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Determination of Dynamic Errors of Converter Temperature and Humidity Measured Quickly Changing Output Signals

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ABSTRACT: A method for determining dynamic errors when measuring rapidly changing output signals, it leads to an increase in measuring accuracy of temperature and humidity transducers of dispersed media, effectively used in environmental systems. Using the calculation method can significantly reduce the dynamic errors of the early stages of design and development of converters, which also contributes to the accuracy and reliability of the structural elements of the converters.

KEYWORDS: converters, dynamic errors, dispersed medium, ecological systems, temperature, humidity, accuracy, measuring system.

I. INTRODUCTION

At measuring the rapidly changing output signals of probe parametric transducer parameters of disperse means is necessary to solve the following problems: input quantity $U_0(t)$ and phase frequency $A(\omega)$ characteristics of linear continuous measuring system for measurement of output signals of parametric probe transducers. At the known output values $U(t)$, obtained with this system, it is necessary to define an input value $U_0(t)$ or a dynamic error $\delta(t)=U(t)-U_0(t)$.

Quantities $U(t)$ and $U_0(t)$ are related by the equation known in the theory of measuring systems:

$$U(t)=\int_0^t f(t-\tau)U_0(t)d\tau, \qquad (1)$$

where, $f(t)$- is the pulse weight function.

$U(t)$ is given, then (1) is the Wolter integral equation of type one.

Followlingly [2] we differentiate both parts of the equation, recorded for the exact values of its variables (1). If $(n-1)$ is the lowest-order derivative of which is not zero $f(t)$ when $t=0$, is equation (1) should be differentiated times. As a result we obtain equation of Volterra of the second type two Volter equation:

$$U^{(n)}(t)=\int_0^t f^{(n)}(t-\tau)U_0(\tau)d\tau+f^{(n-1)}(0)U_0(t), \qquad (2)$$

where (n) and $(n-1)$ are the order of the derivative. Solution of integral equation (2) known [2]:

$$U_0(t)=\frac{1}{f^{(n-1)}(0)}\left[U^{(n)}(t)-\int_0^t \beta(t-\tau)U^{(n)}(\tau)d\tau\right], \qquad (3)$$

where $\beta(t)$-is the equation that describes the dynamic error of measuring probe system of parametric transducers.

After applying the Laplace transform to both parts of the equations (2) and (3) have the image of $\beta(t)$:

$$\overline{\beta}(p)=\frac{p^{(n)}\overline{F}(p)-f^{(n-1)}(0)}{p^n\overline{F}(p)}=\frac{\overline{\beta}_0(p)}{p^{n+m}}, \qquad (4)$$

where $\overline{\beta}_0(p)$ - is a function that has no features at $p=0$,

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$$\overline{\beta}_0(p)=p^{n+m}-\frac{f^{(n-1)}(0)}{\overline{F}(p)}p^m, \tag{5}$$

where m - the order of the zero $\overline{F}(p)$ at the point $p=0$.

Hence $\lim_{p\to\infty} p^n\overline{F}(p)=F^{(n-1)}(0)$, its clear that $\overline{\beta}(p)$ is regular in right hemi plane and on an imaginary axis, except $p=0$, where it has pole of order $n+m$. For finding origin of $\beta(t)$ we present its image as the sum of regular and irregular parts $\overline{\beta}(p)=\overline{\beta}_ч(p)+\overline{\beta}_н(p)$, where

$$\overline{\beta}_н(p)=\sum_{q=0}^{n+m-1}\frac{\overline{\beta}_0^{(q)}(0)}{q!\,p^{n+m-q}}, \tag{6}$$

and $\overline{\beta}_ч(p)=\overline{\beta}(p)-\overline{\beta}_н(p)$, while $\lim_{p\to 0}\overline{\beta}_ч(p)\frac{\overline{\beta}_0^{(n+m)}(0)}{(n+m)!}$ is regular in the right hemi plane and on imaginary axis, because all derivatives of $\overline{\beta}(p)$ on $p=0$ exist. Origin of irregular part is $\beta(t)$ defined like follows:

$$\overline{\beta}_н(p)=\sum_{q=0}^{n+m-1}\frac{\overline{\beta}_0^{(q)}(0)t^{n+m-1-q}}{q!(n+m-1-q)!}. \tag{7}$$

Functions $\overline{\beta}(p)$ and $\overline{\beta}_ч(p)$ regular in right hemi plane and imaginary axis are changed after substitution $p\to j\omega$

$$\overline{F}(j\omega)=P(\omega)+jQ(\omega),\quad \overline{\beta}_ч(j\omega)=\overline{P}_0(\omega)+jQ_0(\omega), \tag{8}$$

their origins can be found by one of following formulas:

$$f(t)=\frac{2}{\pi}\int_0^\infty P(\omega)Cost\omega d\omega=-\frac{2}{\pi}\int_0^\infty Q(\omega)Sint\omega d\omega, \tag{9}$$

$$\beta_ч(t)=\frac{2}{\pi}\int_0^\infty P_0(\omega)Cost\omega d\omega=-\frac{2}{\pi}\int_0^\infty Q_0(\omega)Sint\omega d\omega. \tag{10}$$

After insert into (3) $\beta(t)=\beta_ч+\beta_н$ value, which is defined by (7) and calculate the integral containing $\beta_н$ we shall have

$$U_0(t)=\frac{1}{k^{(n-1)}(0)}\left[\sum_{q=m}^{n+m-1}\frac{\overline{\beta}_0^{(q)}(0)}{q!}U^{(q-m)}(t)+U^{(n)}(t)-\right.$$
$$\left.-\sum_{q=1}^{m-1}\frac{\overline{\beta}_0^{(q)}(0)}{q!}\int_0^t d\tau\int_0^\tau d\tau\ldots\int U(\tau)d\tau-\int_0^t\beta_ч(t-\tau)U^{(n)}(\tau)d\tau\right], \tag{11}$$

where $(m-q)$- multiple integrals.

At $m=0$ the right part (11) does not contain the sum of integrals. Besides, if n is equal to the differential equation, then $\beta_ч=0$.

II. RELATED WORK

As is known, the task of determining $U_0(t)$ from equation (1) is incorrect as $U(t)$ received experimental and contains errors. The given theory $U_0(t)$ also leads to the need address properly the task definition n derived from the function $U(t)$. But in most cases n does not exceed two to three and to approximate the definition of derivative, we can successfully use existing methods [3], based on using regulating algorithms for approximate differentiating and some of them are simple and longly known. It is noted [4], that one should have additional information to solve the problem, and such information can be gathered by studying physical properties of process being investigated.

In [5] possibility of substituting infinite upper limit in (9) and (10) with finite but large quantity ω_n is shown and estimating deviates of calculating such integrals is performed. Lets denote by $Z(\omega)$ one of functions P, Q, P_0, Q_0, and

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by $\Delta(t)$ the deviate of calculating integrals (9) and (10). If $Z(\omega)$ doesn't change when $\omega \geq \omega_n$ then $|\Delta(t)| \leq Z(\omega_n)\omega_n$, otherwise deviate multiplies by two.

With this in mind, it should be noted that small deviations of frequency characteristics measuring system from true will correspond to small changes in values $f(t)$ and $\beta_ч(t)$ in (11) and are calculated by the equations (9) and (10). In an expression of $f(t)$ frequency characteristics are directly, and $\beta_ч(t)$ they influence through functions $P_0(\omega)$ and $Q_0(\omega)$, that continuously depend on $A(\omega)$, $\varphi(\omega)$ and ω.

Note also continuous dependence, $\overline{\beta}_0^{(q)}(0)$, where, $0 \leq q \leq n+m-1$, from values $\overline{F}(0)$, $\overline{F}^{/}(0)$, that are determined by the frequency characteristics of the system and their derivatives at a point $\omega = 0$. Therefore, it can be concluded that the small deviations of frequency characteristics in the field $0 \leq \omega \leq \omega_n$ their derivatives at a point $\omega = 0$ must be small deviations values $U_0(t)$ determined by the formula (11).

III. RESULTS AND DISCUSSION

So, following are needed to define input signal of probe parametrical transformations and dynamical deviate:

1. Build real $P(\omega) = A\,Cos\varphi$ and imaginary $Q(\omega) = A\,Sin\varphi$ frequency characteristics of system from $A(\omega)$ and $\varphi(\omega)$.

2. Find $\overline{F}(0) = P(0)$. If $P(0) = 0$ then find $\overline{F}^{/}(0) = Q^{/}(0)$.

If $Q^{/}(0) = 0$, then find $\overline{F}^{//}(0) = -P^{//}(0)$, etc. Least order of derivative that is non-zero in $\omega = 0$ defines m. If $\overline{F}(0) \neq 0$ then $m = 0$.

3. Build function $f(t)$ near $t = 0$ by formula (9), substituting upper limit with large ω_n. If $f(0) = 0$ then find $f^{/}(0)$ or $f^{//}(0)$ etc. Least order of non-zero derivative $t = 0$ is l. Then n in (11) will be $n = l + 1$.

4. Find derivatives $\overline{\beta}_0^{(q)}(0)$, where $q = 0, 1, \ldots, n+m-1$, and $\overline{\beta}_0(p)$ is defined by (5).

5. Find $P_0(\omega)$ and $Q_0(\omega)$ substituting p by $j\omega$ and dividing real and imaginary parts.

6. Calculate real part $\beta_ч(t)$ describing dynamical deviate of output signal of probe parametrical transformations by formula (10) substituting upper limit by large $\omega = \omega_n$.

7. Using $U(t)$ graphics taken experimentally define to n-order derivatives applying known methods.

8. Calculate input quantity $U_0(t)$ and deviate $\delta(t) = U - U_0$ by formula of $\beta(t)$.

Actions 1-6 are performed one time per given system, then in each experiment its enough to perform 7-8. Its possible to use graphical methods for defining characteristics in 1-2, 3-6. Also there is an analytical method based on using approximate formulas $A_1(\omega)$ and $\varphi_1(\omega)$ built from experimental curves.

This method is most easily realized when amplitude-frequency characteristics of system $A(\omega)$ can be approximated by a curve described by ordinary differential equation of second order:

$$A_1(\omega) = \frac{\omega_0^2}{\sqrt{\left(\omega_0^2 - \omega_2\right)^2 + 4b^2\omega^2}}, \tag{12}$$

where ω_0 and b are the constants so selected that $A_1(\omega)$ is possibly close to $A(\omega)$.

Phase-frequency characteristics is then defined by $\varphi = arctg\dfrac{2b\omega}{\omega^2 - \omega_0^2}$.

Also, by the same method $\overline{F}(0) = 1$, $f(0) = 0$, $f^{/}(0) = \omega_0^2$, $n = 2$, $m = 0$, $\overline{\beta}_0(0) = -\omega_0^2$, $\overline{\beta}_0^{/}(0) = -2b$ and $\beta_ч(t)$.

Expression (11) for $U_0(t)$ looks like

$$U_0(t) = U(t) + \frac{2b}{\omega_0^2}U^{/}(t) + \frac{1}{\omega_0^2}U^{//}(t). \tag{13}$$

This particular case is observed when measuring output signals of probe parametrical transformations using electrical measuring systems.

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On fig.1 experimental $A(\omega)$ and approximate $A_1(\omega)$ frequency characteristics are presented. A curve $A_1(\omega)$ is built on a formula (12) at $\omega_0 = 15.10^3\ 1/s$, $b = 10^3\ 1/s$. Equalization (13) for this measuring system:

$$U_0(t) = U(t) + 8{,}88.10^{-6}U'(t) + 4.10^{-9}U''(t). \tag{14}$$

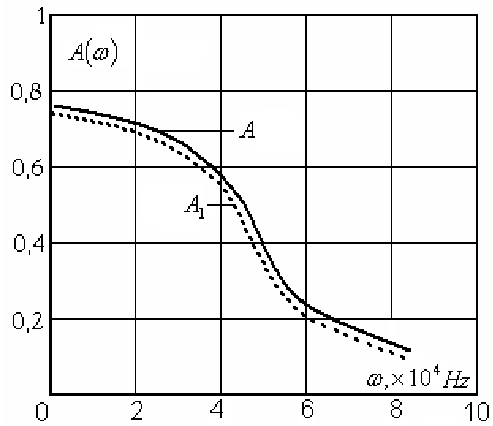

Fig.1. The experimental A(ω) and approximated $A_1(\omega)$ frequency characteristics of probe parametrical transformations

Figure 2 demonstrates how to change the output signal probe of parametric transducers, calculated according to the formula (14) when exposed to a known output signal $U_0(t)$.

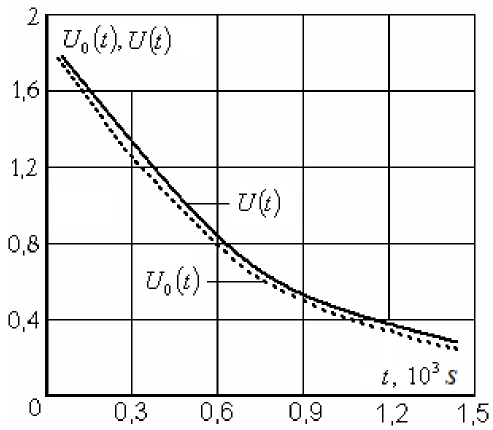

Fig.2. Schedules of target $U(t)$ and $U_0(t)$ entrance sizes of probe Parametrical transformations

IV. CONCLUSIONS

Thus, the analysis of experimental studies and calculations shows that the application of the developed method for determining the measurement errors of temperature and humidity transducers in the measurement of rapidly changing output signals provides a significant reduction in dynamic errors arising from the interaction of electric and thermal flows formed by the conversion of the input values of temperature and humidity with the measured medium, which are characterized by a change depending on time.

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Experimental $A(\omega)$ and approximated $A_1(\omega)$ frequency characteristics of temperature and humidity transducers agree very well, which indicates a decrease in dynamic errors in the measurement of rapidly changing output signals. The change in the output signal $U(t)$, calculated by the formula (14) with the interaction of the known input signal $U_0(t)$, is also characterized by the acceptability of the developed method for determining the dynamic errors of temperature and humidity converters of dispersed media.

The developed method for determining the dynamic errors of temperature and humidity transducers in measuring rapidly varying output signals of transducers can be applied to all measuring transducers of electrical, magnetic and non-electrical physical quantities, but in the second case, it is desirable to use the output dynamic characteristic of the transducer that describes the dynamic process change depending on of time.

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