phase-comparator is proportional to the velocity v. During one burst pulse processing the value $\Delta\Phi$ is determined several times. When the velocity v is calculated, we should be aware that the following is valid

$$\Delta\Phi = \Delta\Phi_v + \Delta\Phi_e \; , \tag{11}$$

where: $\Delta\Phi_v$ – phase difference due to fluid flow velocity v; $\Delta\Phi_e$ – phase-difference as a consequence of the delay through electronics.

The main advantages of this method are:

(i) possibility to minimize the "jitter" influence in shaper and comparator circuits by averaging the phase-difference, and

(ii) installation of the narrow bandpass, instead of the wideband amplifiers with a linear phase characteristic. Demerits are as follows:

(i) for phase differences in the vicinity of $2k\pi$ $(k = 0, 1, ..., n)$, the output of the phase comparator is undefined, i.e. dead-zones exists, and

(ii) when k is not determined precisely, a large error during measurement appears. This shortcoming often limits the implementation of such flowmeters at measurements where restricted velocity range and pipe's profile are met.

The first drawback can be eliminated when the heterodyne technique is applied [24]. However, in this case the main problem is to provide the constant difference between the frequencies of the transmiting and the receiving signals. In order to increase accuracy it is necessary to keep the frequency-difference as smaller as possible.

All phase methods previously mentioned impose a need of velocity compensation since c is a function of temperature. For that reason, in the functional structure of the flowmeter it is necessery to install additional electronics.

2.3. Sing-around technique

Principle scheme based on the sing-around technique is shown in Fig. 7. The system consists of two loops, through which the pulses are propagated. It uses a time overlapping technique. The first loop includes a downstream path of the signal ($P_1 \to P_2 \to M_2 \to R \to T \;-\; M_1 \to P_1$) and the latter the upstream path ($P_2 \to P_1 \to M_1 \to R \to T \to M_2 \to P_2$).

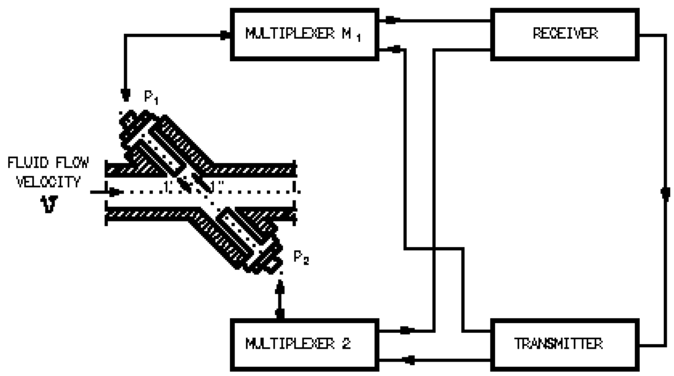

Fig. 7. Sing–around technique

The transducers P_1 and P_2 are used as the transmitters and the receivers. For correct system operation, time overlapping of the transducer's role has to be avoided. Signal time propagation through the loop in downstream direction is t_d, and through the loop in upstream direction is t_u. Accordingly, the circular frequency of the signals through the loop are

$$f_d = \frac{1}{t_d} = \frac{1}{\dfrac{D}{(c + v\cos\Theta)\sin\Theta} + \Delta t_{de}} \tag{12}$$

$$f_u = \frac{1}{t_u} = \frac{1}{\dfrac{D}{(c - v\cos\Theta)\sin\Theta} + \Delta t_{ue}} \tag{13}$$

where: Δt_{de} and Δt_{ue} stands for delays of the signals out of liquid, i.e. in the electronic loops for upstream and downstream directions, respectively.

When $\Delta t_{de} = \Delta t_{ue} = 0$, then we have that

$$v = \frac{D}{\sin(2\Theta)} \cdot \Delta f \; . \tag{14}$$

According to (14) it can be seen that the frequency-difference $\Delta f = f_d - f_u$ is proportional to the velocity v and does not depend on the velocity c.

Due to physical characteristics of the fluid, the operating frequency of the transmitter and the receiver is usually within the range of 1–10 MHz [4] and [10]. In order to estimate the order of magnitude of measured values, let analyze the following example; $v = 1\ m/s$, $d = 1m$, $\Theta = 45°$, $c = 1420m/s$, then $L = D/\sin\Theta = 1,41m$ and $\Delta f = 1\ Hz$.

In the latter example, the influence of Δt_{de} and Δt_{ue}, that essentially determines the measurement accuracy is not taken into account. The influence of these variations as well as the variations of the average path length ΔL and variations of Δc as a function of temperature are analyzed in details in [23] and [26].

The advantages of this method are as follows:

(i) frequencies f_1 and f_2 and their difference Δf are determined by some counter methods, and

(ii) velocity v does not depend on c. This points to the fact, that installation of additional circuits for temperature compensation are not needed during the flowmeter's realization. The main drawbacks are:

(i) practical realization requires installation of high-frequency wideband amplifiers with a linear phase characteristic,

(ii) condition $\Delta t_{de} = \Delta t_{ue}$, which is crucial for measurement accuracy, is difficult to achieve, and

(iii) during continual measurement the time overlapping of the roles between the transmitters and receivers can appear. This effect can cause large errors during measurements.

Some suggestions that relate to the problem of how to eliminate these shortcomings are given in [11] and [15].

The principle of this method has been known since 1930 [19], but its practical realization was not possible before '60-ties, until the electronic components have become fast and qualitative enough. Development of faster electronic components in the last 10 years has provided a wider application of this type of flowmeters [7]. However, due to unstability of the pulse leading-edge their accuracy is limited. Today they are mainly used for fluid flow measurements at larger velocities.

3. Compensation methods

Better accuracy and sensitivity of the ultrasonic flowmeters can be achieved when we combine the methods previously mentioned. Mostly, by their nature these methods are the time-frequency and time-phase ones, and are commonly known as the compensation methods [9].

In essence, a phase of the frequency controlled oscillators is automatically adjusted with these methods. The flowmeters based on the time-frequency method are comprised of two measuring channels. One of the channels is used with a goal to determine the ultrasonic velocity that is opposite to the fluid flow. The second one is used to determine the ultrasonic velocity in a fluid flow direction. Each channel represents a feed-back loop.

The period of the controlled oscillator is proportional to the time delay of the ultrasonic pulse through the fluid. Ultrasonic time propagation in downstream and upstream directions (t_d and t_u), defined by (1) and (2), are sampled by the periods of the controlled oscillators T_d and T_u, respectively, using a time discriminator. The voltage at the output of the time discriminator is proportional to the time differences. Time-differences are determined as follows [9]:

$$\Delta t_d = t_d - N\ T_d \tag{15}$$

$$\Delta t_u = t_u - N\ T_u \tag{16}$$

where: N is coefficient of proportionality, i.e., an integer number.

The periods T_d and T_u of each oscillator are changed unless we obtain $\Delta t_d = 0$ and $\Delta t_u = 0$, namely, till the voltage at the output from the time discriminator becomes equal to 0. Then, accordingly to (1), (2), (13), and (14) we have

$$f_d = \frac{1}{t_d} = \frac{N \sin\Theta}{D}\ (c + v\cos\Theta)\ , \tag{17}$$

and

$$f_u = \frac{1}{t_u} = \frac{N \sin\Theta}{D}\ (c - v\cos\Theta)\ . \tag{18}$$

The frequency difference of the controlled oscillator according to (17) and (18) is

$$\Delta f = f_d - f_u = \frac{N \sin 2\Theta}{D}\ v\ . \tag{19}$$

Analyzing (19) and (14) we conclude that they are similar. Namely, in both cases Δf does not depend on c. According to this by measuring Δf we can determine the fluid flow velocity v.

The flowmeters based on this method are less sensitive to noise. This is achieved thanking both to automatic frequency adjustment in the measurement channels, and to installation of a single element by which the comparison is performed. However, jitter influence on the pulse leading-edge is not yet solved satisfactory. It can be considerably overcome if the comparison, namely adjustment of oscillator's frequency is performed in several steps using the phase-difference between the received and the referent burst pulses, as a correction factor [22].

Basically, this method, belongs to a group of the phase-frequency methods. Theoretically it is concerned in details in [9], but a concrete solution of the problem which concerns the influence of the rise-time of the pulse leading-edge and practical flowmeter's realization are not described in details.

4. Pulse–phase flowmeter

The block scheme of the flowmeter based on the pulse-phase method described in [17] is shown in Fig. 8. The flowmeter represents a small embedded-system. Its achitecture is a combination of the programmable microprocessor core with a memory and hardwired programmable peripherial interface devices accompanied by other processing logic. Hardware and software form together the system. The MicroComputer (MC) generates all necessary control signals k_1, k_2, k_3 and k_4 in defined time-intervals. The ultrasonic transmitter is excitated by sinewave signals of frequency 2.2 MHz (exact value is 2.216767 MHz). The excitation signal is obtained by dividing the frequency of 17.73414 MHz, generated at the output of the block Crystal–Oscillator (OSC). Division is accomplished by a counter logic as a constituent part of the block Counter–Shift–Logic (CSL). Shaping of the rectangular pulses into a sinewave is accomplished in the block Shaper–Output–Stage (SOS). The SOS is realized as a two-stage bandpass amplifier with resonant frequency of 2.2 MHz. The amplitude of the output signal $U_1\angle\varphi_1$ can be discretly adjusted into two levels. The state of the signal k_A defines the magnitude of the output signal $U_1\angle\varphi_1$. The signal k_A is generated by the Counting–Synchronization–Block (CSB).

The Ultrasonic–Transmitter–Receiver (UTR) block incorporates a pair of ultrasonic probes $P1$ and $P2$. Each probe, in accordance to the proposed measurement method, operates alternatively either as the transmitter or the receiver. Switching function is provided through fast electronic switches. States of the electronic switches are defined by the control signal k_4.

The signal from the receiving probe $U_2\angle\varphi_x$, excitates the input stage of the block Input–Stage–Comparator (ISC), where it is first amplified and then shaped into rectangular pulses. The ISC generates two types of output signals $U_k\angle\varphi_x$ and U_{kA} respectively. The signal U_{kA} drives the Counting–Synchronization–Block (CSB) while, the signal $U_k\angle\varphi_x$ the A_input of the Phase–Comparator (PhC).

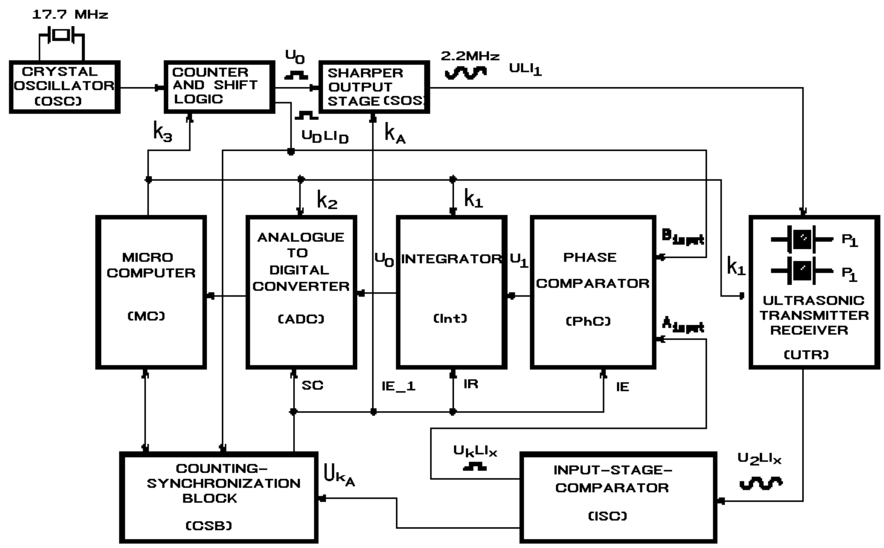

Fig. 8. Global block scheme of the flowmeter

The phase φ_x of the received signal U_2 depends on the fluid velocity.

The B–input of the PhC is driven by the referent signal $U_D\angle\varphi_D$. The duty cycle of the signal U_{in} obtained at the output of the PhC is proportional to the phase difference, $\Delta\varphi = \varphi_x - \varphi_D$.

Further, in the processing chain, an integration is performed. Namely, a train of rectangular pulses is averaged in the block IntegraTor (InT). Activities of InT, related to setting of the initial condition, enabling of the integration period e.tc., are regulated by control signals k_1 and I_R. The output voltage U_0 obtained at the output of InT is proportional to $\Delta\varphi$ and it is led to the Analogue–to–Digital–Convertor (ADC). The ADC provides an interface between the analogue and digital parts of the electronics. Data transfer between the MC and ADC is regulated by the control signals k_2 and SC.

The CSB is specifically designed interface block controlled by MC. In defined time-intervals it generates control signals needed for correct operation of the flowmeter's constituents; i.e. Start–of–Conversion (SC) for ADC, Integrator reset (I_R) for InT, enabling operation (IE) of PhC, output amplitude setting of SOS,...

5. Conclusion

Fluid flow measurement stands for a complex metrological problem both from the aspect of theoretical analysis concerning the nature of fluid movement itself and from the aspect of practical realization of measuring devices and systems. During flowmeter's realization the following problems are dominant:

a) compensation of the influence of ultrasonic velocity variation due to temperature and physical-chemical properties of the liquid,

b) approximation of a variable velocity profile of the liquid by mean velocity, and

c) problem of a small ratio scalling between the mean fluid velocity, $\overline{v}$, and ultrasonic velocity, c, i.e. $(\overline{v}/c)$

d) choice of an optimal hardware configuration for signal processing The pulse-phase method proposed in [17] is solving the problems mentioned above in a satisfactory manner and brings about a new approach of how to estimate mean fluid flow velocity and volume quantity. By the propose method we have found out that it is not necessary to involve:

i) aditional error compensation due to temperature dependence of the ultrasonic velocity and physical-chemical properties of the liquid

ii) delay compensation through electronics and cables, since the volume quantity is determined according to time-difference propagation of the ultrasonic signal in upstream and downstream direction, where the same electronic building blocks are used.

The influence of fluid flow velocity profile variation is also solved, by time-propagation measurement of the ultrasonic signal in upstream and downstream direction. After that, the mean fluid flow velocity value involving the calibration function is determined.

The small ratio v/c is solved by an interdomain conversion of the physical quantity v into the time-domain. During this a time-interval measurenment is realized with a high resolution accomplished in several steps. Thanks to a proper choice of the flowmeter's functional structure based on the microcomputer, the problem of precize time-propagation measurement, performed in several steps during one measuring cycle, is successfully solved such as:

i) marking the moment at the ultrasonic signal from where the time interval measurement has started,

ii) counting of the whole periods of the ultrasonic signals within a measurement interval,

iii) phase-difference measurement with a multiple repetition and results averaging, and

iv) adding of the results in (ii) and (iii).

During practical realization of the flowmeter, described in this paper, a special attention is paid to signal processing and construction of the essential building blocks. Shape of the measured signal is selected so as to contain only the basic harmonic. Thus, sensor operation at the resonant frequency (2.2 MHz) is provided, and electronic circuits are simple in construction. The resonant frequency is chosen according to the minimal phase difference, and amplitude variations of the measured signal for the selected probes.

In concern of the time interval, original solutions for Counting_and_ Synchronization_Block, Phase_Comparator and Integrator are given. Also, an original solution for determination of the marker's position is given, according to which a part of the ultrasonic time-interval propagation in upstream and downstream direction is defined. It coresponds to a multiple integer number of the ultrasonic signal period (NT). The rest of the periods (τ_u, τ_d), which is smaller than T, is precisely determined through applying the tracking technique. In this manner, the resolution of the system is increased for $3 = \log_2 8$ bits.

The flowmeter's structure is based on the microcomputer. Built-in software and hardware allows us to perform multiple measurements in a short-time interval i.e. to obtain a fast response of the system. For the fluid flowmeter having a pipe of $D = 0,1m$ in diameter the following results are obtained: Time-interval is measured with the resolution of $0,12ns$. According to that the estimated velocity resolution is $1,12mm/s$ and the volume quantity resolution is $8,8ml/s$. The instant flow movement sampling is performed in the intervals less than 60ms, and processing and results displaying is performed in time-intervals less than $0,5s$.

The ultrasonic fluid flowmeter, described in this paper, belongs to a group of the soft-real-time-embedded systems and fulfills almost all of the requirements concerning contemporary fluid flowmeters for industrial applications with respect to sensitivity, automatic zero and measurement range linearity adjustment, self-testing, displaying and transfering of the measured results to the host. The accuracy of the flowmeter is better than 1%. This flowmeter can measure different kinds of liquids, and operates as an autonomous measurement equipment or as a part of the complex measuring system intended for automatic process control.

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