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IDENTIFICATION OF MECHANICAL BACKLASH OF NAVIGATION EQUIPMENT TESTING TABLE

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Abstract**—***In the article the technique of identification of the mechanical backlash of navigational equipment test table is considered as means for certification requirements verification. Identification procedures of mathematical model of mechanical backlash are considered in the dynamic oscillatory system. An algorithm for identification of backlash nonlinearity based on Hilbert transform is presented.*

Index Terms—Nonlinearity, identification, backlash, certification.

I. INTRODUCTION

Mechanical backlash in the design and operation of complex systems occurs in many branches of engineering and can play a very important role. On the other hand its appearance in the navigational equipment test table is undesirable; moreover the backlash may increase over time due to wear and tear of mechanics, which leads to additional dynamic loads, as well as to the malfunction of machinery and measuring devices.

In accordance with the current standard of Ukraine "General requirements for the competence of testing and calibration laboratories" DSTU ISO / IEC 17025: 2006 [1], which is the main ISO standard used by testing and calibration laboratories. Navigational equipment testing table, computers and automated equipment for the collection, processing, recording, reporting, storage or retrieval of test data, must hold accreditation in order to be deemed technically competent. To do ensure these, the laboratory must ensure the proper functioning, to carry out maintenance of the computers and automated equipment, and provide them with the environmental conditions and the necessary work required for maintenance the integrity of test data. In addition, the testing equipment and its software which are used for testing must be able to achieve the required accuracy and meet the technical requirements of the tests. Prior to the commissioning all equipment must be checked to establish its compliance with the technical requirements of the laboratory, and the relevant standards. The testing laboratory must have quality control procedures for monitoring of the validity of the tests. All results need to be registered so that it is possible to identify trends and, where possible, statistical methods must be applied to analyze the results.

II. BACKLASH IN THE NAVIGATION EQUIPMENT TESTING TABLE

Mechanical backlash in gears of drives (Fig. 1) can cause a loss of stability of the control system and the deterioration of dynamic parameters. Moreover, it distorts the trajectory of motion and reduces the accuracy of testing procedures.

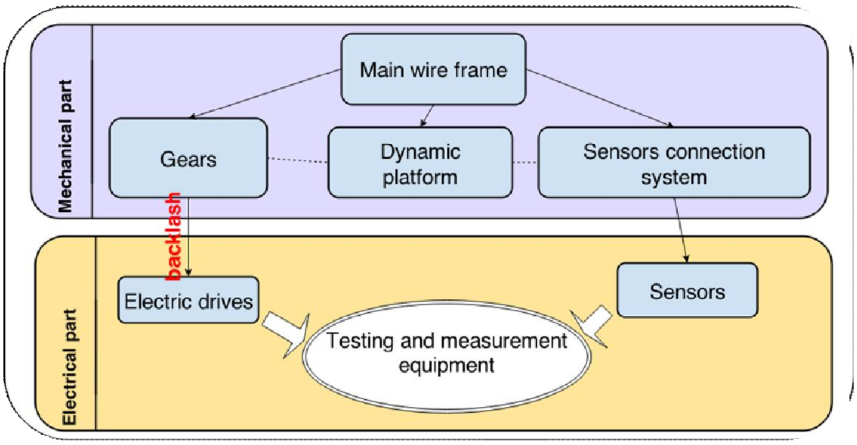

Fig. 1. Mechanical backlash in the navigation equipment testing table

Backlash can occur for various reasons. In particular, it is designing a product with large tolerances, poor fabrication standards, rapid wear of the individual elements (teeth of the wheel), improper use of equipment for the production of teeth and the like. Worm gears main feature is backlash increase proportionally to the wear of the whole system. That is why the worm gears are not suitable for application in positioning systems that require special accuracy of motion. Compared with other gear types backlash values in the worm gears can be significant. For bearing gear indicator of such parameter as backlash, depends on the degree of tightness of bearings. In a pair of angular versus coaxial gearboxes in terms of the index of the angular backlash coaxial are better than angular type. In angular gearboxes backlash is bigger but their advantage is in a compact motor and gearbox combination. Planetary gears are characterized by a small backlash value and high precision of operation. These design properties are achieved by a special assembly technique – gears during assembly stage are in the overtensioned mode.

Thus, in the navigational equipment testing table it is appropriate to use the planetary type gearbox.

III. BACKLASH IDENTIFICATION TECHNIQUE

The purpose of research, the results of which are presented in this paper is to provide a method of identifying the mechanical backlash in the navigational equipment testing table.

Let's consider as a mathematical model of backlash in navigational equipment testing table the following equation.

$$\dot{x}_2(t) = \begin{cases} \dot{x}_1(t), & \text{if } \dot{x}_1 > 0 \text{ and } x_2(t) = x_1(t) - x_+(t) \\ & \text{or } \dot{x}_1 < 0 \text{ and } x_2(t) = x_1(t) - x_-(t); \\ 0, & \end{cases}$$

where $\dot{x}_1$ is the motion input part of the mechanical engagement (the angle of rotation of the motor shaft);

$\dot{x}_2$ is the driven part of the mechanical engagement (the angle of rotation of dynamic platform axis of testing table); x_+ is positive backlash (shaft rotates counterclockwise); x_- is negative backlash (when the shaft is rotated in a clockwise direction).

The task of identification of backlash in navigational equipment testing table is to determine the values $x_+(t)$, $x_-(t)$, taking into account the estimation of the deviation of the random variable

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2},$$

where n is Sample size; x_i is i th element of the sample $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$.

To investigate the controversial type of nonlinearity (backlash) and others in engineering practice widespread method is the harmonic linearization based on the fundamental works of Krylov and Bogolyubov [2]. Later, researchers from at least five different countries have proposed to use this method for the analysis of automatic control systems - Kochenburger in the United States [3], Tustin in the UK [4], Oppelt in Germany [5], Goldfarb in the USSR [6] and in Dutilh in France [7]. Since the appearance of the above-mentioned publications, a lot of articles devoted to this method and its modifications have been published [8] – [11].

Several techniques have been developed for the evaluation and identification of nonlinear dynamic systems [12]. An approach based on Hilbert Transform (HT) to describe the response of nonlinear oscillatory systems in the time domain was one of these methods [13].The aim was to propose a methodology for the identification and classification of different types of nonlinearities on the basis of experimental data.

The proposed method focuses on the methods of HT signal processing, namely the extraction of the signal envelope and instantaneous frequency for direct evaluation of modal parameters, together with the characteristics of the forces of elasticity and friction. Hilbert Transform approach is navigational equipment system response as a function of the instantaneous time. This is a very sophisticated method of detecting existing linear and non-linear amplitude and frequency dependencies. HT approach is suitable for any system with one degree of freedom and does not require a priori knowledge of the data or system parameters. In the current research in the field of various data processing, the method of HT is becoming more and more widely used for the estimation and identification of nonlinear dynamic complex systems [14].

Hilbert Transform identification in the time domain is based on the concept of the analytical signal

$$X(t) = x(t) + j\tilde{x}(t),$$

where $\tilde{x}$ is HT projection of the measured signal $x(t)$ as the result of the testing.

The method also uses the concept of the envelope of the signal and its phase

$$X(t) = A(t)e^{j\psi(t)},$$

where $A(t)$ is the envelope, and $\psi(t)$ is instantneous phase and due to both are real functions,

$$x(t) = A(t)\cos\psi(t), \ \tilde{x}(t) = A(t)\sin\psi(t),$$

$$A(t) = \sqrt{x^2(t) + \tilde{x}^2(t)}, \qquad \psi(t) = \arctan\left[\tilde{x}(t) / x(t)\right].$$

Envelope, phase and their derivatives can be calculated as a function of time, or using the identities of the analytical signal [15].

$$\dot X = X\left(\frac{\dot A}{A}+i\psi\right),\ \ddot X = X\left(\frac{\dot A}{A}-\psi^2+2i\frac{\dot A}{A}\psi+i\ddot\psi\right),$$

where

$\psi(t)=\omega(t)=\dfrac{x(t)\dot{\tilde x}(t)-\dot x(t)\tilde x(t)}{A^2(t)}=\mathrm{Im}\left[\dfrac{\dot X(t)}{X(t)}\right]$ is instantaneous frequency of the signal $x(t)$.

Let us consider a nonlinear oscillatory system of the one of navigation equipment testing table motion axis channels (Fig. 1) with one degree of freedom.

$$\ddot X + 2h(t)\dot X + \omega_x^2(t)X = 0, \qquad (1)$$

where $\omega(t)$ is instantaneous modal frequency; $h(t)$ is coefficient of instantaneous modal damping, and $X(t)=x(t)+i\tilde x(t),\ x(t)=A(t)\cos\left\lfloor\int\omega(t)dt\right\rfloor,$ is the results of measurements.

In the first stage of identification the envelope $A(t)$ and instantaneous frequency $\omega(t)$ are extracted from the signal using the HT.

Further, when the derivatives $\dot X$ and $\ddot X$ are known as a function $A(t)$ of and $\omega(t)$, we can write (1) as

$$X\left[\frac{\ddot A}{A}-\omega^2+\omega_x^2+2h\frac{\dot A}{A}+i\left(2\frac{\dot A}{A}\omega+\dot\omega+2h\omega\right)\right]=0.$$

Separating the real and imaginary parts and equating them to zero, we find instantaneous modal parameters:

$$h(t)=-\frac{\dot A}{A}-\frac{\dot\omega}{2\omega};$$

$$\omega_x^2(t)=\omega^2-\frac{\ddot A}{A}+2\frac{\dot A^2}{A^2}+\frac{\dot A\dot\omega}{A\omega},$$

where A is envelope; $\omega(t)$ is instantaneous frequency of the measured signal.

Hilbert Transform is also used to construct the backbone curve in nonlinear oscillatory systems. Skeleton or backbone curve using HT approach is presented as a function of the envelope and the modal frequency.

Experimental technique should be used for identification the complex dynamic nonlinearities in the testing equipment.

Let us consistently apply sinusoidal signals to the input of the control system of the motor drive:

$$x = A\sin\omega t,$$

gradually changing the value of the amplitude of the oscillation and the frequency.

Plot of the measured signal as a result of such experiment are shown in Fig. 2.

Effectiveness of the methodology is demonstrated below (Fig. 3). Skeleton curve is plotted in Matlab using the HT identification algorithm.

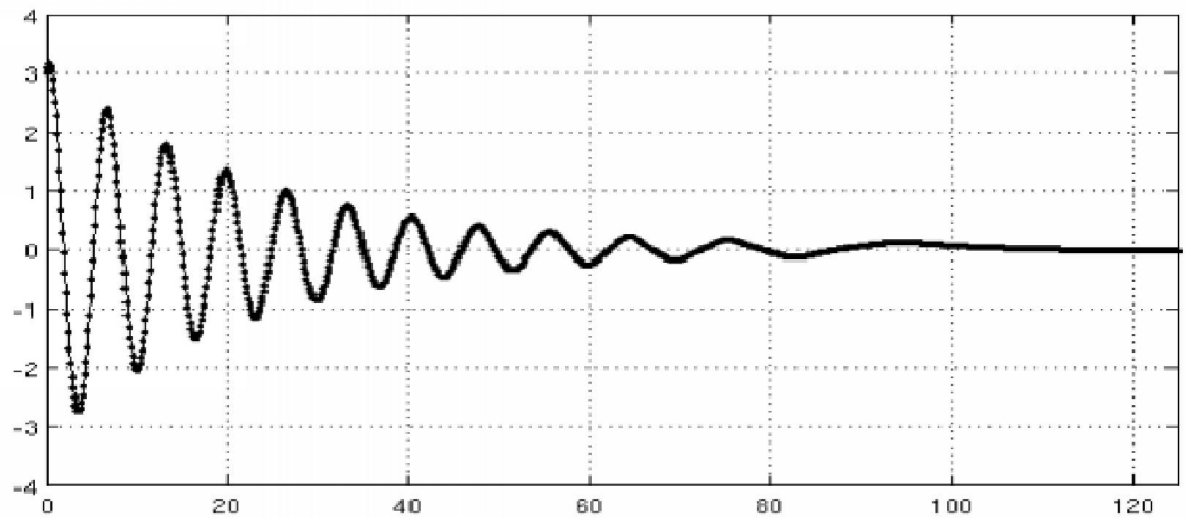

Fig. 2. The experimental results of the system test with backlash nonlinearity

Skeleton curve not only detects the presence of a defect, but it is also allows to determine its type and estimate the value of the backlash.

Backlash value depends on the gearbox model, production line, as well as its purpose. In order to produce a low backlash gearbox, it is necessary to apply selective assembly technique. Moreover high-precision parts from the same batch must be used. After production stage the appropriate testing is conducted, and the gearbox is distributed in the shipment batch with the corresponding value of backlash. It is also possible to provide backlash-free production of gears, where backlash value approaches to zero. Such gears are also characterized by a selective assembly. Main peculiarity is that they are assembled in the overtensioned mode. This allows providing them a different stiffness values within the range required for proper operation of the device. A low backlash precision gear can have one the several planetary transmission types. In addition, these gears are characterized by high levels of gear ratios. One can reduce the backlash of worm gears or bearing gears by adjusting the thickness of shims under the collar, but application of them in the navigational equipment testing tables are not recommended.

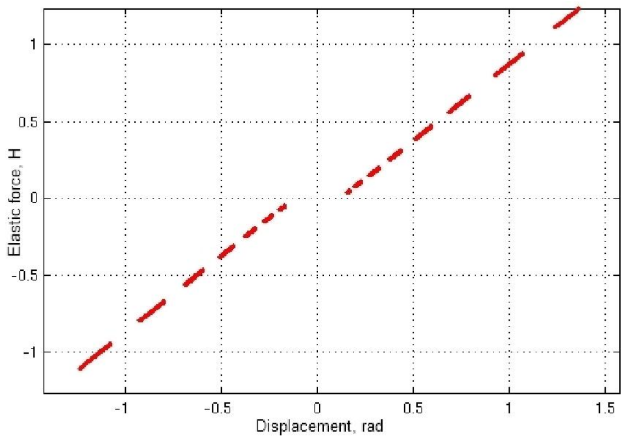

Fig. 3. Skeleton curve of backlash nonlinearity

Quality control procedures based on the described methodology and incorporation of an overall system for technical and quality management results is the necessary prerequisite for a laboratory to become accredited – to have a documented quality management system. Estimation of backlash in the navigation equipment testing table is one of the factors which determine the correctness and reliability of the tests performed in laboratory

CONCLUSIONS

The technique of backlash nonlinearities identification of navigational equipment testing table based on the test results provide required means for achieving accreditation. The algorithm of identification using the Hilbert transform allows evaluating not only the instant dynamic parameters, but their frequency and amplitude trends. Model of testing system backlash increases the efficiency of navigational equipment testing table, as well as allows monitoring its technical condition.

The described method of identification can reduce the time spent on laboratory competence requirements accreditation procedures and data processing of the results.

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В. М. Синеглазов, С. О. Долгоруков. Ідентифікація механічних люфтів випробувального стенда навігаційного обладнання

Представлено методику ідентифікації механічних люфтів випробувального стенда навігаційного обладнання. Розглянуто процедури ідентифікації математичної моделі механічних люфтів у динамічній коливальній системі. Описано алгоритм ідентифікації нелінійності типа люфт, оснований на методі, що використовує перетворення Гільберта.

Ключові слова: нелінійність; ідентифікація; випробувальний стенд; люфт.

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В. М. Синеглазов, С. О. Долгоруков. Идентификация механических люфтов испытательного стенда навигационного оборудования

Представлена методика идентификации механических люфтов испытательного стенда навигационного оборудования. Рассмотрены процедуры идентификации математической модели механических люфтов в динамической колебательной системе. Описан алгоритм идентификации нелинейности типа люфт, основанный на методе использующем преобразование Гильберта.

Ключевые слова: нелинейность; идентификация; испытательный стенд; люфт.

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