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SIMULATION MODELLING IN THE TASKS OF DIGITAL ENGINEERING IN THE CREATION OF INFORMATION-MEASURING SYSTEMS

Г.О. Оборський, В.П. Гугнін, Л.М. Перпері, Г.М. Голобородько, В.В. Голобордько. **Імітаційне моделювання в задачах цифрового інжинірингу при створенні інформаційно-вимірювальних систем.** Об'єктом цього дослідження є віртуальні вимірювальні системи для параметрів відхилення форми. У статті описано спроектований віртуальний прилад для імітаційного моделювання процесу визначення параметрів відхилення форми циліндричних валів. Для реалізації цього завдання запропоновано модель розрахунку параметрів відхилення форми валів, що враховує вплив випадкових дійсних діаметрів деталей, що обробляють на металорізальному обладнанні, на їх геометричну точність. Процес моделювання вимірювання параметрів відхилення форми валів проводиться у два етапи. На першому етапі проводиться моделювання руху щупів приладу до поверхні валу і звуку роботи приводу приладів щупів. На другому етапі проводиться розрахунок параметрів відхилення форми циліндричних валів. Форма циліндричної деталі залежить від випадкових значень дійсних діаметрів валу в різноманітних перетинах циліндричної деталі площинами. Для отримання розрахункових значень діаметрів валу у різних перерізах валу площинами розроблено алгоритм розрахунку поточного положення точки профілю зовнішньої поверхні валу. Внаслідок впливу фізичних процесів різання розташування точок на поверхні валу має випадковий характер. Тому положення розрахункової точки визначається шляхом накладання на теоретичний профіль валу випадкової величини, яка генерується за законом рівної ймовірності. Описано методику обробки масиву координат точок профілю для отримання чисельних параметрів відхилення форми валів, таких як, конусоподібність, бочкоподібність, сідлоподібність та овальність.
Ключові слова: відхилення форми, віртуальні прилади, методи вимірювань, цифрові технології

H. Oborskyi, V. Gugnin, L. Perperi, G. Goloborodko, V. Goloborodko. **Simulation modelling in the tasks of digital engineering in the creation of information-measuring systems.** The object of this study is virtual measuring systems for shape deviation parameters. The article describes the designed virtual instrument for simulating the process of determining the parameters of the shape deviation of cylindrical shafts. To implement this task, a model for calculating the parameters of the deviation of the shape of the shafts is proposed, which takes into account the effect of random real diameters of the parts processed on metal cutting equipment on their geometric accuracy. The process of modelling the measurement of shaft shape deviation parameters is carried out in two stages. At the first stage, the movement of the plungers of the device to the surface of the shaft and the sound of the drive of the plungers are simulated. At the second stage, the parameters of the shape deviation of the cylindrical shafts are calculated. The shape of the cylindrical part depends on the random values of the actual diameters of the shaft in various intersections of the cylindrical part with planes. To obtain estimated values of shaft diameters in different cross-sections of the shaft by planes, an algorithm for calculating the current position of the profile point of the outer surface of the shaft has been developed. Because of the influence of physical cutting processes, the location of points on the surface of the shaft is random. Therefore, the position of the calculation point is determined by superimposing on the theoretical profile of the shaft a random variable, which is generated according to the law of equal probability. The method of processing the array of profile points coordinates to obtain numerical parameters of shaft shape deviation, such as taper, barrel, bow and ovality, is described.
Keywords: deviation of form, virtual instruments, measurement methods, digital technologies

Introduction

In today's conditions of rapid development of the fourth industrial revolution, many enterprises are undergoing the stages of digital transformation of production in various fields of industry, characterized by rapid changes to meet new needs. Modelling and simulation, which are used in digital engineering, are based on a theoretical foundation, but are aimed at finding solutions to problematic issues in various fields. Therefore, questions related to the application of practical skills of digital literacy by specialists in an interdisciplinary context are important [1, 2]. Accordingly, the growth of needs within

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the framework of Industry 4.0 has led to the reformatting of educational components of training programs for specialists in engineering specialties in institutions of higher education in order to approach the practical conditions of work in the production of future engineers. Most universities, thanks to the rapid development of information technologies and the possibility of using Internet technologies, have moved to the creation and use of virtual or remote laboratories during student training, gradually applying the transition from “face to face” training to a distance format [3, 4, 5]. All these aspects contributed to the implementation of the educational process in the conditions of the global pandemic caused by COVID 19 and, unfortunately, do not lose their relevance during the hostilities taking place on the territory of Ukraine today. In the Odessa Polytechnic University, when training mechanical engineers and metrological engineers, virtual instruments are also used to implement the acquisition of digital competencies and practice-oriented learning when training specialists in engineering specialties to manage production processes [6, 7, 8].

Analysis of recent research and publications

In works [9, 10], research was conducted on the effectiveness of using virtual laboratories as a tool for learning. The students’ perception of the experience during training in the virtual laboratory was evaluated. Benefits include maximizing time and space flexibility, simplifying complex seminars, and increasing student enthusiasm. Disadvantages are the impossibility of familiarization with physical tools, as well as the hindrance of direct interaction. In general, virtual laboratories can satisfy some complex requirements for engineering education.

The researched [11] describes the experience of using simulators with the use of mathematical modelling and simulation using LabVIEW and LabVIEW MathScript as a supplement to theoretical and distance learning. A positive result was obtained in confirming the consolidation of theoretical knowledge and facilitating the conduct of research and surveys in the future in real conditions. The article also discusses the creation of modules for control systems and numerical analysis using the specified products.

The authors of the article [12] talk about the wide opportunities that open up from the use of information technologies in the training of engineering specialists. Among the advantages, it is stated that interactive simulators increase the effectiveness of training and develop professionally oriented skills and abilities. However, at the same time, the inadequacy of using only this learning technology was noted due to the possible complication of the stage of adaptation of the future graduate in the conditions of real production.

The purpose of research

The purpose of the presented work is to create a virtual instrument in a software-oriented LabVIEW environment that simulates the process of determining the parameters of the shape deviation of cylindrical shafts. Accordingly, to implement the modelling of the simulation process of determining the shape deviation parameters, it is necessary:

– to describe the process using mathematical modelling;

– to make a software implementation of the process;

– to test the virtual instrument and analyse the obtained results.

Research materials and methods

The case study is devoted to the practical application of common virtual tools for solving digital engineering tasks in the design of information and measurement systems in the field of the machine-building industry. To fulfil the task, theoretical methods based on the theories of mathematical and computational modelling and the use of the basic provisions of the theory of measurements and statistical processing of measurement results were used.

Results and discussion

The use of modern computer technologies in various fields of industry for modelling and simulation when solving digital engineering tasks allows you to obtain information about the object (system) of modelling, its properties and characteristics in general. All this is accompanied by a high degree of visualisation and makes it possible to understand better how exactly the object can behave in one or another case. The use of software products for modelling and simulating objects with obtaining results about their functioning is relevant not only in the conditions of distance learning.

Among the instruments developed at the Odessa Polytechnic, there is a instrument for simulating the process of determining the parameters of the shape deviation of cylindrical shafts. The input parameters for the process simulation are the diameter of the shaft, the upper and lower tolerance zone deviation of the shaft being machined.

When developing such a virtual instrument as a sensor for measuring the diameter of shafts, digital indicators of the clock-type were used for high-precision measurement of external dimensions of products. The sensor (Fig. 1) is equipped with a MicroUSB data transfer port to a computer, has the following characteristics: measurement range 0...12.7 mm; discreteness (separation value) – 0.001 mm; LCD display and touch control buttons.

Fig. 1. Clock-type digital indicator [13]

The scheme of measuring a shaft with six clock-type indicators is shown in Figure 2. The design of a virtual instrument for determining the shape deviation parameters of cylindrical shafts was carried out in the LabVIEW software-oriented environment [14, 15]. When designing the appearance of the virtual instrument for measuring the deviation of the shape of cylindrical shafts, the movement of the indicator plungers relative to the part was simulated.

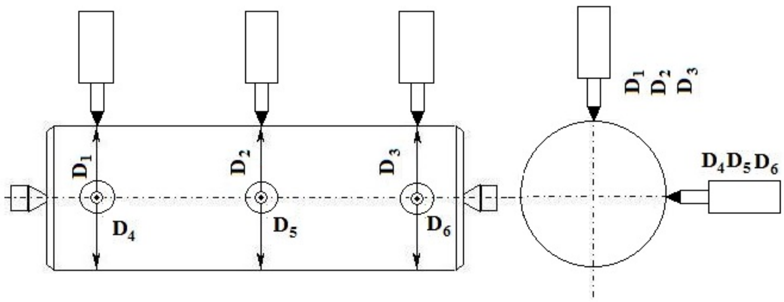

Fig. 2. Scheme of measurement of shape deviation parameters of cylindrical shafts

When designing the appearance of the virtual instrument for measuring shaft diameters, a measuring installation with six measuring heads was modelled. On this basis, the appearance of the executive module of the virtual installation was presented in the form shown in Fig. 3.

After starting the device, the measuring tips of the heads are lowered to the outer surface of the part. During the movement of the measuring tips of the heads, the speakers of the computer on which the program is installed emit a sound that simulates the operation of the drive of the measuring heads. At the moment the tips of the heads touch the outer surface of the controlled shaft, the virtual instrument displays six values of the measured diameters and four parameters of the error of the shaft shape in the display windows.

To control the deviations of the actual shaft size from its maximum permissible values and to control the error of its shape, it is necessary to set the nominal size of the diameter and the limit deviations of the controlled cylindrical surface. When simulating the measurement of the surface diameter, according to the working drawing of the part being controlled, its diameter (mm), upper deviation (μm) and lower deviation (μm) are set (see Fig. 4).

When the virtual instrument is started by pressing the [Run] button on the front panel of LabVIEW, the characteristic sound of the movement of the indicator plungers is heard. The measurement diagram appears on the screen of the "Measurement diagram" window, and in the windows of the "Measured diameters" and "Deviations of form" panels – calculations, measured dimensions of diameters (Fig. 5, *a*) and deviations of form (Fig. 5, *b*).

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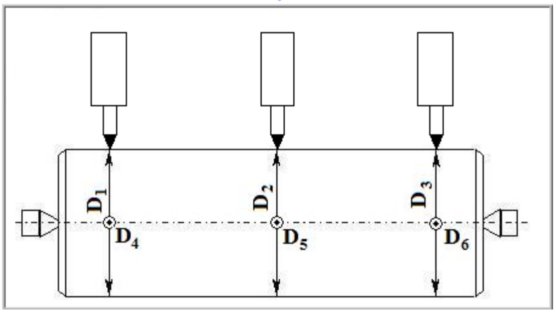


Fig. 3. Appearance of the executive module of the virtual instrument

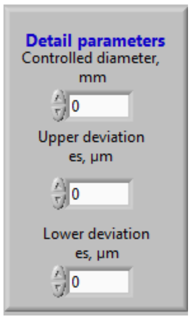
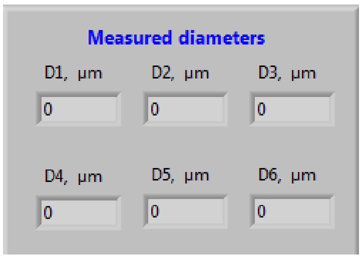
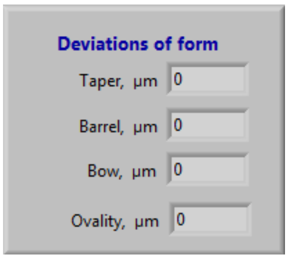


Fig. 4. Initial parameters of the part

The front panel of the virtual instrument after measuring the diameters and calculating the deviations of form is shown in Fig. 6. The operation of the designed virtual device for measuring the diameter of the shaft requires two actions to be performed in sequence. The first action consists in simulating the movement of the tips of the measuring heads. The second action consists in simulating the measurement of diameters and calculating the deviations of form. The execution of two actions separated in time allows the implementation of the Flat Sequence Structure of the G programming language, the LabVIEW software-oriented environment [14, 15].



a



b

Fig. 5. Results of modelling and calculations: *a* – measured diameters; *b* – deviations of form

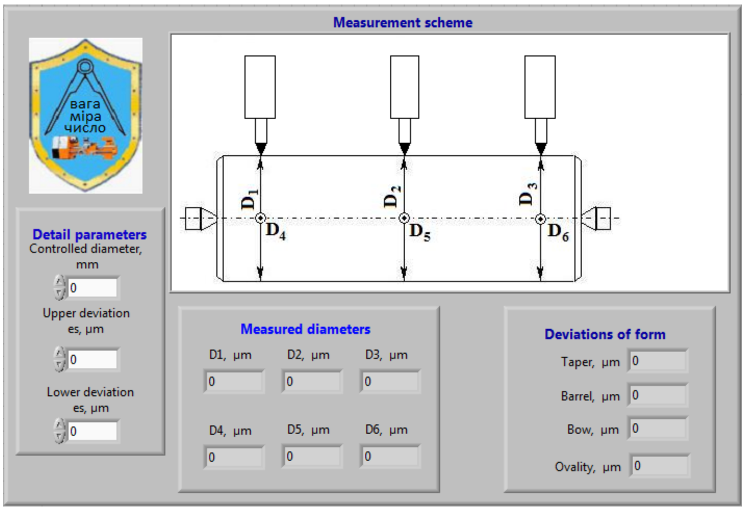


Fig. 6. Front panel of the virtual instrument

The formation of a moving image of the operation of measuring equipment is programmed in the first frame of the Flat Sequence Structure. Simulation of diameter measurement and calculation of shaft deviations of form is programmed in the second frame of the structure (Fig. 7).

A For Loop structure is introduced to the first frame of the Flat Sequence Structure and 10 cycles performed by this structure are defined, for which a constant equal to 10 is connected to the terminal of the number of cycles of the For Loop structure (Fig. 7). In the For Loop structure, the Wait Until Next ms Multiple function is placed and a numerical constant equal to 10 is attached to it. This ensures that one cycle of the For Loop structure takes 10 microseconds. Then the total duration of the first frame of the Flat Sequence Structure will be 2 seconds. Place the 2D Picture graphic indicator on the front panel (Controls ⇒ Modern ⇒ Graph ⇒ Controls ⇒ 2D Picture). The icon of this indicator will appear in the block diagram window. Let's move it inside the For Loop structure. To create an image on the graphic indicator screen, let's place six Drow Rect.vi functions and three Drow Arc.vi functions inside the For Loop structure and connect them sequentially to each other and to the graphic indicator.

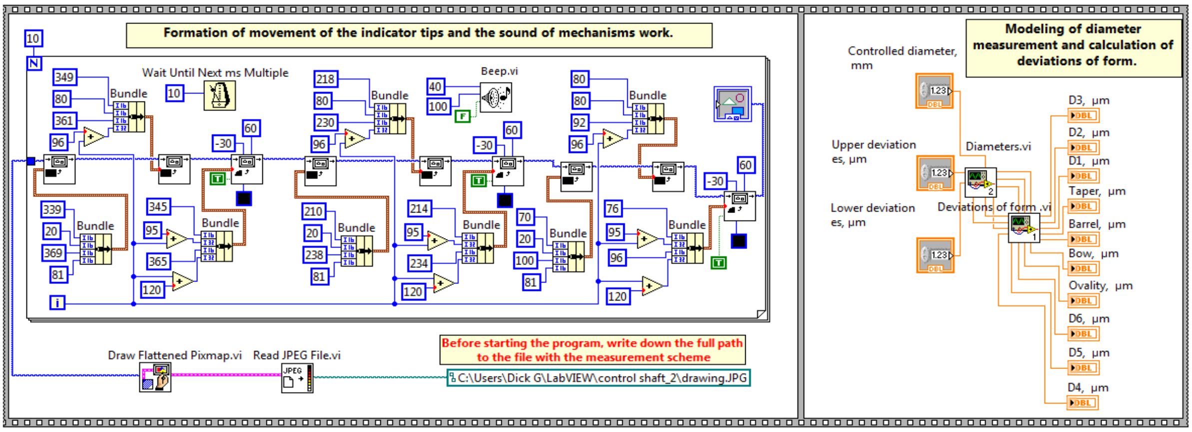


Fig. 7. Block diagram of the virtual instrument

To the six Drow Rect.vi and three Drow Arc.vi functions, we will attach a cluster with the coordinates of rectangles and triangles, which depict three virtual indicator drive cases and three foot tips. To ensure the movement of the tips of the indicators, we will form clusters of coordinates of the corresponding shapes using the Bundle function. We will attach numerical constants that determine the coordinates of the upper and lower sides of rectangles and triangles to the input terminals of the Bundle function. To change the coordinates, we will add numerical constants and add them to the serial number of the executed cycle of the For Loop structure.

To simulate the sound of the indicator mechanisms, let's place the Beep.vi virtual sub-instrument in the For Loop structure. Let's set the frequency and duration of the Beep.vi alarm sound.

To display the shaft measurement scheme on the screen of the graphic indicator, in the first frame of the Flat Sequence structure, we will sequentially place the Read JPEG File.vi and Draw Flattened Pixmap.vi functions, and for the first of these functions, we will show the full path to the drawing drawing.JPG with the diameter measurement scheme.

Finally, the block diagram of the first action of the virtual device is shown in Fig. 7. Calculation deviations of form and simulation of measurement of shaft diameters is in the second frame of the Flat Sequence Structure (Fig. 7).

The virtual sub-instrument «Diameters.vi» carries out simulation of measuring shaft diameters. The block diagram of the virtual sub- instrument is shown in Fig. 8.

In the For Loop structure (Fig. 8), the following functions are used to simulate diameter measurement: rounding to the nearest integer, generation of a random number from 0 to 1 according to the law of equal probability, functions of addition, subtraction, multiplication and division. The result of each cycle is the diameter of the shaft within the tolerance zone. The number of cycles of the For Loop structure is 6. The Index Array function (see Fig. 8) returns the element of the array that was formed by the For Loop structure, according to the index. Thus, the "Diameters.vi" sub-instrument generates six random numeric values for the diameter of the shaft.

The virtual sub-instrument "Deviation of form.vi" carries out the calculation of form deviations. The block diagram of the virtual sub-instrument "Deviation of form.vi" is shown in Fig. 9.

The deviations of form of the cylindrical part is calculated according to the formula:

$$D = \frac{d_{max} - d_{min}}{2}, \qquad (1)$$

where Δ –deviation of form; d_{max} – maximum shaft diameter, mm; d_{min} – minimum shaft diameter, mm.

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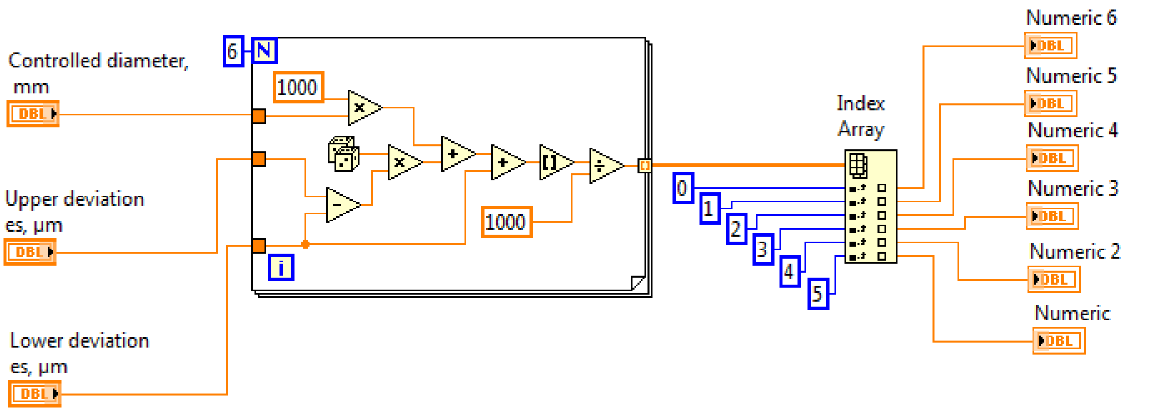

Fig. 8. Block diagram of the virtual sub-instrument “Diameters.vi”

Consider the sequence of calculating the taper value. The value of the diameter D1 and D3 is summarized as an example (Fig. 9). Add the values D3 and D1 to the Subtract function. Since it is not known in advance, which of these values is greater, we use the Absolute Value function to take the absolute value of the result. To calculate the second value of the taper value, we use the values of the diameters D4 and D6 (Fig. 9). Add to the Subtract function to obtain the difference between D6 and D4. Since it is not known in advance, which of these values is greater, we use the Absolute Value function to take the absolute value of the result. Both values of the taper are given to the input of the Max & Min function, the maximum value of the two taper values is divided by two using the Divide function according to formula (1) and the result is given to the element of indication of the calculated taper value. Similarly, we calculate the numerical values of bow, barrel and ovality.

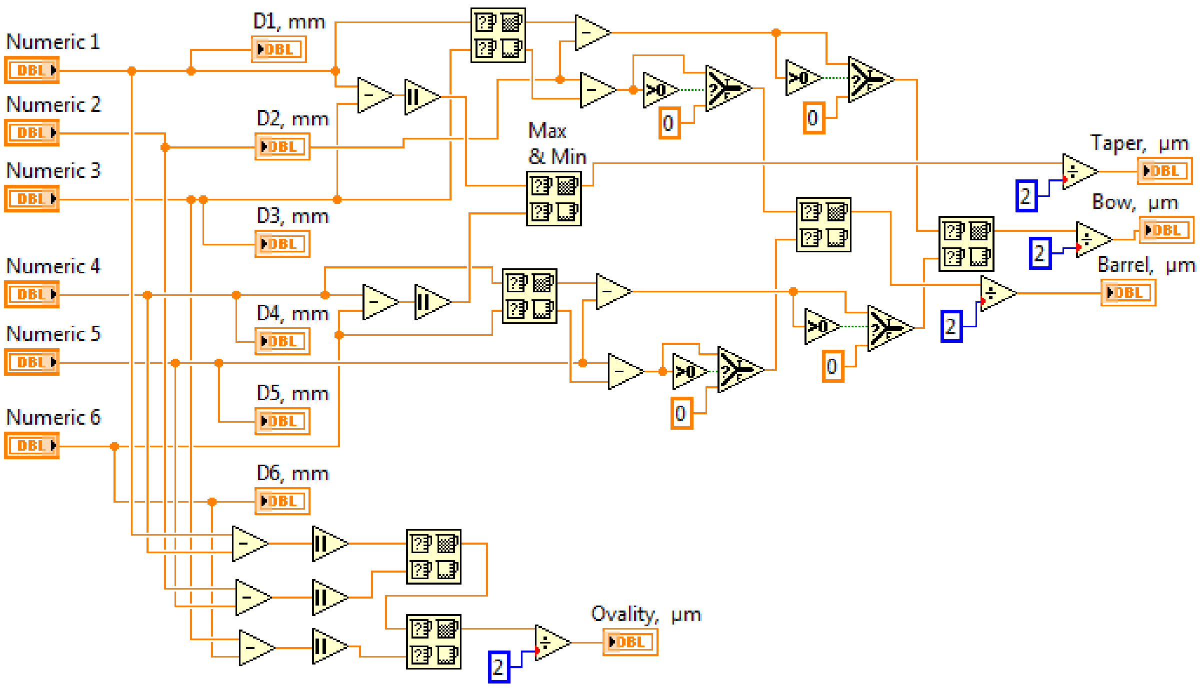

Fig. 9. Block diagram of the sub-instrument “Deviation of form.vi” virtual sub-device “Deviation of form.vi”

Conclusions

The virtual instrument for modelling the process of determining the parameters of the deviation of the shape of cylindrical shafts is used at the Odessa Polytechnic University during laboratory work under the educational programs of the specialties Applied Mechanics, Industrial Mechanical Engineering, and Metrology and Information and Measurement Technologies [7]. Students independently set the numerical value of the diameter of the shaft, the upper and lower deviations of the diameter, obtain the numerical values of the deviation of form of the cylindrical shaft, and form conclusions based on the obtained results.

The design of virtual instrument allows you to get a device with extended functionality, unlike traditional ones, the capabilities of which are determined by the supplier company. It also allows them to be used as devices for distance learning, which in turn provides an opportunity for engineering students to gain practical skills in measuring physical quantities, using knowledge of the theory of measurements, signal processing and measuring circuits, as well as to gain practical experience in using the simulation of the device operation.

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