Simulation Model of Selective Assembly of the Conrod-Piston Group Unit of Internal Combustion Engines, Taking into Account Measurement Errors During Sorting

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Abstract. The process of selective assembly of the conrod-piston group of an internal combustion engine, which provides the required accuracy of the connections, is considered. The functioning of a unit consisting of three main elements is described, the scheme of the assembly set-making is shown. The simulation model of a one-parameter selective assembly of three elements has been modernized by taking into account measurement errors arising from sorting into size groups. The modeling of the assembly process of the unit for a specific engine model has been carried out. A dependence is obtained that connects the required output indicator of the technological process with the parameter of the measurement quality. This research will allow solving the metrological problem associated with the choice of the optimal accuracy of measuring equipment under technical and economic constraints.

1. Introduction

Selective assembly of complex products, the main idea of which is the rational selection of elements, is based on the statements of the accuracy theory and functional interchangeability [1...7]. Achieving the specified accuracy with a multi-element one-parameter assembly of products is a difficult task both in terms of the organization of the technological process and due to economic constraints.

Simulation models are widely used to analyze the behavior of stochastic dynamic systems consisting of a large number of interacting elements and processes. Simulation is the process of building a generalized computer model of a system with an algorithmic description of the basic rules of its behavior. To describe the considered technological process, the mathematical apparatus of the theory of queuing and discrete-event modeling is used, where the functioning of the system is presented as a chronological sequence of events that occur at certain points in time and signify a change in the state of the system. One of the most popular systems for constructing discrete-event models is currently GPSS World [8...12].

The basic principles of building a basic model of the process of one-parameter selective assembly of two elements are given in [13]. In [14], a simulation model of a similar process was built, taking into account the measurement errors of both elements that make up the assembly set. Basic models for selective assembly of complex products are constructed in [15, 16], but they do not take into account the specifics of the measurement process. The purpose of this work is to build a simulation model of the selective assembly of the conrod-piston group of internal combustion engines, which makes it possible to assess the influence of the quality of measurements on the quantitative indicators of the technological process.
2. Problem statement
The main working elements of any internal combustion engine are the conrod-piston group and the crankshaft. The principle of operation of the engine consists in converting the translational movement of the piston into the rotational movement of the crankshaft using a connecting rod jointed with the upper head with a piston pin and the lower head with a neck of the knee of the shaft. The main elements of the conrod-piston group are the cylinder, piston, piston rings, piston pin. A fragment of the unit of this group is shown in figure 1.

![Figure 1. Unit fragment: 1) pin; 2) piston; 3) bush; 4) connecting rod.](image)

Piston pin 1 serves for pin joint of piston with connecting rod. It is in the form of a hollow cylinder, made of chromium-nickel steel, undergoes cementation and hardening, followed by grinding and polishing. When using floating type piston pins, bushings 3 are pressed into the piston head of the connecting rod 4. The connection of the pin with the bush of the upper connecting rod head is characterized by a clearance, and with the piston bosses, depending on the design, by a clearance or interference. These clearances and interferences are small enough, therefore, the piston pins are selected to the pistons and connecting rods by the selective assembly method to maintain accurate fit. In this article, as an object, we will consider an internal combustion engine of the ZMZ-53/5233 (-672/5234) model. For this engine model, the piston pins are divided into 4 groups along the outer diameter as the size increases. A similar number of groups have holes in the piston for the piston pin and the hole in the bush of the upper connecting rod head. The problem of selective assembly of the considered unit is the problem of one-parameter assembly of three elements (parts). In this case, piston pin 1 mates simultaneously with two parts (piston 2 and connecting rod bush 3) that do not form mating.

3. Model of one-parameter selective unit assembly
Sorting elements (parts) into size groups is one of the main stages of the selective assembly of products. In continuous production, the process is provided by control and sorting machines – special devices, which are designed for automatic continuous control of the parameters of the mating parts and their subsequent sorting into size groups. In some cases, these devices, in addition to these operations, carry out set-making and assembly.

Control of parts is always accompanied by random errors, the appearance of which leads to the fact that instead of the true value of the parameter $x_i$ in the measurement process, a quantity $z_i$ becomes known, usually associated with the initial following additive dependence:
where $\delta_i$ is the measurement error.

Consider the assembly process of the unit above. In this unit, the assembly of three parts is carried out, forming joints among themselves according to fit with a clearance. For set-making, we will take the following rule: the sizes of parts selected in a certain way from the corresponding groups during assembly should provide clearances $S_{3-1}$, $S_{2-1}$, lying within

$$S_{\min 3-1} \leq S_{3-1} \leq S_{\max 3-1}, \quad S_{\min 2-1} \leq S_{2-1} \leq S_{\max 2-1}$$

however, parts from these groups must be completely interchangeable.

One of the possible schemes of one-parameter acquisition of three elements, considered in this work, in accordance with the designations adopted in [1], is shown in figure 2.

Let’s assume that the parameters $x_i$ are independent random variables with distribution densities $f_i(x_i)$, finite mathematical expectations and standard deviation, as well as the values of extended tolerances $X_i$ for the production of batches of parts of equal volumes $Q_1 = Q_2 = Q_3 = Q$, the number of sorting groups $l_i$. As a result of sorting parts according to the actual values of the parameter, sorting errors may occur: the part gets into one of the neighboring selective groups instead of the required group, where it would go when sorting by the true values at $\delta_i \to 0$ (figure 3).
In turn, sorting errors will affect the quality of products: when using a single-variant set-making algorithm, products obtained from such parts will be deliberately defective in terms of the output parameter, the accuracy of which is being achieved by the method of group interchangeability. The probability of obtaining such events will be the less, the smaller the value of the measurement error, i.e. more closeness of the actual value of the parameter to the true one. When solving this metrological problem, the issue of choosing the required accuracy of measuring equipment is of paramount importance.

The layout of the tolerance intervals of the elements parameters of the conrod-piston group, for the engine model ZMZ-53/5233 (-672/5234), according to which the assembly is carried out, is shown in figure 4. The following designations are adopted in the figure: \( X_1 \) - the value of the tolerance for manufacturing the diameter of the pin, \( X_2 \) - the size of the tolerance for making pin holes in the piston, \( X_3 \) - the size of the tolerance for making a hole in the bush of the upper connecting rod head, \( S_{\text{min} \ 3-1} \) - the minimum clearance in the connection of the bush of the upper connecting rod head and the pin for the second group of sorting, \( S_{\text{max} \ 3-1} \) - the maximum clearance in the connection of the bush of the upper connecting rod head and the pin for the second group of sorting, \( S_{\text{min} \ 2-1} \) is the minimum clearance in the connection between the piston and the pin for the second sorting group, \( S_{\text{max} \ 2-1} \) is the maximum clearance in the connection between the piston and the pin for the second group of sorting. The clearances in the connections of elements for other sorting groups are indicated in the same way.

![Figure 4. Tolerance intervals layout of parameters \( x_i \) (i = 1, 3).](image)

As an assessment tool, we will use a simulation model of the assembly process [16], modernized taking into account probable sorting errors.

The model assumes that the measurement error is a random variable distributed normally with zero mathematical expectations and standard deviations equal to

\[
\sigma_i = \Delta_i / 2,
\]

where \( \Delta_i \) are the limits of permissible errors \( \delta_i \) (i = 1, 3).
In this case, both real and true values of each of the parameters will become known in the model. Sorting is carried out according to actual values (with the possibility of errors), and the suitability of the assembly set is determined by the belonging of the output indicators to the specified limits. As the initial data for modeling, we will take the data for the conrod-piston group of the internal combustion engine ZMZ-53/5233 (-672/5234), shown in figure 4.

The simulation model allows us to assess the impact of measurement quality on the quantitative indicators of the assembly process. During the simulation, several runs of the model with different generators were used, and then the arithmetic mean of the number of assembly sets and the number of suitable assembly sets for all runs was found, which allowed us to obtain more accurate simulation results.

The simulation results are shown in figure 5. The resulting functional dependence illustrates the relationship between the difference between the total number of assembly sets and suitable assembly sets \((\Delta_{CK})\) and the ratio of the maximum permissible measurement error to the value of the group tolerance interval \((\Delta / X_i^{(k_i)})\).

![Figure 5. Dependence of \(\Delta_{CK}\) from \(\Delta / X_i^{(k_i)}\).](image)

4. Conclusion
The research carried out will make it possible to solve the metrological problem associated with the choice of the required accuracy of measuring equipment. The solution of such a problem will make it possible to select the measuring instruments for each of the parameters that are optimal in accuracy under technical and economic constraints.

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