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*increase of accuracy,
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INCREASE OF ACCURACY OF MEASUREMENT SIGNALS READING FROM ANALOG MEASURING TRANSDUCERS

The article presents way of increase of measurement signals accuracy of reading defining safe criteria from analog measuring transducers. The increase of accuracy has been obtained by software correction of measuring transducer dynamic errors based on the differential equation of mathematical model describing the transducer dynamics. Results of the measuring transducer work simulation obtained before and after correction have been shown.

ZWIĘKSZANIE DOKŁADNOŚCI ODCZYTU SYGNAŁÓW POMIAROWYCH Z ANALOGOWYCH PRZETWORNIKÓW POMIAROWYCH

Artykuł przedstawia sposób zwiększenia dokładności odczytu sygnałów pomiarowych z analogowych przetworników pomiarowych, określających kryteria bezpieczeństwa. Zwiększenie dokładności osiągnięto przez programową korekcję błędów dynamicznych przetwornika pomiarowego opartą na równaniu różniczkowym opisującym jego dynamikę. Przedstawiono wyniki symulacji pracy przetwornika pomiarowego przed i po korekcji.

1. PREFACE

Means of transport are being tested in view of safe criteria on the basis of measuring transducers data analysis. Accuracy of transducer measurement, especially coming from his inertia, is important part of measuring chain [1].

Software estimate of measurand can be a corrective element of measuring transducers dynamic errors [4]. Measuring chain with correction of dynamic errors is shown in Fig.1 [5].

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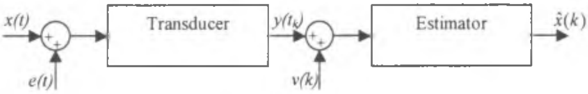

$x(t)$ – input signal
$e(t)$ – input noise signal
$y(t_k)$ – result of a measurement quantity in time t_k
$v(k)$ – random noise signal
$\hat{x}(k)$ – estimate of $x(t)$

Fig.1. Measuring chain with correction of dynamic errors

2. MEASURING SYSTEM

Simulation of dynamic errors correction has been done on the basis of real data got from accelerometers which have been mounted on the electrodynamic vibration exciter. Output data has been obtained from measuring accelerometer with sensitivity 1,16mV/ms^{-2}. Standard data has been obtained from standard accelerometer with sensitivity 10,61mV/ms^{-2}. Function signals from two accelerometers have been watched on a digital oscilloscope from which the signals were transmitted to computer by RS232 and next calculated by software estmation. Measurement system is shown in Fig.2.

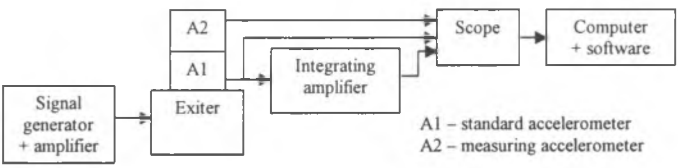

Fig.2. Measuring system

3. IDENTIFICATION OF DYNAMIC PARAMETERS OF MEASURING SYSTEM

Algorithm of dynamic correction needs knowledge of dynamic parameters in form of n order differential equation. It was assumed that the parameters will be determined by model ARX (AutoRegressive with eXogenious input). The identity signal is a displacement of exciter motion element got by passing a signal from standard accelerometer through integrating amplifier. The input signal is signal from standard accelerometer. Identification model, signals from accelerometers, characteristics of verification and identification error are shown in Fig.3. As a result of conversion of the obtained model to continuous form was transfer function.

$$G(s)=\frac{6{,}769s^2+5{,}6278\cdot10^5 s+1{,}698\cdot10^9}{s^2+1{,}108\cdot10^5 s+1{,}698\cdot10^9} \tag{1}$$

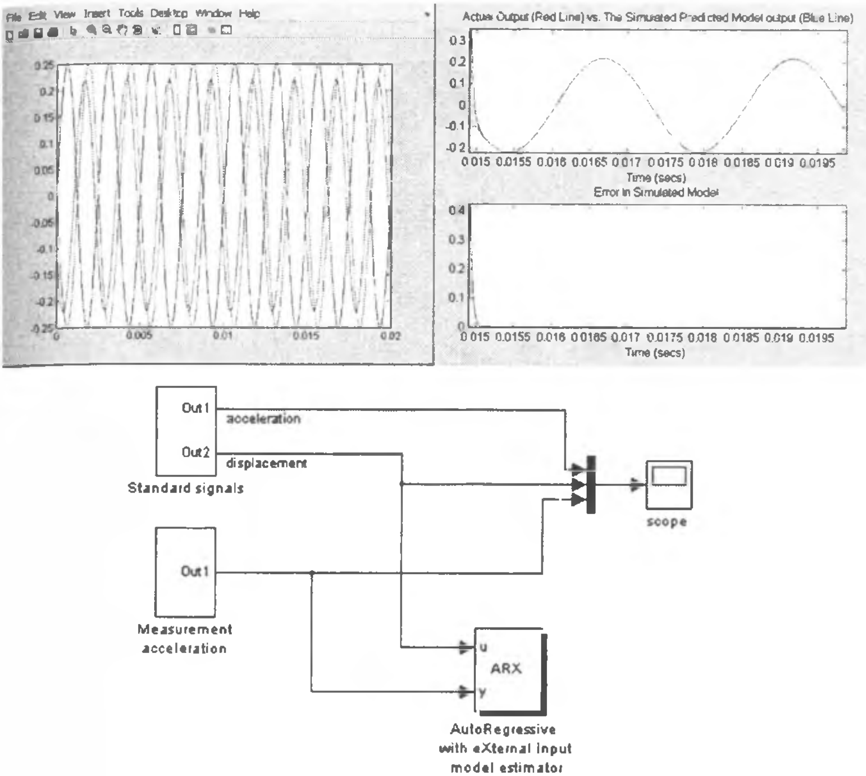

Fig.3. Identification model of measuring system

4. ALGORITHM OF DYNAMIC CORRECTION

Equation (1) can be written

$$\ddot{y}+1{,}108\cdot10^5\dot{y}+1{,}698\cdot10^9 y=6{,}769\ddot{x}+5{,}627\cdot10^5\dot{x}+1{,}698\cdot10^9 x \tag{2}$$

or

$$\ddot{y}+a_1\dot{y}+a_0 y=b_2\ddot{x}+b_1\dot{x}+b_0 x \tag{3}$$

Inserting to equation (3) variable

$$u_1 = y - b_2 x \tag{4}$$

and noting them as a system of equations

$$\begin{aligned} \dot{u}_1 &= -a_1 u_1 + u_1 + (b_1 - a_1 b_2)x \\ \dot{u}_2 &= -a_0 u_1 + (b_0 - a_0 b_2)x \end{aligned} \tag{5}$$

and as a matrix

$$\dot{u} = \boldsymbol{F}u + \boldsymbol{G}x \tag{6}$$

where

$$\boldsymbol{F} = \begin{bmatrix} -a_1 & 1 \\ -a_0 & 0 \end{bmatrix}, \quad \boldsymbol{G} = \begin{bmatrix} b_1 - a_1 b_2 \\ b_0 - a_0 b_2 \end{bmatrix} \tag{7}$$

Solution of an equation (6) between moments $t_{(k)}$ i $t_{(k+1)}$ is equation [2]

$$u_{(t_{k+1})} = e^{FT_d} u_{(t_k)} + \int_{t_k}^{t_{k+1}} e^{F(t_{k+1}-\tau)} G x_{(\tau)} d\tau \tag{8}$$

where $T_d = t_{(k+1)} - t_{(k)}$ - digitize time

Taking assumption that change of input quantity proceeds by steps in discrete moments there is obtained discrete equation

$$u_{(k+1)} = \boldsymbol{F}_d u_{(k)} + \boldsymbol{G}_d x_{(k)} \tag{9}$$

where

$$u_{(k)} = \begin{bmatrix} u_{1(k)} \\ u_{2(k)} \end{bmatrix} \tag{10}$$

$$\boldsymbol{F}_d = \begin{bmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{bmatrix} \tag{11}$$

$$\boldsymbol{G}_d = \begin{bmatrix} \psi_1 \\ \psi_2 \end{bmatrix} \tag{12}$$

Matrixes F_d and G_d are constant for given digitize time T_d and determined on the basis of the formula (7) as expressions

$$F_d = e^{FT_d} \tag{13}$$

$$G_d = \left(\int_0^{T_d} e^{F(T_d - \tau)} d\tau \right) G \tag{14}$$

Algorithm of dynamic correction for equation (3) is written as following [4]

$$\begin{aligned} \hat{x}_{(k)} &= \frac{1}{b_2}\left[y_{(k)} - \hat{u}_{1(k)}\right] \\ \hat{u}_{1(k+1)} &= \varphi_{11}\hat{u}_{1(k)} + \varphi_{12}\hat{u}_{2(k)} + \psi_1\hat{x}_{(k)} \\ \hat{u}_{2(k+1)} &= \varphi_{21}\hat{u}_{1(k)} + \varphi_{22}\hat{u}_{2(k)} + \psi_2\hat{x}_{(k)} \end{aligned} \tag{15}$$

where

$\hat{x}_{(k)}$ - estimate of input quantity at moment k calculated on the basis of measurement result $x_{(k)}$ and estimation of variable $\hat{u}_1$ from the previous step

$\varphi_{11} .. \varphi_{22}, \psi_1 .. \psi_2$ - factors of discrete state-space model transducer.

5. SIMULATION

Algorithm of dynamic correction in form of equation (15) has been written in MATLAB 7 environment. Simulation block diagram and its result as characteristics are shown in Fig.4. Standards signals and measuring displacement are real signals obtained by procedure written in point 2.

Standard acceleration and displacement signals are shown in Scope 1. Differences between standard acceleration and measuring acceleration are shown in Scope 2. Differences between input and output estimator signals are shown in Scope 3. Estimation final result compared to the standard displacement are shown in Scope 4.

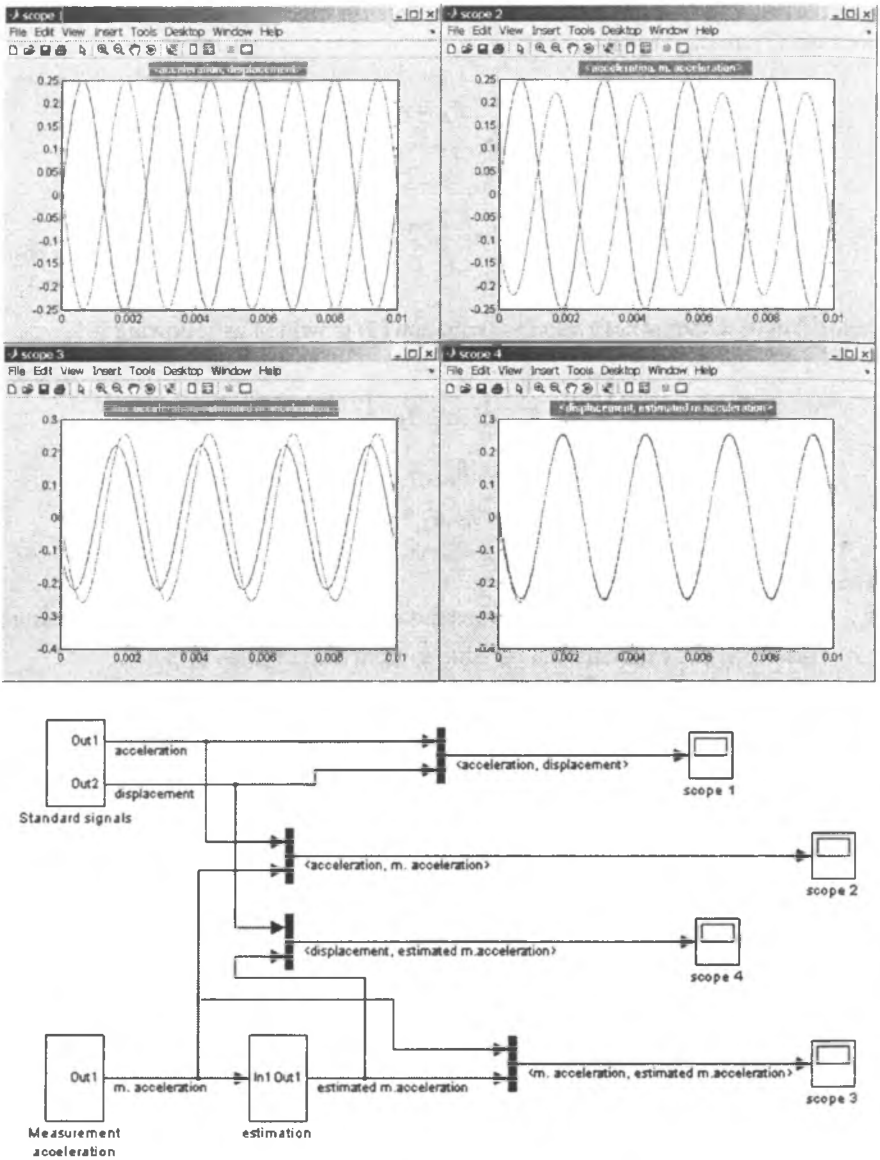

Fig.4. Estimation of measuring data

Simulation block diagram and simulation final result of displacement estimation with added random noise are shown in Fig.5. Input displacement and output acceleration for transducer's model written by equation (2) are shown in Scope 1. Result of estimation compared to input displacement are shown in Scope 2.

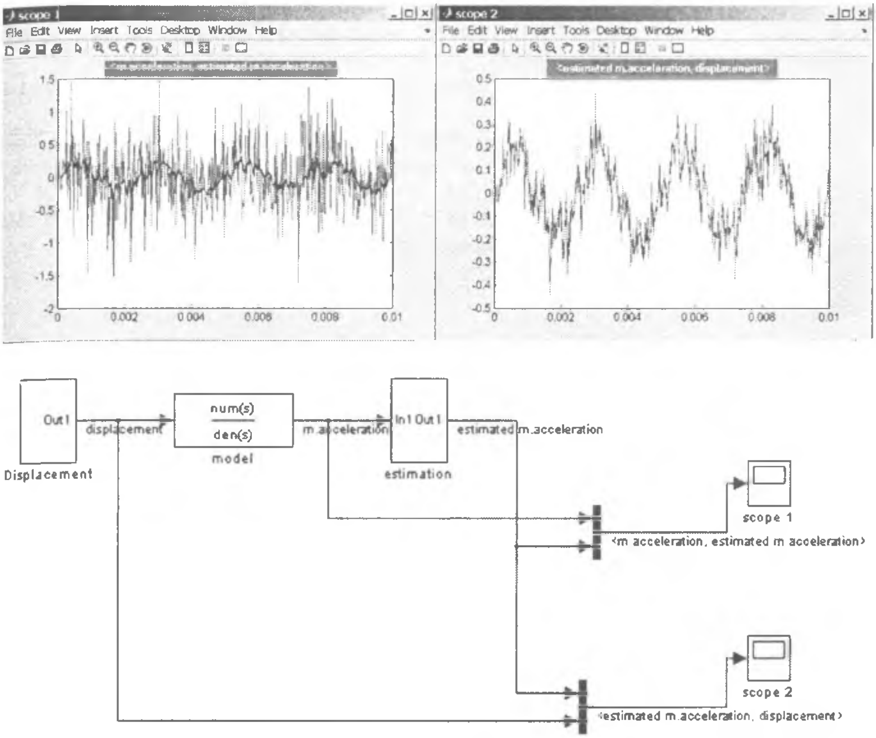

Fig.5. Estimation of measuring data with noise

6. CONCLUSIONS

Presented way of increase of accuracy of measurement signals reading by algorithm of dynamic correction for showed simulations was correct. Data output from software estimator compared to transducer's input data was proper.

Simplicity of algorithm of dynamic correction depending on performance only multiplications and additions allows measuring signals correction on-line.

Used method of determining parameters of differential equation describing measuring transducer model, ARX (AutoRegressive with eXogenious input), allows universal implementation of dynamic correction algorithm. The method can be used for single transducer as well as for measuring systems.

Destination of the estimator, thanks to accurate and fast reproduce of measuring system input data, should be increasing of accuracy of measuring systems reading especially responsible for safe criteria.

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