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MEASUREMENT OF BIOLOGICAL TISSUE PROPERTIES USING THE ULTRASOUND METHOD

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The elastic properties and velocity of acoustic sound propagation in soft tissues, permits applying the liquid model in research. In regard to the low level of ultrasound power admissible in research in vivo, a new method, implementing quasi-continuous wave, was proposed. The base for determination of the medium parameters, is utilising the conversion of receiver signal to digital form and counting the phase of signal numerically.

Presented method was implemented in monitoring the condition of brain, and it gives the possibility to detect changes of density on level 50 ppm, and changes of temperature 0,02^{O}C with medium power over 100 times less then the admissible.

That method, in regard to the measurement set-up's simplicity and high accuracy, can find implementation in other technical solutions and scientific research.

INTRODUCTION

The duration of broadcasting signal is long enough for the amplitude of harmonic vibration in receiver to be constant. Simultaneous utilise of the transducer's resonant propriety significantly reduces the power level. Implementing the quartz generator as source of signal (high stability of frequency) and appropriate AD frequency sampling, results in high accuracy of signal's phase measurement.

This method was elaborated for medical measurements –changes of brain density, but it can be useful in technical and scientific research because it has a good ratio of costs and accuracy.

1. PRINCIPLE OF MEASURING METHOD

The general idea of measuring method is presented for the simplest case, i.e., for homogenous and isotropic media. In this case phase velocity of an acoustic wave depends on both the medium elasticity K and the density p in accordance with equation

$$c = \sqrt{\frac{K}{\rho}} \qquad (1)$$

Most methods [1-3] utilise measurements of an acoustic wave Tp run time and then calculate the phase velocity using the known formula (2):

$$Tp = \frac{L}{c} \quad (2)$$

Or the other way, knowing the phase velocity of acoustic wave, distance L is calculated.
The main principle of this method is implementation of quasi-continuos wave packet in order to calculate the run time of an acoustic wave. The scheme of transmission version set-up, utilising the quasi-continuos wave packet is shown on fig.1

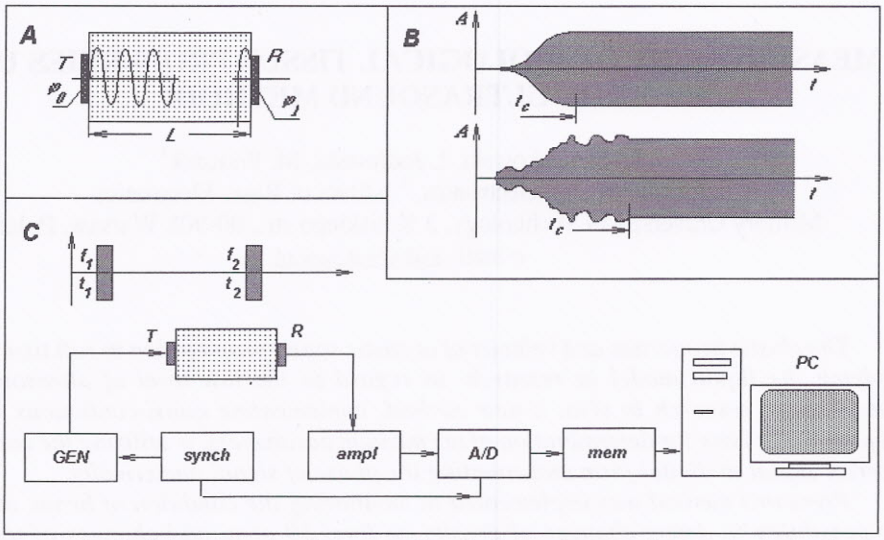

Fig.1. Scheme and principle of work of set-up. A) principle of measuring method –in the space between transmitter and receiver some of full length wave and a "rest" expresses by phase φ_1 was located, B) for non-homogenous medium the time of excite vibration t_c is longer then for the homogenous one, but after t_c time, the amplitude and phase be come constant, C) scheme of transmission version set-up

The system consists of measurement vessel of the length L and transmitter and receiver of ultrasonic waves. As it is shown in Fig. 1A at the given transmitters frequency within a vessel length a certain utter number of the oscillation periods P and "a part of period" expressed as phase difference $\varphi_1 - \varphi_0$.

$$\Phi = 2\pi f Tp = 2\pi P + (\varphi_1 - \varphi_0) \quad (3)$$

On part B of fig.1 the excitation of vibration, in the receiver, was shown. In case of a homogenous medium, the time of the excitation of vibration (t_c), is shorter than in non-homogenous one (lower part), but after sufficient time, the amplitude and phase of vibration be come constant So the measurement of the phase of acoustic wave is done in this area. It requires generating sufficiently long acoustic packet.

The scheme of set-up is shown on fig. 1C. The main synchronisation unit (synch) pushes the generator (GEN) and AD converter. Electric signal from acoustic head, after amplifying in block (ampl), and converting into digital form, is stored in the memory (mem) of acquisition card. PC computer (PC) is used to calculate and visualise the results.

Depending on specific character of investigations (changes detection in a phase method or parameter determination in a time method) the problem is always reduced to determination of phase relations R $= \varphi_1 - \varphi_0$ with the lowest experimental error. For of the run time measurement *Tp* an additional determination of utter number of the wave length *P* within the probing distance *L* is necessary [4].

The kernel of both methods is procedure of elementary phases determination. It is possible to determine the signal parameters including the phase value φ using solutions of the problem approximation of *n* samples performing equation of harmonic wave in a general form

$$g(t) = S + A\sin(\omega t + \varphi) \tag{4}$$

so it is possible to find the parameters of signal, and the searched value of phase φ.
In this equation:

$$S = \frac{y - C\cdot\sin - D\cdot\cos}{n}, \qquad \varphi = arctan\frac{D}{C}, \qquad A = \frac{D}{\sin(\varphi)} = \frac{C}{\cos(\varphi)},$$

$$D = \frac{(n\cdot y\sin - y\cdot\sin)(\sin\cdot\cos - n\cdot\sin\cos) + (y\cdot\cos - n\cdot y\cos)(\sin^2 - n\cdot\sin\sin)}{(n\cdot\sin\cos - \sin\cdot\cos)(\sin\cdot\cos - n\cdot\sin\cos) + (\cos^2 - n\cdot\cos\cos)(\sin^2 - n\cdot\sin\sin)},$$

$$C = \frac{y\cdot\sin - n\cdot y\sin + n\cdot D\cdot\sin\cos - D\cdot\sin\cdot\cos}{\sin^2 - n\cdot\sin\sin},$$

where: $\sin = \sum_{i=1}^{n}\sin(\omega t_i)$, $\cos = \sum_{i=1}^{n}\cos(\omega t_i)$, $y = \sum_{i=1}^{n} y_i$, $\sin\cos = \sum_{i=1}^{n}\sin(\omega t_i)\cos(\omega t_i)$,

$\cos\cos = \sum_{i=1}^{n}\cos(\omega t_i)\cos(\omega t_i)$, $\sin\sin = \sum_{i=1}^{n}\sin(\omega t_i)\sin(\omega t_i)$, $y\sin = \sum_{i=1}^{n} y_i\sin(\omega t_i)$,

$y\cos = \sum_{i=1}^{n} y_i\cos(\omega t_i)$, n –quantity of samples

C [sign of value]	+	-	-	+
D [sign of value]	+	+	-	-
φ [degree]	0-90	90-180	180-270	270-360

The time method is free of limitations of the previous solution and gives a measurement process the value of passing time of probing signal *Tp*. The solution has several limitations. Though the conditions that have to be fulfilled are not too excessive, only their strict keeping can bring reliable results. Two-stage measuring procedure makes it possible to determine the rough *Tp* value with the resolution $+\text{-}t_{pr}$ in a typical way used for pulse methods but the measurement of a precise term of the equation is based on phase analysis for each of the probing frequencies f_1 and f_2.

$$Tp = (t_1 - t_0) + \frac{1}{4\pi}\left(\frac{R_1 + 2\pi P_1}{f_1} + \frac{R_2 + 2\pi P_2}{f_2}\right) \tag{5}$$

$$P_1 = wart.calk\left(\frac{R_{12} f_1}{2\pi(f_1 - f_2)} - \frac{R_1}{2\pi}\right), \quad P_2 = wart.calk\left(\frac{R_{12} f_2}{2\pi(f_1 - f_2)} - \frac{R_2}{2\pi}\right),$$

$R_1 = \varphi(t_1) - \varphi(t_0)$ for f_1, $R_2 = \varphi(t_1) - \varphi(t_0)$ for f_2, $R_{12} = R_1 - R_2$

Proprieties and limitations of both methods with extended presentation of results, was presented on earlier papers [5-9].

2. EXPERIMENTAL VERIFICATION

The measuring system is based on transmitting - receiving module composed of wave packets generator and amplifier and computer with A/D converter card.

For system testing, to generate wave packets, acoustic heads with the following parameters were used: diameter *D=20 mm*, middle frequency f_n*=l.43 MHz* and quality factor *Q~5*. The process of data acquisition was based on using A/D converting card (AMBEX LC-30-1612), and data processing (determination of phase relations *R* in phase method [6] and passing time of acoustic signal *Tp*, in time method [7]) was done on PC computer Pentium 166.

The proposed testing of the measuring method was based on low frequency signal sampling and relatively long duration of probing pulses.

Analysis of the developed measuring method in the proposed application was based on:

- computer simulations showing that 12-bits A/D conversion card sampling signals with frequency 500 kHz limits theoretical measuring resolution (concerning indeterminate of a sampling time) to $Rr = 0.2^0$ and $Tpr = 0.4\ ns$;
- signal generator (Hewlett Packard 33 120A), generating harmonic signals made possible to determine $Rr = 0.4^0$ and working at a frequency (f_1 and f_2) switching mode enabled us to determine $Tpr = l\ ns$;

As an example of changes the phase of signal by temperature is that test. The wave propagation velocity in water (*c*), depends from temperature by equation [10]:

$$c = 1402{,}385 + 5{,}038813T - 5{,}799136 \cdot 10^{-2} T^2 + 3{,}287156 \cdot 10^{-4} T^3 +$$
$$-1{,}398845 \cdot 10^{-6} T^4 + 2{,}787860 \cdot 10^{-9} T^5$$

where T is the temperature in degree Celsius)

As a test, changing the temperature from 22,5 to 25,5 ^{0}C within 3 hours, was used. The changes of phase were measured utilising reflection version of set-up with measure length *L = 300 mm*.

The obtained results confirmed high agreement with theoretical ($\Delta R \approx -585\ ^{0}$) and experimental ($\Delta R \approx -580\ ^{0}$) results.

Other investigations of phase's changes in case moving the reflecting wall and changing the density of medium were done. On this base of it, the resolution of method was determined. The results are shown in tab.1.

Tab. 1. Resolution of measured magnitude value determination

Measured value	**Value**
Phase relations *R*	$2{,}5^0$
Run time *Tp*	5ns
Shift	3,75µm
Acoustic wave velocity	3,7 mm/s
Temperature	0,002 ^{0}C
Density	$0{,}3 \times 10^{-3}$ kg/m^3

The measuring device *Encefalodensometer* designed for monitoring of blood circulation changes in blood vessels caused by some diseases was elaborated in cooperation with Prof. Roman Mazur from Neurology Clinic of Medical Academy in Bydgoszcz. The up to now obtained results show possibilities of investigation of this kind of brain blood vessels pathology [11].

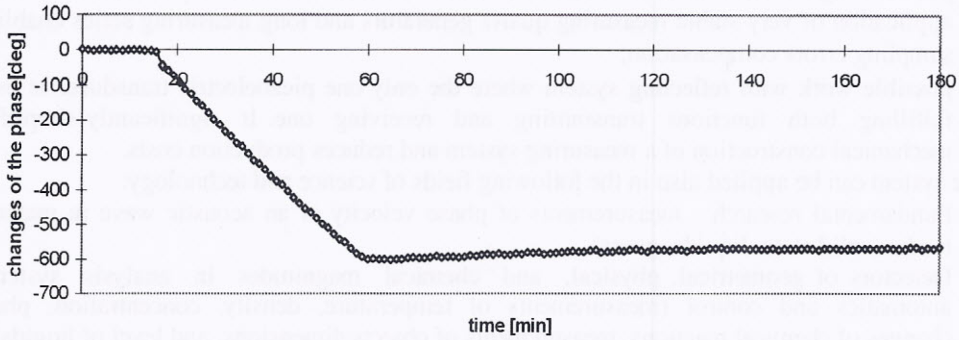

Fig. 2. Test results of temperature changes within an investigated object

3. CHARACTERISTIC OF MEASUREMENT S METHOD, POSSIBLE APPLICATIONS

The proposed measuring method is innovative one:

1. It is a solution including elements applied in the methods based on a continuous wave and elements used for pulse technique.
2. Steady oscillations of piezoelectric receiver are used for measuring process both for transmission and receiving of signals what ensures enables to get very good quality of harmonic signal and decreases an error of phase determination in a consequence.
3. Wavelength of the applied wave packets and the number of examined samples is optimised for minimum error of phase detection, what is in close relation to frequency of the tested signal and its sampling rate. It is possible to use lower sampling rates of a signal than the frequency of wave propagating in a medium with similar measurement precision. Good enough phase determination can be obtained using at least 10-bits A/D converters (recommended 12-bits). It has been shown in the analysis of errors and confirmed by experiments.
4. The phase relation analysis for a single frequency of acoustic probing signal (phase method) is suitable for measurements of relative signals (phenomena monitoring). Using two different and appropriately optimised probing frequencies enable absolute in form of run time of a probing wave.
5. The measuring method, based on phase relations analysis, makes it possible to achieve a time resolution of the range of a few hundredths of a period of the used probing wave.

The presented above features makes this method attractive for applications. It doesn't employ any sophisticated equipment.

The measuring method is characterised by:

- a very low instantaneous and average power density and in connection with it, those systems are especially useful for biological media investigations;
- a simple and fast algorithm of phase determination, an easy way of visualisation. The data can be collected directly from sampling cards assembled inside a personal computer PC. The system of control, data acquisition and information visualisation is flexible;

- wide measurement range for a change of medium parameters and probing frequency. It is also possible to use lower frequencies than the sampling frequency of a measuring card, similar and even much higher frequencies;
- possible high resolution of the method (~1/100 of an acoustic wave period) results from application of very stable measuring quartz generators and long measuring series enabling sampling errors compensation;
- possible work with reflecting system where the only one piezoelectric transducer is used fulfilling both functions transmitting and receiving one. It significantly simplifies mechanical construction of a measuring system and reduces production costs.

The system can be applied also in the following fields of science and technology:

1. Fundamental research - measurements of phase velocity of an acoustic wave in material media (solid state, liquids, gases).
2. Detectors of geometrical, physical, and chemical magnitudes in analysis systems, automatics and control (measurements of temperature, density, concentration, phase changes of chemical reactions, measurements of objects dimensions, and level of liquids).
3. Medical diagnostics concerning resultant acoustic properties of tissues.

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