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ORIGINAL ARTICLE

Automation of component selection of ball-bearing support of drilling bit

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Abstract In the article, the solution of a problem of increasing efficiency of a drilling bit at the stage of its manufacture is proposed. The method of solving this task offered by authors consists in integration automatic contactless and contact stylus method of control elements of pairs leg/cutter of the drilling bit in production conditions. The authors give detailed justification of the offered automatic control methods in the form of special devices. Schemes and descriptions of the work of devices and also calculations of the main characteristics of construction of the device for contact stylus control are provided. The algorithm, excluding time costs of calculations, to determine the group of received size of the roller way leg/cutter is developed by authors for managing sorting devices. The solutions proposed by the authors can be used in the manufacturing engineering, and also in modernization of acting facilities, on which there is a requirement for receiving and selection of couple parts of the roller way.

Keywords Drilling bit · Leg · Cutter · Contactless control · Automation

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1 Introduction

Increase in useful life of the drilling tool influences the effectiveness of drilling of wells in the rock [1, 2]. The useful life of the drilling tool should be understood as the time interval during which it retains its workability [4, 5]. In turn, the precision of separate elements of the drilling bit exposed to significant loading influences the workability of tool [6]. For instance, the surfaces of roller way composing the bearing support are the most loaded elements of drilling bit. At the same time, the geometry deviation of profiles of the roller way leads to premature wear of surfaces of roller way of the drilling bit [3]. At manufacturing, elements of the drilling bit containing these surfaces and the set size tolerance should be strictly observed. Therefore, the organization of control of the received sizes is required. The organization of control of the sizes also allows to organize the sorting of the received elements in order to select pairs of corresponding details [17]. These actions will not only improve the workability of the drilling tool but also reduce its cost by excluding additional producer's costs at correcting rejects. For these purposes, the authors suggest to choose the optimum method to control the surfaces of roller way of the drilling bit and to develop method to select of couple parts of the roller way.

Given that the control and sorting device are inserting in existing flow and automatic production line of the drilling tools, at the solution of task, the condition (Eq. 1) should be observed:

$$Ts \leq Tc \leq To \tag{1}$$

where T_C—time of the control, min;
T_{T0}—output cycle time, min;
T_S—sorting time, min.

Only under condition (Eq. 1) that the cost reduction of products can be achieved.

2 Structural features of bearing assembly of the drilling bit

The roller way, both leg and cutter, represents the surface formed by rotation of the profile of round section around an axis of detail [6, 7]. The technical requirements for drilling bits are given in [8]. Figure 1 shows the bearing assembly of the tricone drilling bit.

The surfaces of the roller way are obtained by "hard turning" that is by hsc-machining of details without grinding, with the achieving the desired accuracy. The next stage of the process is control of the received geometry of the roller way, which can be executed either manually by special measuring instruments or in automatic mode—as a rule—using modern methods and control devices without direct contact with the measured detail.

3 Method of control of the roller way of leg

This method is based on the analysis of the monochrome photographic projection of the controlled object, received in the form of pixel image, and is similar [10]. The authors have developed a special software [11], which allows the control device to function, adjusting measuring axis and also defining the error of form of the roller way in automatic mode. The algorithm of work program is based on recalculation of pixel coordinates of the monochrome image of profile of the roller way and detailed in [9]. The scheme of the control is shown in Fig. 2.

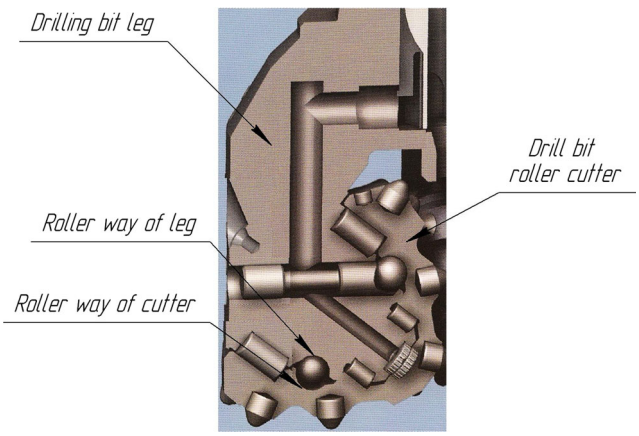

Fig. 1 Bearing assembly of the drilling bit

4 Design of the device for control of the roller way of cutter

However, it should be noted that the application of the method of contactless control of the roller way of the reciprocal detail of bearing assembly, namely cutter, is not possible. One of the obvious reasons of this is feature of design of cutter, where the roller way is located in the detail cavity. There are measuring instruments, which are specially developed at manufacturers of the drilling tool for control of the form of cutter. But such solution of the problem of control of the roller way of cutter is not optimal because these control devices are made without any scientific bases; therefore, their reliability is doubtful. In that regard, the authors propose the following devices for control of the form of the roller way of cutter [12], which scheme is shown in Fig. 3.

The device for control of the form accuracy of the roller way of cutter of the tricone drill bit includes an external hydraulic cylinder 1 with coaxially mounted therein an internal hydraulic cylinder 2. The external hydraulic cylinder 1 contains a piston 3 supported by a spring 4. The internal hydraulic cylinder 2 contains a piston 5 supported by a spring 6.

An extendable spring-loaded rod 7 is placed in the central opening of the piston 3 of the external hydraulic cylinder 1. From one end face, the road is rigidly connected with the piston 5 of internal hydraulic cylinder 2. A contact tip of hemispherical form 8 is established coaxially to the extendable spring-loaded rod 7 on its other end face. Not magnetic plug 9, which is connected to the piston 3 of external hydraulic cylinder 1, is coaxially located with a gap.

The grip 10 is fixed on the wall of external hydraulic cylinder 1 and also interfaced by the internal surface with a wedge surface of not magnetic plug 9 passing through a cuff 11. The cuff 11 is established in the opening performed on the wall of external hydraulic cylinder 1. The piston 5 of internal hydraulic cylinder 2 passes through the cuff 11 established in the opening formed on the end face of internal hydraulic cylinder 2.

External hydraulic cylinder 1 and internal hydraulic cylinder 2 are connected with hydraulic cylinders 12 by unions 13 and connected to them are flexible tubes 14. Hydraulic cylinders 12 contain the pistons 15 connected to the linear pulse electric motors (LPEM) 16 by rigid couplings 17. The enkoder 18 is electrically connected with microcontrollers (MC) 19, which are connected to drives 20 and the block of the interface 21, are installed on shaft of LPEM 16.

In the process of control, the accuracy of the roller way cutter 22 is fixed in the auxiliary device or a main spindle (in Fig. 3 it is not shown).

The presence in the device of the extendable spring-loaded rod contacting to pistons of external and internal hydraulic cylinders with the contact tip of hemispherical form allows to increase the positioning accuracy of "contact" that, in turn, increases the control accuracy. Also, this feature defines that

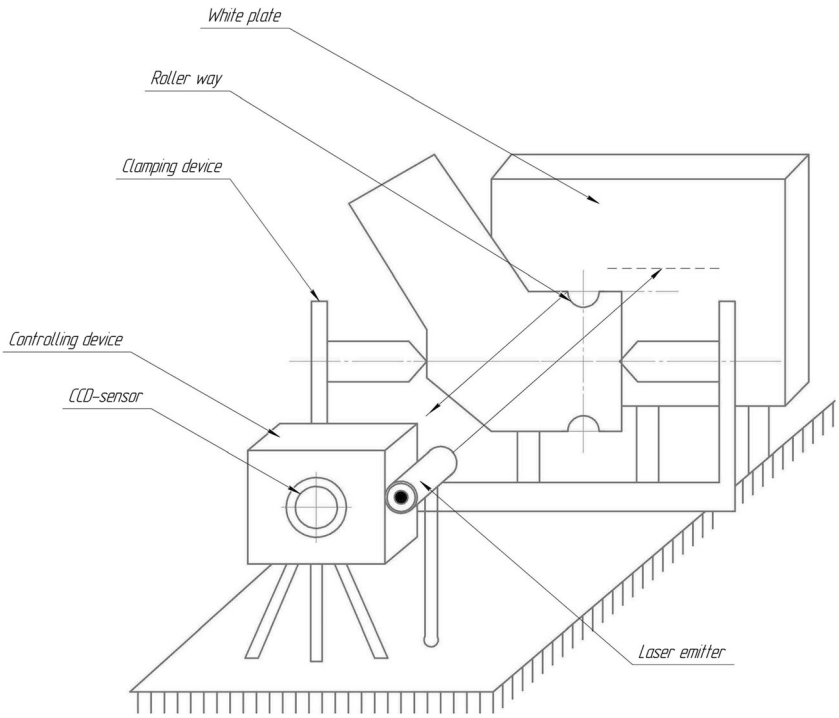

Fig. 2 Scheme of the control of the roller way of leg

by means of the extendable spring-loaded rod, it is possible to measure the depth of the roller way as one of control parameters, which characterize the form accuracy of the roller way.

Supply of the device with grip allows to expand its functionality and, in connection with the contact tip of hemispherical form established on the extendable spring-loaded rod, to define geometrical characteristics of the roller way and its profile. It happens at the expense of contact of surfaces of grip and the contact tip of hemispherical form with cutter in three "characteristic" points of the profile of the roller way.

5 Working principle of the device

The device for control of the form accuracy of the roller way of cutter works as follows.

Initially, the device is installed thus the extendable spring-loaded rod 7 with the contact tip of hemispherical form 8, fixed on it, was located on a normal to the axis of cutter 22 and on the contrary to roller way. The device is based relative to the internal cylindrical surface of cutter 22.

The control values of geometrical parameters of the roller way of cutter 22 are set to the MC 19 through the block of the interface 21. Then, the signal for performance of measurements arrives. MC 19 forms sequence of the signals for the drive 20. The drive 20 transmits the control signal for LPEM 16, which transmits momentum through the rigid coupling 17 to the piston 15. The piston 15 pushes hydraulic liquid, which is in cavity of the hydraulic cylinder 12. Cavities of the external hydraulic cylinder 1 and the internal hydraulic cylinder 2 also filled with hydraulic liquid. Thus, there is a movement of the piston 3 of the external hydraulic cylinder 1 and the piston 5 of the internal hydraulic cylinder 2.

The springs 4 and 6, which the pistons 3 and 5 are sprung respectively, serve for return of pistons 3 and 5 to the starting position.

The cuffs 11 provide tightness of the connection of the extendable spring-loaded rod 7 with the opening of the internal hydraulic cylinder 2 and also connection of not magnetic plug 9 with the opening of the external hydraulic cylinder 1.

Unions 13 connect the external hydraulic cylinder 1 and the internal hydraulic cylinder 2 by means of flexible tubes 14, through which liquid is transmitted.

The contact tip of hemispherical form 8 established on the extendable spring-loaded rod 7 moves with it before making contact with the surfaces of the roller way of cutter 22. Simultaneously, not magnetic plug 9 fixed on the piston 3 also moves, touching their wedge surface of the opening in the grip 10, thus unclenching it before making contact with the surfaces of the roller way of cutter 22.

After that, there is a closure between MC 19 conclusions "+" and the general "−". The contact closure "+" stops movement of LPEM 16 by means of MC 19, and MC 19 fixes an angle of rotation of shaft of LPEM 16 and transfers these data to the computer, which will transform them to absolute values.

The values of movements of pistons 15 depend on angle of rotation of shaft of both LPEM 16. The values of movements of the extendable spring-loaded rod 7 with the contact tip of hemispherical form 8 and not magnetic plug 9 with the grip 10 are connected with values of movements of the pistons 3 and 5

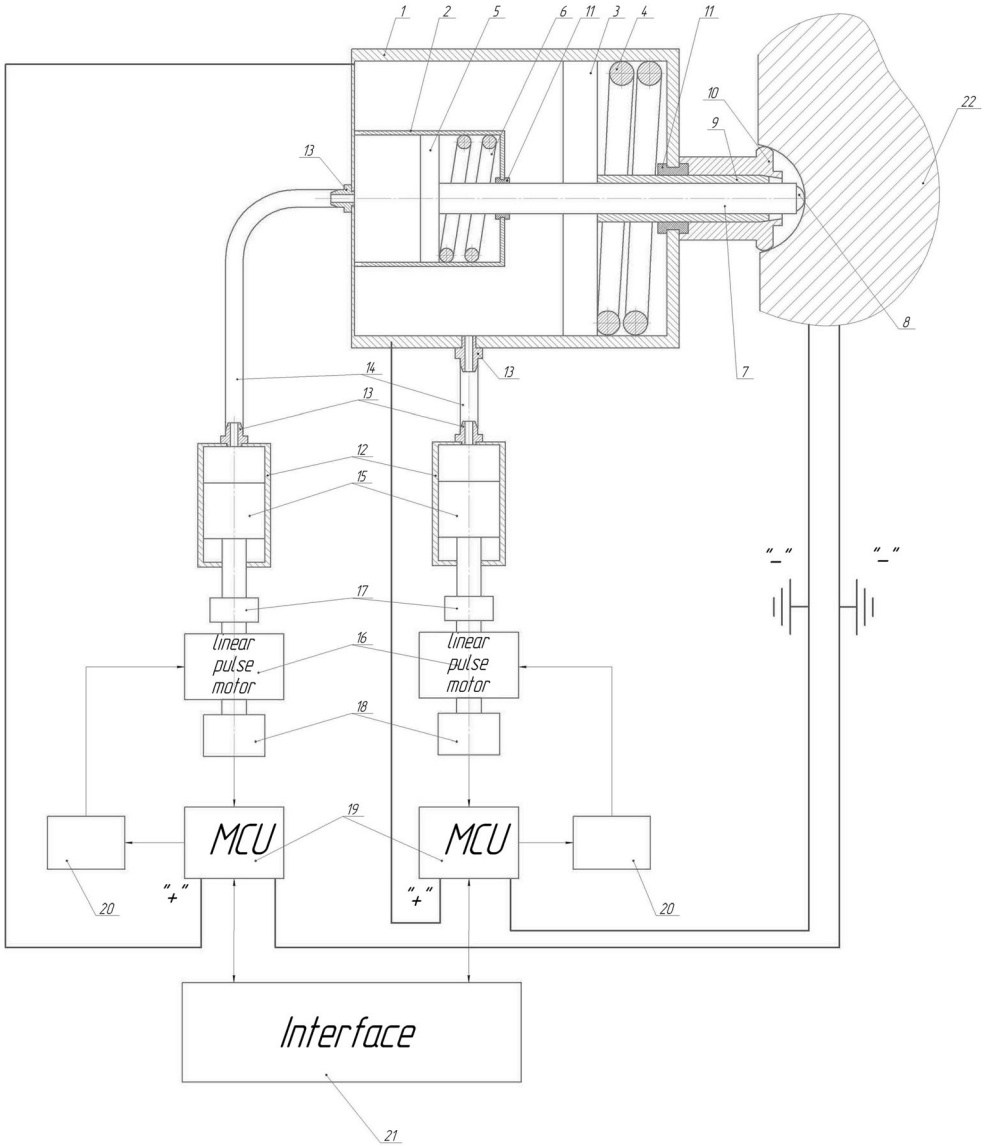

Fig. 3 Scheme of the device for control of the form accuracy of the roller way of cutter

corresponding to them. Thus, from a ratio of squares of diameters of the corresponding piston 15 and the piston 5, it is possible to calculate a scaling factor that allows to determine the value of movement of extreme point of the contact tip of hemispherical form 8 from its initial situation by the value of angle of rotation of shaft of LPEM 16. The value of movement of not magnetic plug 9 fixed on the piston 3 can be determined similarly. From the ratio of squares of diameters of the corresponding piston 15 and the piston 3, it is possible to calculate the scaling factor that allows to determine the value of movement of extreme point of not magnetic plug 9 from its initial situation by the value of angle of rotation of shaft of corresponding LPEM 16.

Thus, the big movements of shafts of LPEM 16 transform into the small movements of the extendable spring-loaded rod 7 and not magnetic plug 9, equipped with the contact tip of hemispherical form 8 and the grip 10, respectively.

The sizes of the grip 10 are known in advance and are determined with the corresponding size of the roller way of cutter 22.

Control is done as follows: the grip 10 brought to the roller way by means of forward coaxial movement of not magnetic plug 9 is unclenched before making contact with two control points of the roller way of cutter 22.

Simultaneously, there is the forward coaxial movement of the extendable spring-loaded rod 7 with the contact tip of hemispherical form 8 fixed on it before making contact with the third control point of the roller way of cutter 22.

According to the amount of movement of the executive bodies connected with shafts of LPEM 16 by rigid couplings 17, the conclusion about existence of deviations from roundness of the roller way is drawn. The form of the roller way is defined. Then, the final conclusion about the validity or marriage of cutter 22 is drawn.

6 Calculation of diameters of hydraulic cylinders

The existence of hydraulic cylinders allows to make transfer of kinematics between the elements of the device with minimum losses because hydraulic liquid has an insignificant compression ratio. And the existence in the design of the device executive bodies in the form of pairs of hydraulic cylinders with the pistons, having for each pair ratio of squares of the areas not less than 20, provides performance of condition of measurement of the sizes from 2 μm and less. In that case, the accuracy of measurement [*delta*] is defined by the relation (Eq. 2):

$$\text{delta} = \frac{Z_{el}}{D_{max}^2 \Big/ D_{min}^2} \tag{2}$$

where Z_{el}—step of LPEM,

$D_{\max}$—diameter of the bigger piston (position 3 and 5 in Fig. 3),

$D_{\min}$—diameter of the smaller piston (position 15 in Fig. 3).

It should be noted that the choice of diameters of the pistons is not standardized and can be accepted by anyone, but a satisfying condition (Eq. 3):

$$\frac{D_{\max}{}^2}{D_{\min}{}^2} \geq \frac{Z_{el}}{\Delta} \tag{3}$$

According to the technical requirements for the accuracy of the roller way of cutter, diameter of its profile is 8.5 + 0.07 mm. Therefore, it is necessary to ensure the accuracy of measurements to the hundredth of millimeter, that is [*delta*] =0.01 mm.

The control of form is performed in one section. Reinstallation of cutter in the special device for the purpose of its rotation around its own axis is necessary for control of all surface of the roller way.

The scheme of control of the form accuracy of the roller way of cutter offered by authors is shown in Fig. 4. Cutter is fixed in the clamping rotary device allowing to carry out rotation around axis of symmetry of cutter for control of profile of the roller way on all its surface. The rack with the device for control is installed at the given distance *h* from the end face of cutter and fixed on the steady basis. The axis of rotation of the device coincides with the axis of rotation of cutter and is exhibited on devices of control of deviation of coaxiality.

Measurement of the geometry deviation of profiles of the roller way is proposed to act as follows: the grip brought to the roller way by means of forward coaxial movement of not magnetic plug is unclenched before making contact with two control points of the roller way of cutter.

Simultaneously, there is a forward coaxial movement of the extendable spring-loaded rod with the contact tip of a hemispherical form fixed on it before making contact with the third control point of the roller way of cutter.

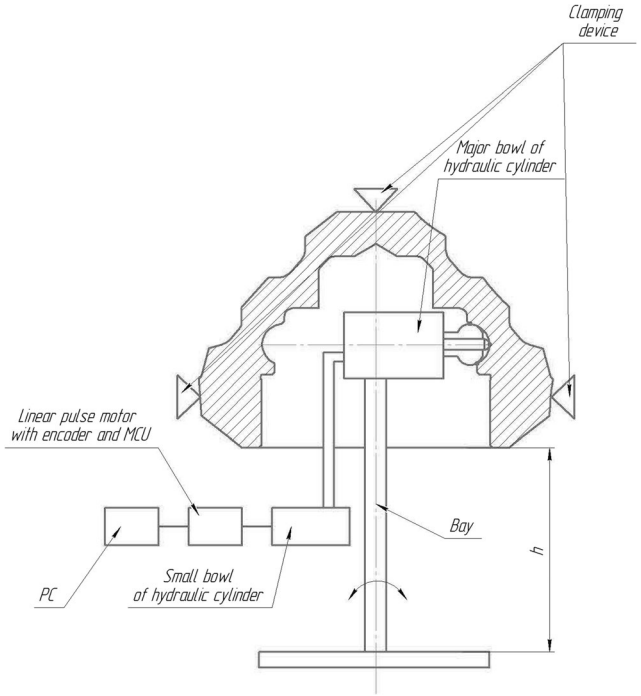

Fig. 4 Scheme of control of the roller way of cutter

According to the amount of movement of the executive bodies connected with shafts of LPEM by rigid couplings, it is possible to conclude that there is, for example, deviations from roundness of the roller way. Thus, the method of control offered by authors makes it possible to identify the suitability of the roller way of cutter.

7 Developed version of algorithm of selection of pairs leg/cutter

Therefore, there is the opportunity of selection of corresponding pairs of leg and cutter according to the results of control of both parts of the roller way of bearing assembly of the drilling bit [13, 14]. The authors offer selection of pairs of details of equal accuracy of production of roller way that would allow to increase workability and service life of the drilling bit.

For this purpose, the following algorithm for sorting of details and selection of the corresponding pairs was developed (Fig. 5).

The algorithm of selection of coupe parts offered by authors allows to realize the sorting devices, for example, on the basis of separators [17, 18]. That is, it allows to organize the movement of the received product to the corresponding flow output. If the product does not have specific size corresponding to one of the groups, then it goes in reject. The algorithm allows to organize the sorting of both legs and cutters of drilling bit that is details with both inner and outer working

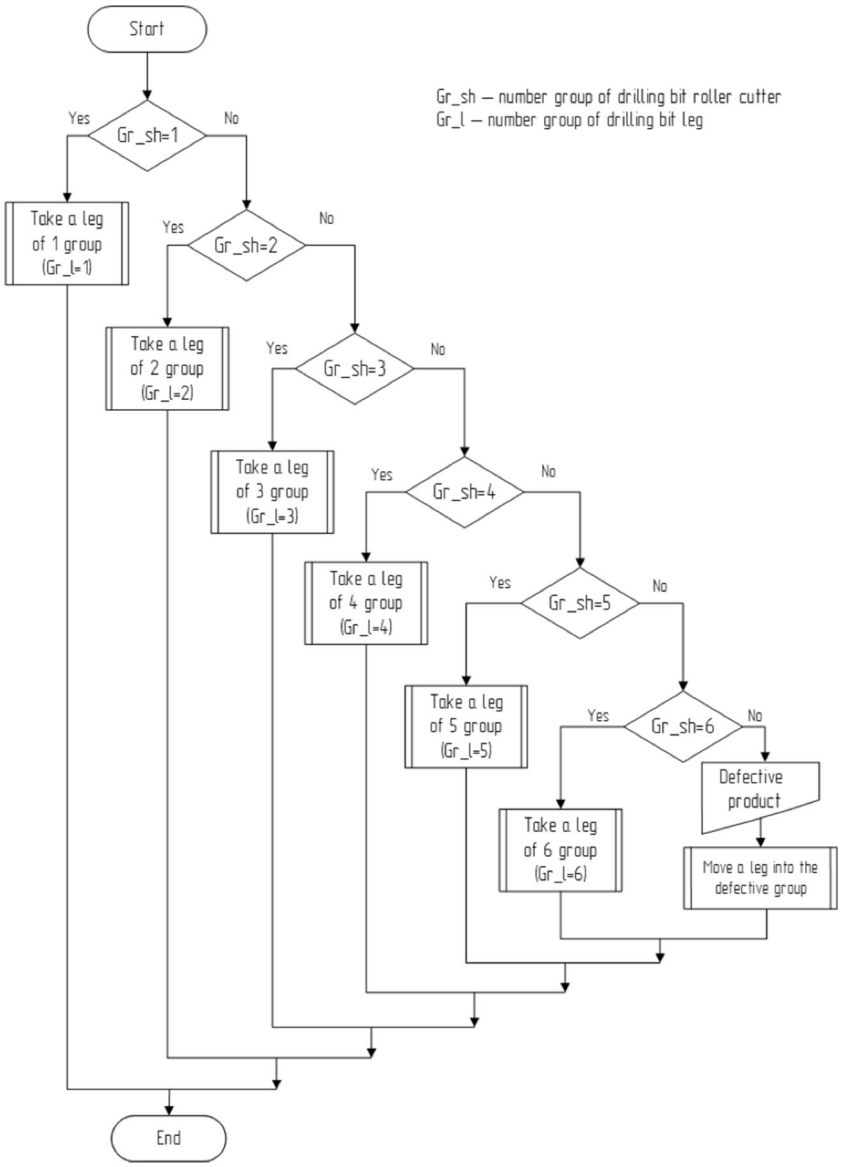

Fig. 5 Algorithm of selection of pairs leg/cutter

surface. It gives the opportunity to use the same software for various production flows [16].

Another advantage of the offered algorithm is that it has a software part, able to equally function not only in digital, but also in analog implementation. Generally, the scheme of sorting presented in the form of algorithm in Fig. 5 barely has time costs of calculations.

The authors suggest that it is necessary to reveal the contents of the procedure "Move a leg into the defective group" of the proposed algorithm. The size received by machining may have residual stock or be more than demanded that counts as reject. If the allowance is removed by the more value than required, then the product goes to waste. If the allowance is removed by the value less than the minimum allowable, then the correction of reject by return of product to the "forming" operation is possible. Thus, the procedure described above must fulfill the control function of movement product to the workpost.

8 Conclusions

Integration of contactless control of profile of the roller way of leg and contact stylus controls of the roller way of cutter of the drilling bit ensures the accuracy of interface between couple parts of the roller way of drilling tool [15]. Implementation of algorithm for sorting legs and cutters offered by authors provides effective selection of pairs of the roller way. At the same time, the offered control methods are implemented in the form of automatic devices, which are part of automatic sorting machines that, in general, lead to successful results-oriented solutions to increase workability of the drilling tool.

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