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A SIMULATION INVESTIGATION OF DIFFERENTIAL ALGORITHM FOR THE "BLIND CORRECTION" OF DYNAMIC ERROR IN MEASURING CHANNELS WITH PERIODIC NONSTATIONARITY

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Abstract: The paper presents the application of a differential algorithm for the "blind correction" method with respect to measuring systems where both: the measured signal and parameters of the measuring channels are varying with the same fundamental frequency. The influence of the measuring channels' parameters on the effectiveness of correction was investigated for the polyharmonic case, using the simulation methods.

Keywords: dynamic error, blind correction, nonstationary transducer

1. INTRODUCTION

The correction method, presented in this paper, can be applied to such cases where the dynamic properties of measuring channels are not sufficiently known and therefore the series correctors with fixed parameters can not be employed. A distinctive property of the proposed correction method is the use of the measured signal for identification of the coefficients of the applied model, simultaneously with the measurement. The self-identification can be therefore carried out at the system's operating site, taking into account the non-measurable influences of the system environment.

So the „blind correction" method can be used in measuring systems in which the operating conditions of transducers affect their dynamic properties. In such situation even a precise determination, under laboratory conditions, of the coefficients of differential equations describing the transducers' dynamic properties, does not lead to a good quality correction because the coefficients undergo uncontrolled changes after installation of transducers at the operating site.

The dynamic „blind correction" can be performed in a system containing two measuring channels, which measure the same input quantity. A unique analytic solution of this task for a stationary case, requires the dynamic properties of these analogue channels to be different. The algorithm applied to the results obtained from both channels consists of two stages: the identification of dynamic properties of measuring channels and, subsequently, the series correction. In practice, this algorithm can be performed numerically, and for this purpose the channels shall be provided with A/D converters. The applied method of identification allows to employ various algorithms of the "blind correction".

The identification method, employed in this work is based on the optimisation of the parameters of series correctors in such a manner that the difference between the results obtained from the both correctors would be zero. Such identification algorithm can be named a differential algorithm or the algorithm for equivalence of two parallel measuring channels.

The authors, in their works published until now [1],[2],[3], present the results of simulation studies on the dynamic "blind correction" method, carried out under the assumption that dynamic properties of the analogue part of measuring system do not change over time, or at least undergo very slow fluctuations, much slower than the time-rate of change of the measured signal. From the results of this investigation it can be concluded that computer simulation can be, first of all, a useful tool for determining the conditions of applicability of such method for dynamic correction.

This work presents the results of simulation, illustrating the presented method, carried out for the cyclic case in which the coefficients of a measuring channel are varying with same fundamental frequency as the measured signal does. The functions which describe time-variable coefficients of a measuring channel, may contain numerous harmonics.

2. THE MATHEMATICAL MODEL OF THE CORRECTION SYSTEM

The measuring system which performs "blind correction" consists of two independent analogue channels, synchronously measuring the same input quantity U(t) with the fundamental harmonic period $\Theta=1$, $\omega=2\pi/\Theta$. The sensitivity of both channels was assumed unity, k=1, and it is not subject to identification. The measuring channels are modelled in the form of nonstationary first-order differential equations (1) (2) and they generate outputs: X_1 (t) and X_2(t).

The coefficients of channel's dynamics (coefficients of the first derivative) have the form of dc component plus alternate sinusoidal component with the frequency of the measured signal:

$$U(t) = (T_{10} + T_{11} \cdot \sin(\omega t + \varphi_{11})) \frac{d X_1(t)}{dt} + X_1(t) \qquad (1)$$

$$U(t) = (T_{20} + T_{21} \cdot \sin(\omega t + \varphi_{21})) \frac{d X_2(t)}{dt} + X_2(t) \qquad (2)$$

The reconstruction of instantaneous values of the measured signal U(t) is achieved by means of series correctors, operating as numerical algorithms, independently in each of the two signal-processing channels. The form of the series correctors (3) (4) is matched to the form of the measuring channels' models:

$$Y_1(t) = X_1(t) + (\alpha_1 + \beta_1 \cdot \sin(\omega t + \gamma_1)) \frac{dX_1(t)}{dt} \qquad (3)$$

$$Y_2(t) = X_2(t) + (\alpha_2 + \beta_2 \cdot \sin(\omega t + \gamma_2)) \frac{dX_2(t)}{dt} \qquad (4)$$

α_1, β_1, α_2, β_2, γ_1, γ_2, – are parameters, i.e. of the dynamics coefficients of both channels whose values are tuned in the process of parametric optimisation. The A/D converter is modelled in the form of a quantizing operation (5) (parameters - the range R, and word length WL, $q = \frac{R}{2^{WL}}$):

$$X_{1k} = q \cdot \text{Entier}\left[\frac{X_1 + q/2}{q}\right], X_{2k} = q \cdot \text{Entier}\left[\frac{X_2 + q/2}{q}\right] \qquad (5)$$

Finally, the output quantity $\hat{U}(t_i)$ defined, at each sampling instant t_i, as the average of the both channels outputs $Y_{1,i}$ and $Y_{2,i}$. The index of the criterion J minimized in the algorithm for optimisation of correctors' parameters is defined as a norm H_2 of the difference $|Y_{1,i} - Y_{2,i}|$.

In this work, the correction efficiency index Q was adopted for evaluation of the quality of the measuring system performance. This index defines how many times the maximum instantaneous value of dynamic error was reduced, in result of the correction, with respect to a measurement (the better one) without the correction.

3. THE SIMULATION RESULTS

The purpose of simulation was to determine how the efficiency Q of the "blind correction" method depends on parameters of dynamics of the both measuring channels. It was therefore assumed that the measured signal should has the polyharmonic form.

The investigation was carried out for the signal U(t), modelled as a trapezoid waveform with unity period Θ=1 and adjustable coefficients which determine its shape. Duration of the signal high value U_{hi}=4.5 is 0.3, and of the low value U_{lo}=1.5 is 0.2. The rise time is 0.2, and fall time is 0.3. The range of A/D converter was therefore ±5 V (R=10 V). On the basis of preliminary simulations the following parameters were used in further investigation: A/D converter word length – 24 bits, sampling rate – 512 per period, the optimisation method – Monte Carlo. The simulation was performed using the GODYS-PC language.

In the process of simulation all the parameters were subjected to change: dc components – T_{10} and T_{20} were altered from 0.1 to 1.5, alternate components – T_{11} and T_{21} within 10% to 95% of the dc component value, phase shift – φ_{11} and φ_{21} in the range ± 1.35 rd.

Inferring from the correction conditions for a stationary case, it has been assumed that the dc components of dynamics of both channels – T_{10} and T_{20} will be different. Firstly, it was investigated how the correction efficiency varies with the change in the dc component of the dynamics' coefficient of one of two channels (T_{20}). The investigation has been carried out for two cases: the first - when the value of dc component of the dynamics coefficient in the first channel (T_{10}) suggests good dynamic properties, and the second - when poor properties can be expected.

In the first case the parameters of the first channel were set to: T_{10}=0.1, T_{11}=90% T_{10} (0.09), φ_{11}=-0.75 rad, whereas in the second channel the T_{20} value was altered over the range from 0.2 to 1.5, with other parameters fixed at: T_{21}=90%T_{20} and φ_{21}= -0.35 rad.

The maximum value of dynamic error before the correction in the first channel was 0.68, whereas in the second channel it was varied from 0.80 to 1.9, depending on the values of T_{20} and T_{21}. The maximum error after the correction was 0.014 to 0.039. The correction efficiency index Q versus the dc component of the dynamics' coefficient - T_{20}, is shown, for this case, in Fig. 1.

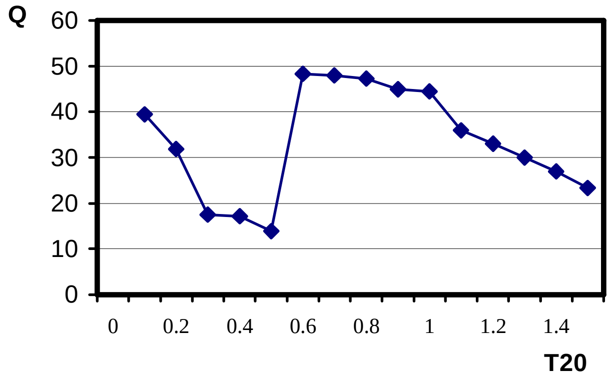

Fig. 1. The correction efficiency index Q as a function of changes in the dc component of the dynamics' coefficient (T_{20}) in one of the measuring channels.

In the second case the parameters of the first channel were set to: T_{10}=1.0, T_{11}=90%T_{10} (0.9), φ_{11}=-0.75 rad, whereas in the second channel the T_{20} value was altered from 0.1 to 1.5, with other parameters fixed at: T_{21}=90%T_{20} and φ_{21}= -0.35 rad. The maximum value of dynamic error, prior to correction, in the first channel was 1.54, whereas in the second channel it varied from 0.68 to 1.85, depending on the values of T_{20} and T_{21}. The error value after the correction was 0.015 to 0.16. The correction efficiency versus the dc component of the dynamics' coefficient - T_{20}, for this case, is shown in Fig. 2.

Next, it was investigated how the efficiency of correction varies with the change in the amplitude of the alternate component of the dynamics' coefficient in one channel. The other parameters of dynamics' coefficients were set to: T_{10}=0.1, T_{11}=90% T_{10} (0.09), φ_{11}= -0.75 rad, whereas in the second channel the T_{21} value was altered from 10% to 95% of T_{20}, with other parameters fixed: T_{20}= 0.2 and φ_{21}= -0.35 rad. The maximum value of dynamic error, prior to correction, was in the first channel

0.68, whereas in the second channel it varied, depending on the T_{21} value, from 0.89 to 1.07. The error value after the correction was 0.0075 to 0.037. The correction efficiency versus the alternate component of the dynamics' coefficient - T_{21}, is shown for this case in Fig. 3.

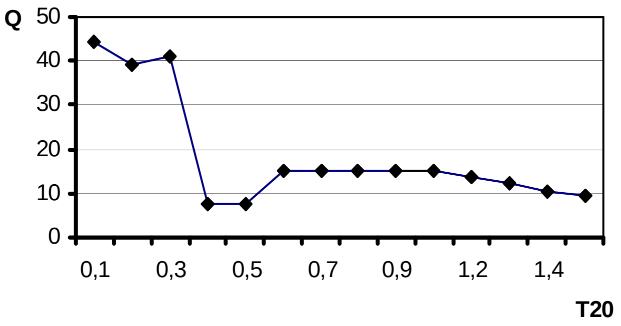

Fig. 2. The correction efficiency Q as a function of a change in the dc component of the dynamics' coefficient (T_{20}) with T_{10} = 1.0

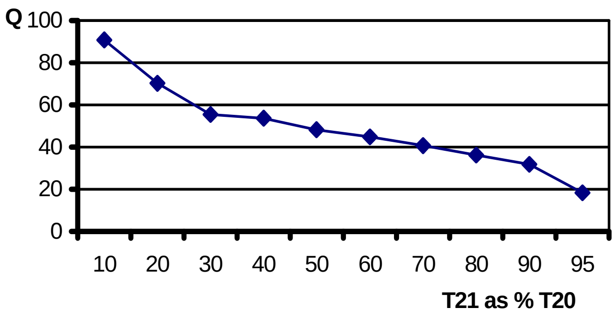

Fig. 3. The correction efficiency Q as a function of a percentage change in the amplitude of the alternate component of the dynamics' coefficient in the second channel (T_{21}) with respect to the dc component of this coefficient

Then, it was investigated how the efficiency of correction varies with the change in the phase shift of the alternate component of the dynamics' coefficient in one channel. The other parameters of dynamics' coefficients of both channels were set to: T_{10}=0.1, T_{11}=90%T_{10} (0.09), φ_{11}=-0.75, whereas in the second channel the phase value was altered from –1.35 rad to +1.35 rad, with other parameters fixed: T_{20}= 0.2 and T_{21}= 50% of T_{20} (0.1). The values of the second channel parameters were selected, based on the former investigation, to provide the average value of efficiency. The maximum value of dynamic error in the first channel, prior to correction, was 0.68, and in the second channel it varied from 0.81 to 1.06. The error value after the correction was 0.012 to 0.045. Figure 4 shows the correction efficiency as a function of the dynamics' coefficient phase shift - φ_{21}.

4. CONCLUSIONS

Bearing in mind that the models of dynamics of measuring channels are nonstationary, and the correction algorithm executes an optimal choice of six parameters, the obtained values of the correction efficiency can be regarded as satisfactory.

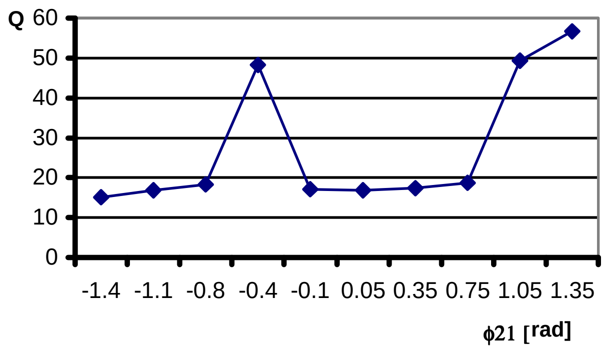

Fig. 4 The correction efficiency Q as a function of the change in the second channel dynamics' coefficient phase shift φ_{21}, with other parameters in both channels fixed.

Comparing the obtained efficiency values with the results former research [2,3], it can be noticed (as formerly [3]) that, due to the differential nature of the "blind" correction algorithm, numerical errors and quantizing errors have no significant influence on the final result of correction. As follows from figures 1 and 2, the correction of a "good" (i.e. fast - in terms of T_{10} and T_{20} values) measuring channel can be made, with a satisfactory efficiency, by means of the second channel, also a "good" one, and even better when using a "poor" channel, whereas a "poor" channel (i.e. slow - in terms of T_{10} and T_{20}) can be corrected only with the other "good" channel. A seemingly obvious deduction follows from figure 3 that the larger is the percentage share of the alternate component in the dynamics' coefficient, the worse the correction efficiency is. From figure 4 it can be inferred that changes in phase shift of the alternate component of the dynamics' coefficient have a not uniquely determinable influence on the efficiency of correction.

Summarizing, we can conclude that each case of determining the conditions for an effective "blind" correction with non-stationary dynamic properties of the corrected measuring channels, should be considered individually. It is possible, as the presented results confirm that simulation investigation can be a useful tool for determining the conditions of applicability of the dynamic correction.

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