The sphygmography measuring converter “pressure – frequency” dynamic characteristics examination.

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Abstract. *Dynamic characteristics of a sphygmography measuring converter definition technique on the basis of the state-of-the-art analysis of dynamic characteristics definition modes are presented. An apparatus for the transmitter dynamic characteristics definition is offered as well.*
Keywords: *sphygmography, measuring converter, sensing element, dynamic characteristic, transfer function.*

1. Introduction.

Sphygmography is the cardiovascular system diagnostic based on pulse-wave oscillations. It is possible to define arterial pressure, cardiac rate and other parameters cardiovascular system of the person on these oscillations [1, 6, 7, 8]. Many small details pulse waves help the doctor to put the true diagnosis. To show up these details it is necessary the resolution ratio 0,01 mm of mercury [2,7].

2. Subject and Method.

The object of our research is a measuring of the converter “pressure - frequency” characteristics. The results are applied for relative pressure measurement. It works in a dynamic range (0 - 300 mm of mercury overpressure). It is used for systolic and diastolic pressure measurement and for cardiac beat frequency measuring instrument (one part was created by us - oscillometrical sphygmograph “Stanislav - TON_01”), as well as for the arterial pressure pulse wave (sphygmogram) recorder.
The sphygmographic converter of pressure to frequency represents itself a quartz with the modulated interelectrode clearance ($f_{carrier}$=10MHz), pitot-static head of type "bandage", flexible connective hose (Fig.1). Such head and a flexible connective hose are applied in sphygmography systems to gear the arterial pressure pulsation from the patient to a measuring converter. It is carried out in such a way that does not produce any audio effects.

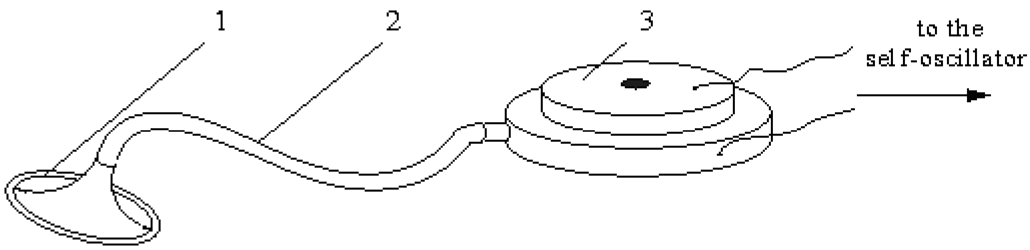

Fig. 1. Sphygmographic converter. 1 - pitot-static head of type "bandage"; 2 - flexible connective hose; 3 - quartz with the modulated interelectrode clearance.

This “pressure - frequency” converter is included in the self – oscillator circuit which is the circuit of a three-point capacitor. This generator model was investigated both theoretically and experimentally. The necessary parameters of this generator and elements of correction required for reception of maximum linear dependence “pressure frequency” have been specified in result. The design of the sensor is shown on Fig. 2. The equivalent electric circuit is shown on Fig. 3. The calibration characteristics “pressure - frequency” is shown on Fig. 4. An indirect error of the tested converter “pressure - frequency” (registered with the help of an ideal manometer verified as the secondary standard) is less than 0,02 %. This sensitive element is described in detail in [3].

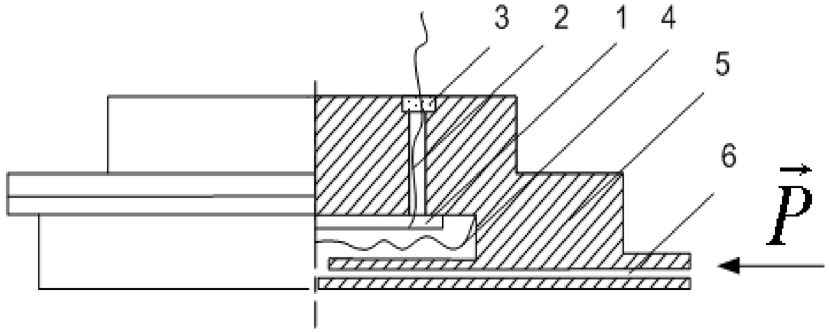

Fig. 2. Quartz sensitive element design.
1 - quartz with spray-coated, motionless electrode; 2 - wire; 3 - hermetic sealing; 4 - mobile electrode - membrane; 5 - case; 6 - channel for air inlet.

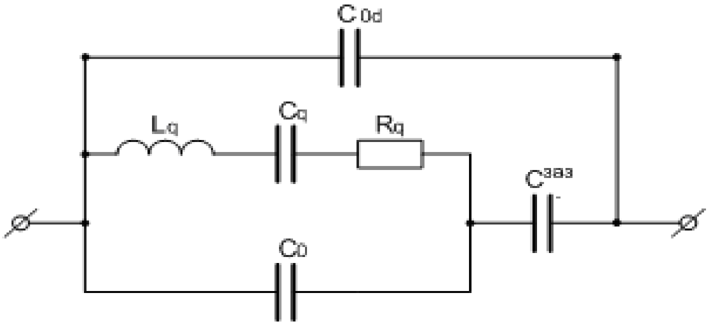

Fig. 3. Equivalent electric circuit of a quartz sensitive element L_q C_q, R_q - equivalent parameters of quartz; C_0 - parallel capacity of quartz; $C_{заз.}$ - capacity losses ; C_{0d} - additional (parasitic) parallel capacity.

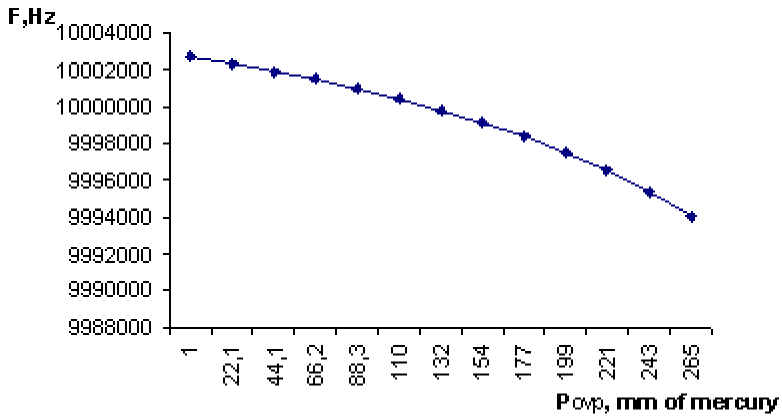

Fig. 4. Calibration characteristic of the measuring converter “pressure - frequency”; P_{ovp} – overpressure.

We deal with dynamic conversion because input (pulse-wave pressure) and output (a deviation of frequency) signals vary in time.
Dynamic characteristics are the main characteristics of any system with varying input and output signals. It is difficult to judge some parameters on a static response of a system. Especially, it concerns error of conversion [4].

Dynamic characteristic
The dynamic characteristic gives comprehensive information about a system with varying input and

output parameters [5]. It is possible to receive a complete dynamic characteristic with the help of a test signal. Various instruments and techniques are applied to create of test signals. In our case it is the unit step or the σ- function.
The system response on the unit step or the σ- function is transition function $h_0(t,\tau)$.
The special apparatus for the unit step effect realization has been developed in our laboratory.
The dynamic characteristics and the transfer functions research is made by carry of a spectrum on low frequencies (using of heterodyne mixing with detachment IF about 1-10 kHz).

Instrumentation
The instrumentation is represented by:

equipment for realization of a pressure drop up to 200 mm of mercury;

measuring bench for observation and experiments outcomes storage.

This apparatus is shown in operational status in Fig.5. The pressure drop is carried out in the following way: necessary pressure is pumped in the waterproof chamber (2) with the help of the compressor (1). Magnitude of pressure is controlled with the help of a manometer (3) in the chamber. The synchronizing device (5) produces impulse of a high voltage after receiving a "start-up" signal from a computer (10). The device simultaneously produces impulses of activation for a frequency counter (7) and the oscilloscope (8)

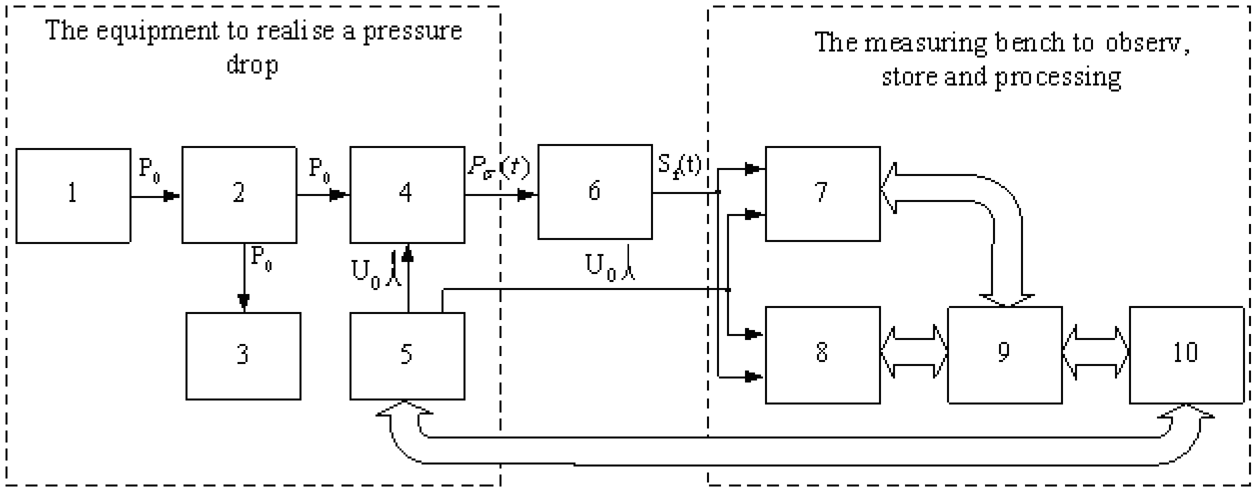

Fig. 5. Apparatus for measuring converters "pressure - frequency" dynamic characteristics definition.
1 - compressor; 2 - reservoir with overpressure; 3 – manometer; 4 - diaphragm, which divided the pressure in reservoir and sensing pressure element; 5 - the device for synchronous start the frequency meter, the oscilloscope from a computer, and lighting of diaphragm; 6 – testing measuring converter 7 – frequency meter Ч3-64/1; 8 - oscilloscope C9-8; 9 – the interface (IEEE488); 10 – computer.

High voltage impulse goes through a separator (4). The elastic thin diaphragm made of special thin rubber is applied as a separator. The mechanism of destruction of this membrane allows to model single pressure drop in system that contains a sensitive element of pressure. After diaphragm has been ruptured the single pressure drop $P_\sigma(t)$ first of all acts on a measuring converter (6). The frequency deviation from a primary sensing element (measuring converter) (6) is transmitted to the measuring bench. It consists of frequency counter Ч3-64/1 (7) and digital oscilloscope S9-8 (fig.6) (8). These instruments on IEEE488 (9) interface transmit to a computer measure result for the subsequent mathematical computing.

3. Results of measurement

Transfer function in an implicit form - as oscillations frequency deviations is shown in the diagram (Fig. 5).

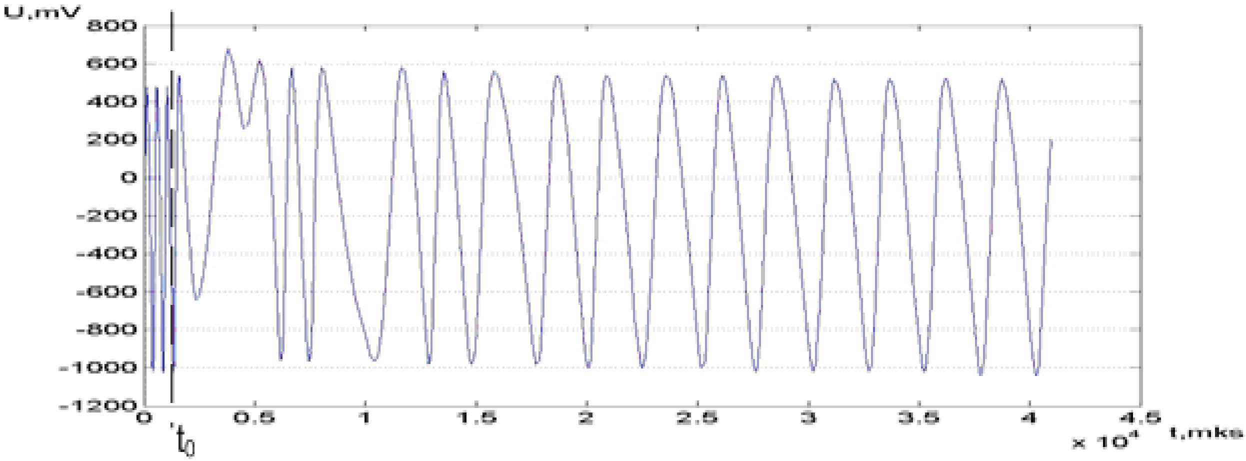

Fig. 6 a). Voltage from the oscillator output on the screen of a digital oscillograph at pressure in the chamber of 100 mm of mercury. t_0 – the time moment corresponding to the pressure drop beginning.

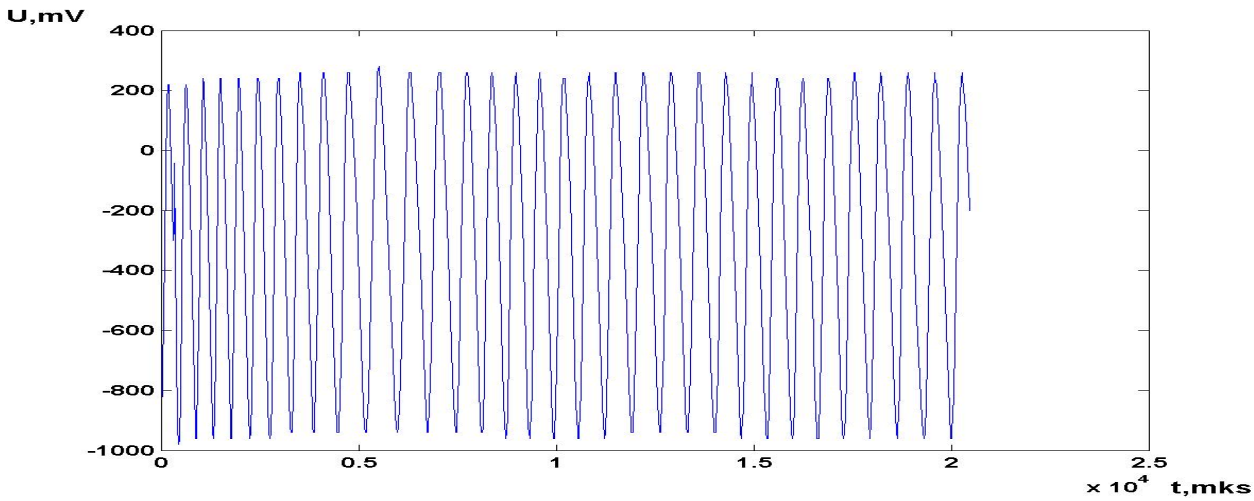

Fig. 6 b). Voltage from the oscillator output on the screen of a digital oscillograph at pressure in the chamber of 60 mm of mercury. t_0 – the time moment corresponding to the pressure drop beginning

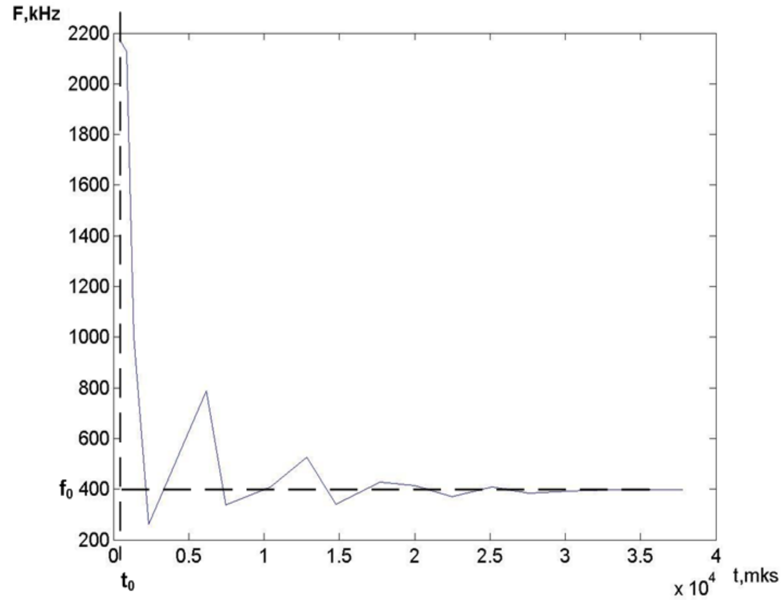

Fig. 7 a). Frequency deviation change counted from the diagram Fig. 6 with the help of Matlab software at pressure in the chamber at 100 mm of mercury.
t_0 – time moment corresponding to the pressure drop beginning
f_0 - frequency that has set after transient

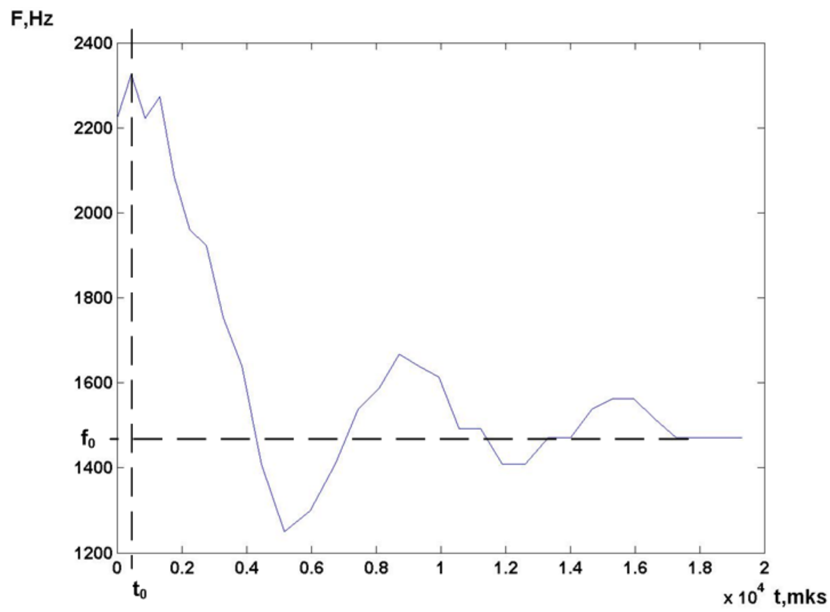

Fig. 7 b). Frequency deviation change counted from the diagram Fig. 6 with the help of Matlab software at pressure in the camera 60 mm of mercury.
t_0 – time moment corresponding to the pressure drop beginning
f_0 - frequency that has been set after transient

Thus it is possible to determine transfer function $g(t,\tau)$ from the diagram resulted on Fig. 5 after data processing.
The measuring result is carried out from (Fig. 6) to (Fig. 7, 8) either with the help of software package MATLAB 6.0, or with the help of the special program, which has been written in our laboratory. In the first case SIMULINK – Communication Block set is used. But the best results are obtained as a result of our special program application (Fig. 4).
The results of mathematical computing allow selection of optimal test conditions of measuring

converters trials (Fig. 8).
The equation (1) a process of the quartz measuring converter “pressure - frequency” reaction on pressure drop is theoretically precisely described. The equation (2) is the response of system to a unit impulse [5]. Its parameters concern to a membrane (mobile electrode) used in the sensitive element (Fig. 1, 2).

$$\frac{d^2W(t)}{dt^2} + 2\varepsilon_0\omega\frac{dW(t)}{dt} + \omega_0^2 W(t) = P(t), \tag{1}$$

where W(0)=W_0, W'(0)=W'$_0$ and $\varepsilon_0 = \dfrac{k_1}{2\sqrt{mc_1}}, \omega_0^2 = \dfrac{c_1}{m}$,

m – membrane mass, k_1 – coefficient of a membrane oscillations damping, c_1 – membrane inflexibility, W(t) – current value of a membrane sag, P(t) –measured pressure, ω_0 – natural frequency of undamped oscillations.

Equation for a unit-impulse response obtained from the equation (1) (the complete description look through [5]) is as follows:

$$g(t,\tau) = g(t-\tau) = \frac{k}{T_0\sqrt{1-\varepsilon^2{}_0}} * \exp\left[-\frac{\varepsilon_0}{T_0}(t-\tau)\right] * \sin\left[\frac{\sqrt{1-\varepsilon^2{}_0}}{T_0} * (t-\tau)\right], \tag{2}$$

where τ is started process instrument delay.

The approximating curve (Fig. 5) is plotted with the help of Graphical Analysis software and the equations corresponding coefficient for the processes described in (Fig. 4) are defined in eqn. (2).

Equation (2) rewritten for processing in Graphical Analysis software is given:

$$y = A/(B * sqrt(1-C\hat{}2)) * \exp(-C/B*(x-D)) * \sin(sqrt(1-C\hat{}2)/B*(x-D)). \tag{3}$$

where A = k, B = T_0, sqrt(1-C^2) = $\sqrt{1-\varepsilon^2{}_0}$, D = τ, y = $g(t-\tau)$ (unit-impulse response), x = t.
Obtained results after numerical calculation:

A = 42,3; B = - 0,17; C = - 0,987; D = - 0,73.

The resonance frequency of the transformer membrane:

$$\omega_0 = \frac{1}{T_0} = \frac{1}{|B|} = \frac{1}{0{,}17} = 588 Hz. \tag{4}$$

Quality value :

$$Q = \frac{\pi}{\delta} = 18{,}26, \tag{5}$$

where δ - logarithmic decrement.

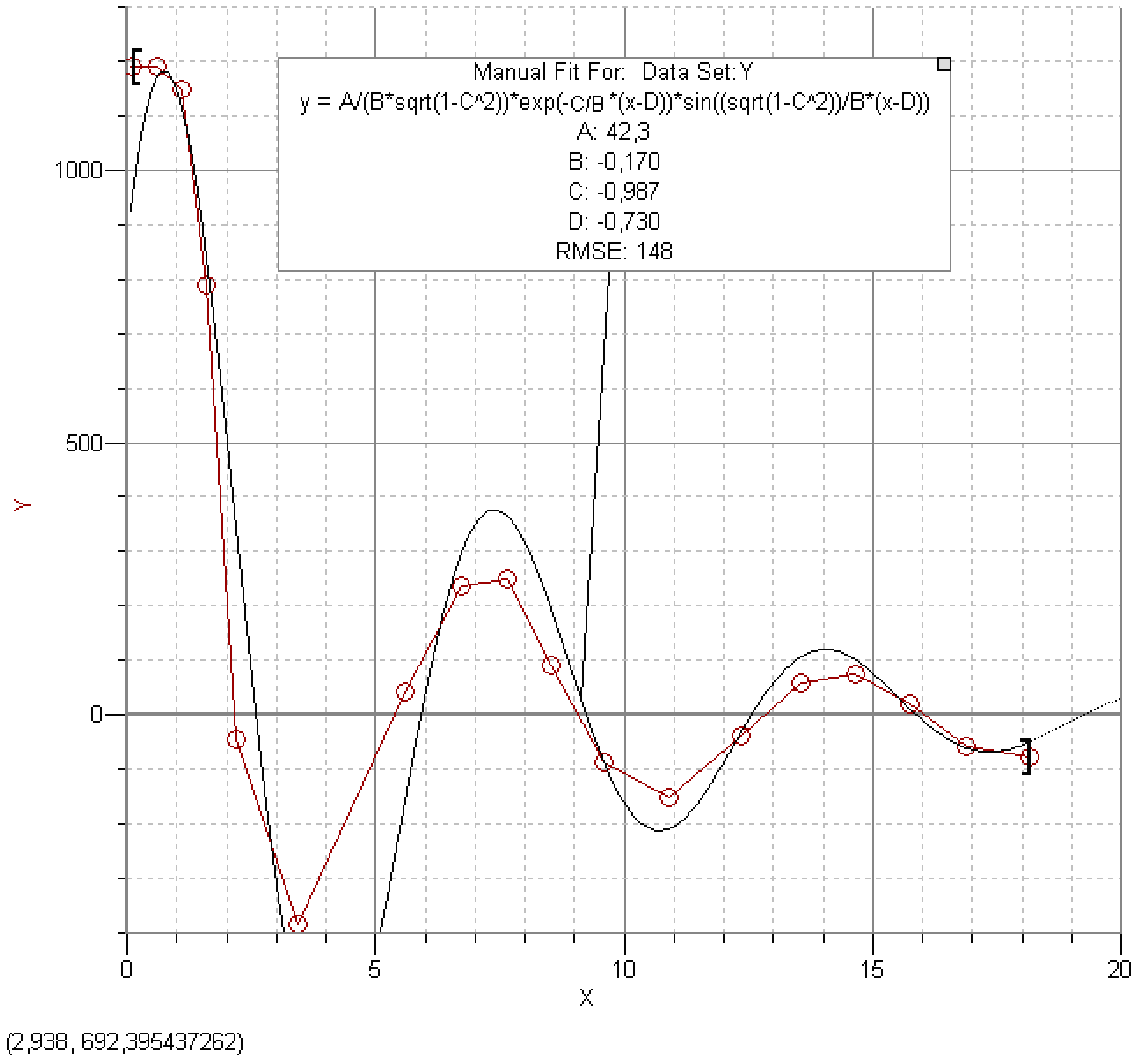

Fig. 8. Function obtained during experiment, approximation with the help Graphical Analysis programs; " —— " – theoretical curve; " " - the curve constructed on points which were obtained during experiment

4. Conclusion

The system operating frequencies from 0,3 to 10 Hz lay much below a natural frequency of the membrane that is why explored sphygmographic converter does not bring any distortions in major frequencies.

As mechanical quality is high, the stabilization time of steady-state conditions is high as well, in accordance with Fig.8, it makes 25 to 30 ms. It is possible to achieve reduction of the quality if a converter membrane oscillations damps and consequently a readiness time of the transformer is reduced.

The suggested procedure error can be expressed by the value of approximation by root-mean-square error (RMSE = 148Hz), that shows an error no more than 10 % (total random error of approximation of all experimentally received points by the curves received theoretically).

The suggested procedure of a dynamic characteristic research can be applied practically to any measuring converters types with the frequency output.

5. References

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