AVIATION IN THE XXI-ST CENTURY

INTERNATIONAL CIVIL AVIATION ORGANIZATION
NATIONAL ACADEMY OF SCIENCES OF UKRAINE
MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY

PROCEEDINGS

THE SIXTH WORLD CONGRESS "AVIATION IN THE XXI-st CENTURY"

"Safety in Aviation and Space Technologies"

Volume 1

September 23-25, 2014
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O. M. Vasilevskyi, Ph. D. (Ministry of Education and Science of Ukraine, Kyiv),
O.I. Osmolovskyi, Ph. D. (National Aviation University, Ukraine)

ELEMENTS OF THE THEORY OF CONSTRUCTION OF METHODS ASSESSMENT OF DYNAMIC UNCERTAINTY IN MEASUREMENT OF PARAMETERS MOTION ROBOTIC COMPLEXES

Proposed a new approach to evaluating uncertainty during dynamic measurement is suggested, which is based on the use of the power spectrum of the input signal and a priori data of the frequency characteristics of the measurement means utilised.

When reporting on the results of dynamic measurements, it is necessary to provide a quantitative assessment of the quality of the experiment in order that its reliability may be correctly appraised [1-4]. Without such a reference value, the results of dynamic measurement can neither be compared with other equivalent studies, nor with standard reference values. It is therefore necessary to develop a uniform and understandable assessment methodology of the quality characteristics of dynamic measurements.

In drawing up relevant differential equations, input signals are recorded on the right, i.e. the reason that led the MM to function, while the left side of the differential equation, describes the output signal (or response of the MM), and for linear transducers, it is written in the form [3, 5]

$$\sum_{i=0}^{n} a_i y^i(t) = \sum_{k=0}^{m} b_k x^k(t), \tag{1}$$

where $x(t)$, $y(t)$ are respectively the input and output values; i, k are the order derivatives; and a, b are the coefficients that characterize the properties of the MM.

To express the differential equation in the area of frequency, the differentiation symbol $j\omega$ may replace d/dt as the time coordinate, and then the equation (1) takes the form

$$\frac{y(j\omega)}{x(j\omega)} = S_0 \frac{b_m (j\omega)^m + b_{m-1}(j\omega)^{m-1} + ... + 1}{a_n (j\omega)^n + a_{n-1}(j\omega)^{n-1} + ... + 1},$$

or

$$y(j\omega) = S(j\omega)x(j\omega), \tag{2}$$

where $y(j\omega)$, $x(j\omega)$ are respectively the spectral functions of the input and output measurement signal; $S_0 = b_0/a_0$ is the static sensitivity, i.e. the sensitivity to the constant input value (when $j\omega = 0$); $S(j\omega)$ is the transfer function of the MM or operational sensitivity.

The most typical properties of the MM are dynamic characteristics, which are described by differential equations of the first or second order, although in some cases, the third or higher order [5-7].

Information about the dynamic characteristics should be found in the regulatory and technical documentation of the MM, although if data is not available, it can be obtained on the basis of a priori data on the MM.

To express the experimental uncertainty of the results of dynamic measurements, it may be convenient for practical use to refer to the frequency characteristics of the measuring means [5], listed in Tab. 1.

Table 1

Transmission functions for the most typical dynamic links

Frequency characteristics of the MM	Typical Units
$S(j\omega) = K$ where K is the transmission coefficient	Non-inertial (ideal measurement transducer)
$S(j\omega) = \dfrac{K}{1 + j\omega\tau}$ where τ is the time constant determined by the parameters of the MM	Aperiodic (temperature transducer)
$S(j\omega) = \dfrac{K}{j\omega}$	Integrated (integrated amplification)
$S(j\omega) = K(1 + j\omega\tau)$	Forcing (differential amplification)
$S(j\omega) = exp(-j\omega\tau)$	Delay (analog-to-digital converters)
$S(j\omega) = \dfrac{K}{1 + j\omega\tau_1 - \omega^2\tau_2^2} = \dfrac{K}{1 + 2j\omega\beta\tau - \omega^2\tau^2}$	Oscillating (electromechanical transducers)

It is also known that the existing international experience in the concept of evaluation and expression of measurement uncertainty [1] does not describe how to undertake estimation of dynamic uncertainties in the performance of metrological works (or experiments in dynamic modes of MM).

[1] only makes it apparent that in existence there are ways of estimation as demonstrated by type A and type B, and in addition ways to demonstrate uncertainties, which may be standard, combined or enhanced. The definitions of these uncertainties are given in [1]. A well-known approach, as investigated in the papers [3, 6-9], is that dynamic uncertainty is calculated as a standard uncertainty of type B, itself determined by the dynamic error value divided by the square root of 3 (assuming a uniform distribution law).

Using classical theory in the measurement of dynamic error in the expression of dynamic uncertainty is unacceptable, given the concept of measurement uncertainty expression, which, as set out in the international standard [1], is moving away from the concept of measurement error, as such, which does not use known values, and cannot have absolute values. This is as opposed to measurement uncertainty, which can be evaluated, and for a particular measurement result is not a single value, but has an infinite number of values, which are scattered around the result.

Consequently, there is a need to develop a new approach to the expression of dynamic uncertainty that can be evaluated without using the classic dynamic errors used in error theory.

The measurement of dynamic uncertainty depends on measurement uncertainty that is conditional on the responses of the measurement means to determine the speed (frequency) of the input signal, which is itself dependent both on the dynamic properties of the measurement means and on the frequency spectrum of the input signal.

Dynamic uncertainty measurement $u_D[y(t)]$ can be expressed by the square root of the integral of the product of the square of the spectral function of the input signal and the square of the modulus of the frequency response of the measurement means that is used during dynamic measurements over a wide range of frequencies [8]

$$u_D[y(t)] = \sqrt{\frac{1}{2\pi}\int_{-\infty}^{\infty} |S(j\omega)|^2 |X(j\omega)|^2 \, \mathrm{d}\omega} \; , \qquad (3)$$

where $|S(j\omega)|$ is the modulus of the frequency characteristics of the MM that is used for dynamic measurement, or the amplitude frequency characteristics of the MM, which is defined by formula [7]

$$|S(j\omega)| = \sqrt{a^2(\omega) + b^2(\omega)} \, , \qquad (4)$$

where $a(\omega)$, $b(\omega)$ are respectively the real and imaginary parts of the frequency characteristics of $S(j\omega)$ of measuring instruments; $X(j\omega)$ is the spectral function of the input signal that is associated with the input time function $x(t)$ of the Laplace expansion [5]

$$X(j\omega) = \int_{0}^{\infty} x(t) e^{-j\omega_0 t} dt \; , \qquad (5)$$

where ω_0 is the frequency of the input signal.

The upper limit of integral equation (5) on a finite time interval can be changed by the total observation time T.

If the measured signal $x(t)$ is determined by sampling, then the integration of equation (5) can be replaced by a summation operation, when the following substitutions are made: t is replaced by nT_a, where n varies from 0 to $N-1$, through T_a which designates a sampling period, then $x(t)$ has the form $x(nT_a)$, and $e^{-j\omega_0 t}$ is replaced by $e^{-j\omega_0 n T_a}$ [7].

Should such replacements be made in equation (5), it may then be written in a discrete form [5, 9]

$$X_d(j\omega)=\sum_{n=0}^{N-1} x(nT_a)e^{-j\omega_0 nT_a} =$$

$$=\sum_{n=0}^{N-1} x(nT_a)\cos\omega_0 nT_a - j\sum_{n=0}^{N-1} x(nT_a)\sin\omega_0 nT_a\,, \qquad (6)$$

where $\omega_0 = 2\pi k/(NT_a)$, $k = 0,1,\ldots,N-1$.

In this case, so that the discrete spectral function value corresponds to a continuous spectral function, it needs to be multiplied by the sampling interval [7, 9]

$$X(j\omega) = T_a X_d(j\omega). \qquad (7)$$

During dynamic sampling measurements during the production of a signal, the equation to express dynamic uncertainty (3), taking into account equations (6) and (7), may be written in the form

$$u_D[y(t_i)] = \sqrt{\frac{T_a}{N}\sum_{k=0}^{N-1}\sum_{n=0}^{N-1} x^2(nT_a)e^{-j\frac{4\pi nk}{N}} A^2\left(k\frac{2\pi}{NT_a}\right)}\,, \qquad (8)$$

where $A\left(k\frac{2\pi}{NT_a}\right) = A(\omega) = |S(j\omega)|$ represents the amplitude frequency characteristics of the MM supported by the dynamic measurement values taken: $\Delta\omega = \frac{2\pi}{NT_a}$ is the interval of the discrete defined frequency values: T_a is the sampling time; N is the number of samples; NT_a is the total duration of observation.

Given the above, a way of expressing the dynamic uncertainty of measuring includes the following stages: the execution of dynamic measurements; determination of the frequency response measurement tools used; determination of the spectral function of the input signal; dynamic evaluation of uncertainty of a measuring instrument.

Conclusions

A new approach to the expression of experimental dynamic uncertainty in dynamic measurements is proposed on the basis of a priori information on the frequency characteristics of the Measurement Means and the spectral functions of the input signal. These allow us to obtain evaluations of the results of dynamic measurements to international requirements for the precision specifications. The proposed approach to estimating dynamic uncertainties can be used for measurement means which are characterized by dynamic circuits of any type under the operation of a stationary random input signal.

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