UDC 681.5.09/.7.023:621.9 EDN: YZXMCR

THE DEVELOPMENT OF ACTIVE CONTROL METHOD OF THREAD MILLS

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Abstract

This paper considers solution to a problem of ensuring the threaded joints manufacture on the computer numerical control machines and development of the thread mill active control method. This method is realized by introducing the non-contact measurement system, and implementing the developed algorithms adapted to the cutting tool features. The presented method automates tool measurement and reduces the number of thread manufacture defects caused by using the worn or broken tools, as well as by incorrect determination of a zero-point coordinate of the thread mill installed on a computer numerical control machine. Main benefit of the recommended approach lies in the missing requirement to use additional sensors to be installed on the computer numerical control machine, which probably could become relevant for the majority of instrument-making and machine engineering enterprises. Moreover, the proposed method could be used to obtain data required in constructing a forecast model of the cutting tool wear. This would simplify the technological processes planning aimed at reducing the risk of loss of the cutting tool operation condition in a machining step

Keywords

Automation, cutting tool wear, active control, cutting tool, CNC machine, measurement method

Received 04.12.2023
Accepted 19.01.2024

Introduction. Threaded metric joints are widely used in the majority of mechanical engineering and instrumentation products [1]. Metric threads manufacture on shafts and in large diameter holes is usually performed on the computer numerical control (CNC) milling machines by thread mills with the replaceable inserts [2]. The thread mill cutting edge wear, as well as the incorrect tool zero-point coordinates determination on the CNC machine could lead to a product defect due to the thread [2, 3].

Modern machine tool methods in measuring thread mills and determining their wear are generally not accurate enough due to incomplete automation of the tool measurement processes [4–7]. It should be noted that in the frames of working conditions, precise measurement of a cutting tool with complex geometry, such as a thread mill, is associated with certain difficulties [8–11]. First, the majority of the cutting tools measurement methods do not guarantee the required result accuracy [12]. Based on this fact, these days the cutting tool with 60–70 % wear from the standard is changed in flexible production systems after machining a certain number of workpieces; this significantly increases the product manufacture cost and does not guarantee compliance with the thread design and technological requirements. Second, an error in determining the cutting tool zero-point coordinates on the CNC machine could also lead to a technological defect. This causes a shift in the tool trajectory relative to that specified in the Numerical Control (NC) program code provided for manufacture of an element with a certain size. Third, not all the tool wear measurement methods could be adapted to control the cutting tool manufacture conditions on the regular basis [3].

As a result, implementing the thread mill active control approach is an urgent task, especially for the flexible manufacture systems [12, 13]. Active cutting tool control means monitoring the tool wear by measuring its geometric dimensions at the beginning and at the end of the machining steps. This measuring method uses a laser system to identify breakages and to adjust the cutting tool motion coordinates on the CNC machine according to the detected wear [14]. To address the issues raised in the framework of this study, a hypothesis was developed that, in order to ensure active control of thread mills on the CNC machines and adaptation of equipment to various changes in the technological characteristics, a new method of cutting tools active control could be introduced. This method is based on the CNC machine algorithms and the machine equipment operation.

Method for solving problems. Non-contact laser machine tool measurement systems are characterized by high accuracy (5 microns) and results repeatability (only one-two microns); however, to achieve their correct operation, the tool measurement cycle programming is necessary [15]. The tool measurement cycle is developed in a special macro language that is supported by a specific CNC system. There are parameters in the tool measurement cycle, which have to be entered manually using the CNC system; as a result, this leads to missing the automated cutting tools active control algorithm. Therefore, to ensure high quality in the threaded joints manufacture, it is necessary to develop a thread mill active control method using the non-contact measurement system on the CNC machine.

The developed thread mills active control algorithm (Fig. 1) includes the cutting tools dimensions determination between the machining steps by a laser measurement system, as well as the automatic measurement results preparation. This algorithm is aimed at reducing the product failures that could be caused by machining with worn cutting tools, incorrect cutting tool measurement and its set upping, as well as by other reasons [16]. The entire system automated operation is determined by including the tool measurement cycles into the NC program code. In case of measuring a new tool, which was not previously controlled, the tool is provided to the laser system accounting for its length and diameter dimensions, which were earlier entered into the machine tool data table named the Tools Offset.

To avoid incorrect input into the machine tool data table, as well as to check the laser measurement system operability in loading a new tool into the machine shop, the tool measurement results taken on the presetter are entered into the table assigning a zero value in the Tool Wear column. To exclude the error of inserting the incorrect installation data into the cutter body, the first measurement results by the laser system are compared with the previously obtained values on the presetter. These values should not differ more than the manufacture error of the Δset insert. If the received tool measurement results differ from those previously entered in the Tools Offset table for more than the Δset value, the tool is blocked for further verification outside the machine. At the same time, the program for searching a duplicate tool in the machine shop is called on the machine. If the Δset value is not exceeded, the thread mill measured diameter is rewritten into the Tools Offset table; moreover, the 0.001 value is automatically registered in the wear column to mark the tool as measured. This value is selected as the minimum value to be considered during machining.

After machining is completed, the NC program code also has a thread mill measurement cycle that measures all the cutting edges to prevent production defects due to at least one insert cutting edge breakage. After receiving the measurement results, conditions fulfillment is analyzed for the absence of exceeding the thread mill diameter wear value, as well as for the tool failure. The measured tool wear value is compared to the maximum allowed Tool Breakage value. If the tool wear exceeds the Tool Breakage value, the machine tool program Tool Lock and Machine Pallet Lock is engaged to quickly change the machine tool pallet with another for further checking the manufactured product dimensions. If the tool wear in diameter does not exceed the Tool Breakage value, then the tool wear in diameter is compared with the MAX

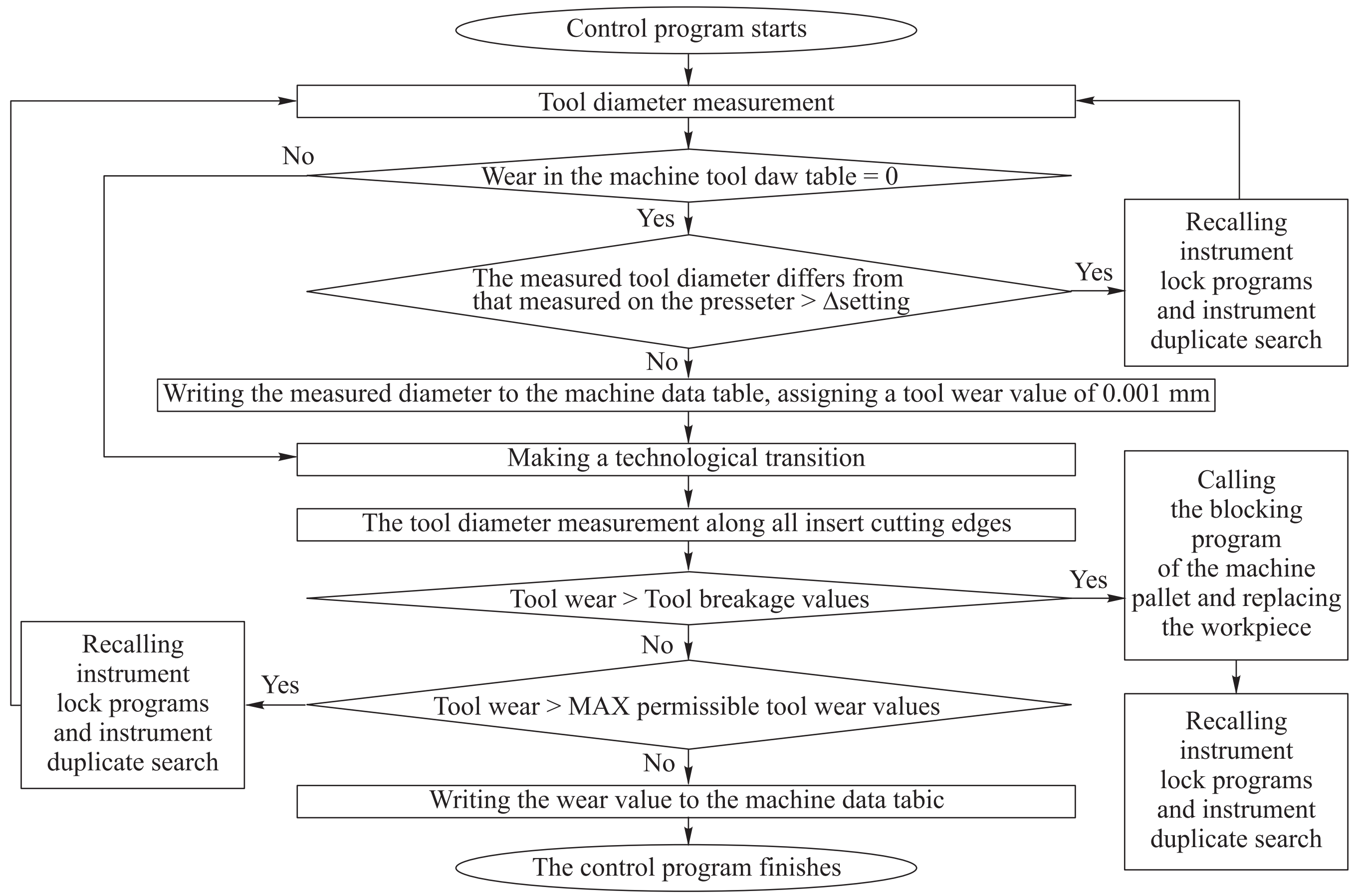


Fig. 1. Algorithm for the thread mill active control

Permissible Tool Wear value. If the MAX Permissible Tool Wear value is exceeded, the Tool Lock program is engaged and the thread mill is replaced with its duplicate to continue the technological operation. Active thread mill control according to the presented algorithm could be used to ensure the flexible manufacture system smooth operation, compliance of the threaded milled joints technological characteristics, as well as to reduce the product manufacture cost due to the full-fledged tool consumption and manufacture defects reduction.

Data for solving problems. As is known, to obtain a thread profile on the workpiece, it is necessary to copy the tool profile (see Fig. 2). It should be noted that thread milling programs are basically developed with automatic correction of the tool radius. This correction is used to automatically offset the tool trajectory specified in the NC program code by the wear amount. Moreover, in most cases, the internal thread external diameter value, when the internal thread size is ensured during machining, is used in the thread milling NC program. As a result, the cutting tool moves along a helical trajectory, while rotating around its axis (as shown in Fig. 2); therefore, the error in determining the tool diameter corrector directly causes expanding the spiral trajectory diameter of the thread mill extreme point, and, consequently, leads to increased removal of the workpiece material. This fact directly influences the internal thread average diameter of the machined workpiece due to the above-mentioned thread mill motion.

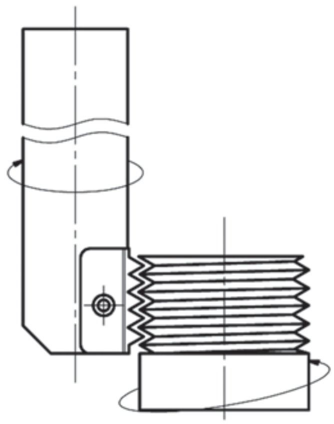


Fig. 2. Threading process

Likewise, if the parameters incorrect values are input into the tool measurement program, the tool zero-point coordinates would be inaccurate. Therefore, further thread mill trajectory displacement with their zero-point already shifted could lead to an even greater expansion of the tool path and high probability of obtaining a thread product defect. Furthermore, results accuracy in the non-contact measurement (laser) system operation, as well as the thread manufacture quality, directly depend on the tool measurement cycle parameter values. The *PX* and *PZ* parameters are crucial in determining the laser beam tool scanning points for measuring the cutting tool length and radius, respectively. These values have to be set in accordance with the cutting tool characteristics and the measurement type. Actual spiral diameter of the extreme point motion trajectory of the thread mill profile would expand, if the tool dimeter is corrected with an error due to the *PZ* parameter incorrect value in the tool measurement cycle.

To measure the thread mill correction length, the measurement point should be located on the flat part of the insert top. In order to accurately measure the diameter correction, the cutting tool measurement point is positioned on the maximum tool diameter, preferably on the tool first cutting edge, due to its faster wear compared to the other edges (see Fig. 3) [17].

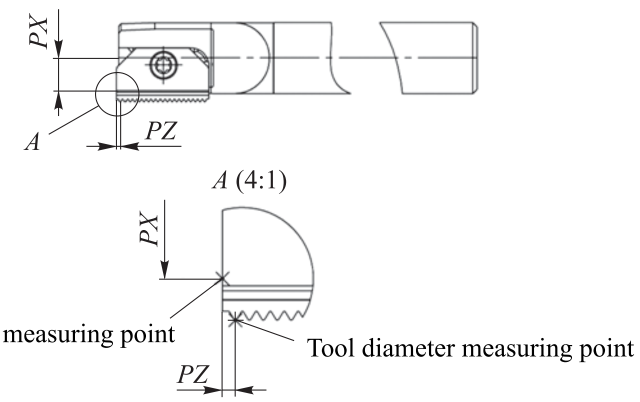


Fig. 3. Thread mill measurement points

Thus, the *PZ* variable parameter value of the tool measurement cycle should be entered equal to the distance from the thread mill end to the inserting first cutting-edge top. Likewise, the *PZ* axial displacement value influence on the tool radius (diameter) measuring results is demonstrated by the following example of milling the M20 × 1 metric thread by the MTE D13.7-1-C10C-14-B thread mill equipped with the ISCAR MT LNHU 1403 I1.00ISO IC908 insert. The cutting tool was measured by the MICRO COMPACT NT (L400) laser system (BLUM-Novotest GmbH) using the Haidenhain iTNC 530 CNC system by means of measuring tool length and radius cycle at different values of the *PZ* parameter. The *PZ* value in the tool measurement cycle was assigned in the range of 0.25–0.75 mm with the increments of 0.050 mm.

As is known, the internal thread average diameter is mainly controlled by means of through-threaded plugs with the normalized dimensions. The internal thread average diameter could be computed using the internal thread external diameter according to Formula in ISO 724:1993:

$$D_2 = D - 0,6495P, \tag{1}$$

where D_2 is the average internal thread diameter; D is the internal thread external diameter; P is the thread pitch.

Table 1 shows the internal thread actual average diameter calculated according to Formula (1) and considering the external diameter value of the internal thread. The internal thread actual milling diameter is computed considering the tool diameter value obtained in the case of substituting different values in the *PZ* parameter in the measurement cycle.

Table 1

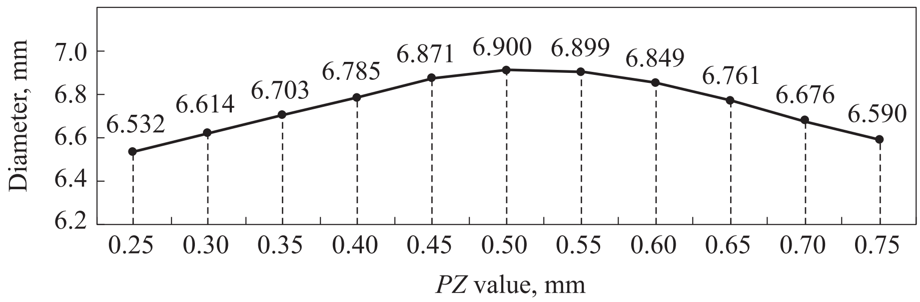
Measurement results

Designation	Numeric values, mm										
PZ parameter value	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
Thread mill measured diameter value	13.063	13.227	13.405	13.569	13.743	13.800	13.798	13.698	13.522	13.351	13.18
Thread actual outer diameter value	20.737	20.573	20.395	20.231	20.057	20.000	20.002	20.102	20.278	20.449	20.62
Actual average thread diameter	20.087	19.923	19.746	19.581	19.408	19.351	19.352	19.453	19.628	19.800	19.97

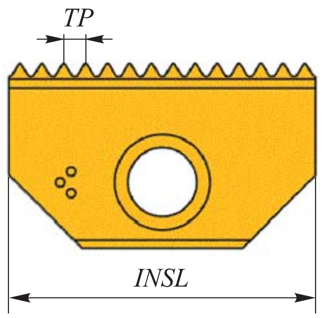
The maximum permissible average diameter value of the M20 × 1-6H internal thread is 19.52 mm; the minimum permissible value is 19.35 mm. Figure 4, *a* demonstrates a graph of the measured diameter dependence of the abovementioned thread mill (Fig. 4, *b*) on the *PZ* parameter value. Thread insert used in the experiment is presented in Fig. 4, *a*. Figure 4, *a* provides a graph of the internal thread average diameter values dependence on the entered *PZ* value in the tool measurement cycle. According to the graph shown in Fig. 5, it could be concluded that the internal thread actual diameter value exceeds the boundary values, if the *PZ* axial displacement error exceeds ± 0,1 mm compared to the actual — 0,5 mm for this insert.

It should be noticed that the thread mill leading manufactures do not indicate in their catalogues the *PZ* parameter. Therefore, it should be determined by a presetter. Moreover, the complex geometry tool measurements using a presetter are showing low results in accuracy and are difficult to perform.

Results. To ensure correct operation of a non-contact tool measurement system the formula is presented to determine this parameter value. In developing this formula, the thread mills inserts with straight cutting edges designed for milling the external and internal metric threads according to the ISO standard



a



b

Fig. 4. Thread mill data:
a — thread mill measured diameter by the *PZ* variable parameter values; *b* — thread mill insert, where *TP* is the thread pitch; *INSL* — insert length

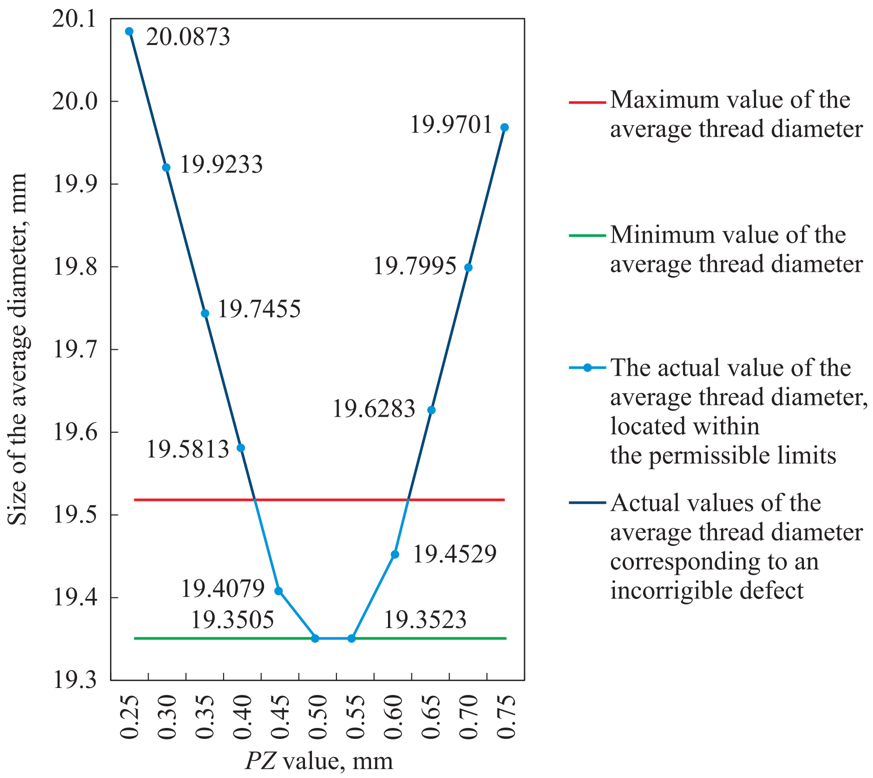


Fig. 5. M20 × 1-6H thread actual outside diameter from the *PZ* value measurement cycle

in increments from 1 to 2 with the insert length from 12 to 21 mm designed for internal and external threads were considered. Each insert was measured three times on the PRECISION 400 instrument presetter (Precitool); data on the inserts from the tool suppliers' electronic catalogues, Generic Tool Catalog (GTC), and 3D models from tool suppliers were analyzed. As a result, the Formula 2 was established to calculate the distance from the insert end to the cutting edge top, using available insert data in the catalogue:

$$PZ = \frac{INST - \left(\left[\frac{INST}{TP} \right] - 1 \right) TP}{2}, \quad (2)$$

where *PZ* is the distance from the thread mill insert top to the cutting edge top; *INSL* is the insert length; *TP* is the thread pitch (insert).

Unified information about the tool is used in Formula (2) in accordance with the ISO 13399 international standard making it applicable in establishing parameter values to the laser beam axial displacement for all tools of different suppliers supporting the international standard. Figure 3, *b* also shows the inserts and their dimensions indicated in accordance with ISO 13399, which are used in the Formula (2). Formula (2) demonstrates that it is firstly necessary to calculate the whole part of a product and then perform the other mathematical operations.

As is known, the tool insert manufacturers are guided by such standards as the AS9100. Therefore, the developed formula provides correspondence in the *PZ* parameter value in measuring different inserts of the same tool type. Table 2 presents measured distances from the thread mill insert top to the cutting edge top (PZ_1) on the tool preset device

Table 2

Measurement results

Insert catalogue designation	PZ_1, mm	*INSL*, mm	*TP*, mm	PZ_0, mm	ΔPZ, mm
MT LNHT 1202 I 1.50 ISO IC908	0.800	12.1	1.5	0.80	0
MT LNHU 1403 I1.00ISO IC908	0.508	14.0	1.0	0.50	0.008
MT14 E 2.00 ISO IC908	1.010	14.0	2.0	1.00	0.010
MT14 I 2.00 ISO IC908	1.011	14.0	2.0	1.00	0.011
MT21 E 1.50 ISO IC908	0.750	21.0	1.5	0.75	0

Values were computed by the *PZ* parameter of Formula (2). Difference in the above ΔPZ values were computed by Formula (3) for different insert sizes:

$$\Delta PZ = PZ_1 - PZ_0, \quad (3)$$

where PZ_1 is the measured value parameter; PZ_0 is the calculated value.

According to data provided in Table 2, difference between PZ_1 and PZ_0 is not more than 0.022 mm, which confirms validity of the found formula for this tool type. Thus, the obtained formula application makes it possible to exclude the previously measured PZ value for the used thread mills on a presetter due to possibility of calculating this value. This method automates the thread mill measurement process on a CNC machine and increases accuracy in the measurement results. These results could further be used in development of the cutting tools database to generate the NC programs.

Discussion of the results obtained. These days, there are a lot of cutting tool wear measurement methods. Nevertheless, not all these methods could be adapted to perform the cutting tool control in the manufacture conditions on a regular basis. It should be noted that many methods are not fully automated, and, therefore, they are unreliable, time-consuming, and take a lot of machining time [18].

The existing cutting tool control systems are based in most cases on application of several types of sensors in the cutting process and are related to the signal processing methods. Multiple sensor application greatly increases the control system cost, and also involves additional maintenance, which could be implemented effecting its use. It should be noted that many cutting tool wear control systems require development of complex mathematical models, while they are not always sufficiently reliable in the results [19]. Many systems are not adapted sufficiently to alterations in processing the technological characteristics due to the use of inaccurate algorithms. Therefore, development of a simple and economical system to monitor the thread mill state with a minimum number of installed sensors and high efficiency is relevant [20, 21].

Automated tool measurement and correct tool zero-point determination on a CNC machine could be provided by the contact tool measurement sensor (system) and the non-contact tool measurement system. However, it is necessary to consider a number of the thread mill measurement features on these systems. Contact tool measurement sensors work in touching the tool with a sensor on a specific segment; i.e., they are not suitable in regular measurement and in several separate points control of the thread mill cutting edges. On the contrary, the laser system operation is to measure the tool using a laser beam at several points. It should be also noted that the tool is scanned by the laser system at certain points determined by the special machine tool measurement program, namely, by the tool measurement cycle. The tool measurement point incorrect determination in that system leads to the erroneous measurement results, as well as to operation errors in the laser system.

Summary. The paper proposes an active control method; it is developed on the thread mill active control algorithm on the CNC machine using the non-contact tool measurement system. The thread mill active control is ensured by measuring the tool dimensions at the beginning and at the end of the machining step according to the tool measurement program adapted to the tool features. The tool measurement program controls the thread mill edge wear and allows identifying the tool breakage. The contactless changed system smooth operation is ensured by substituting values calculated according to the developed formula in the tool measurement program. Possibility of using the laser tool control system without additional measurements outside the machine was proven.

The above method allows automating the thread mill measurement mechanism on a CNC machine; and, therefore, contributes to accuracy in the thread manufacture. This method is also universal due to using the traditional machine measurement systems. Besides, it could be adapted to operate with other types of tools and the non-contact tool measurement systems.

Implementation of the presented method provides the following results:

– exclusion of manual data in entering the cutting tools;

– increase in manufacture efficiency and waste reduction;

– equipment autonomous operation without additional installation of expensive sensors onto the machine, even when the machining technological characteristics are changing;

– just-in-time active tools control and measurement on the CNC machine;

– product manufacture automation with the exact dimensions.

Main advantage of the recommended approach lies in avoiding the necessity to install additional sensors in the CNC machine. In addition, the proposed method could be used to obtain the data required in constructing predictive models of the cutting tool wear [22]. Applications of these models are able to simplify the technological processes planning aimed at reducing the risk of loss of the cutting tool working conditions at the machining stage.

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Please cite this article as:

Andreev Yu.S., Basova T.V. The development of active control method of thread mills. *Herald of the Bauman Moscow State Technical University, Series Instrument Engineering*, 2024, no. 3 (148), pp. 91–103. EDN: YZXMCR