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# Standard accuracy tests of machine-tools prognosis in their state

Key words

Machine-tool, technical state, accuracy test, diagnosing, prognosis.

Słowa kluczowe

Obrabiarka, stan techniczny, badanie dokładności, diagnozowanie, prognozowanie.

Summary

The main goal of machine diagnostics is their state determination, prognosis, and discovering its origin. All the three above-mentioned phases are necessary for proper operation of this important group of technological machines. In order to carry out these tasks, new methods have been constantly searched for. In this paper, there is presented a new approach to machine-tools state prognosis, based on their accuracy tests. Base on the cycle of standard diagnostic tests, the history of diagnostic symptoms, necessary for the phase of the state prognosis, is being created. The same, constant testing conditions enable observation and comparison of the machine state changes in time and, on this basis, prognosis of its further operation. Algorithm activities that make it possible to work out the state prognosis have also been shown. The procedure proposed in this paper extends the set of diagnostic tools (in the field of prognosis) for the numerous and undoubtedly important group of technological machines which make up machine tools.

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## 1. Introduction

Machine tools belong to one of the groups of technological machines that are commonly used in virtually all branches of industry. The widespread application of these machines makes their diagnosis an essential problem, and their accuracy tests are a fundamental element of machine-tools diagnostics. The above-mentioned arguments make this group of technological machines the subject of numerous investigations and technical analysis.

The main purpose of diagnostic investigations of all technical objects, including technological machines, is assessment of their current technical condition. Moreover, they should make it possible to establish causes of this condition and its prognosis. The last of the mentioned phases (prognosis) requires to be familiar with the results of diagnostic investigation history and allows for estimation of the machine reliable operation time and/or the value of work to be executed by the machine in the future, in terms of assumed units (number of elements, their value, volume, etc.). Thus, prognosis is a diagnostic element of great importance, indispensable for taking decisions concerning the machine future.

In the paper, study on application of the machine-tool accuracy tests, as the basis for prognosis of the machine condition, have been carried out. Many elements, common to diagnosing and the above tests, confirm hypothetical possibilities of the above mentioned tests applicability for diagnostics, especially the operational one.

## 2. Quantities describing machine tool condition

Considering the machine tool as a whole, it is possible to identify several functional units in its structure [1]. Technical states of all units affect the machine tool efficiency, but this influence also depends on different factors, e.g., the kind of the machine tool, and its structure complexities.

Taking into consideration the destination and functions of the machine tool basic units, it is possible to establish the hierarchy of their importance. According to diagnostic criteria, it is as follows:

- body – bearing unit,
- fixed headstock, and
- tool moving element.

These elements exist in all kinds of machine tools, and they directly affect the machine tool work efficiency, including dimensional accuracy of the machined element.

The quantities essential for the description of the machine tool current technical condition are different for each of the mentioned unit. They are useful for the machine tool diagnostic process, as well as for their particular units.

The first of the above is the machine tool bearing unit. It can have the form of body, frame or another constructional form. Here are the basic features required from a well-constructed body:

- stiffness, understood as resistance against external forces,
- invariability of dimensions – heat and time resistance .

Because stiffness of the body, made of a definite constructional material, depends mainly on its geometrical constructional features (suitable sections of sides, reinforcements in places where large loads occur), they are to be specified in the processes of design and construction. However, the manufacture process is essential for ensuring these features; because the material structure (in the case of cast body), as well as, strength of the body links made of welded elements are effects of activities done in this particular stage of the product existence.

Nowadays, the machine tool body usually consists of a set of elements. They are joined in a temporary or permanent way and create a spatial structure in the form of, e.g. a frame. It results mainly from optimisation of the body structure, according to technological criteria. In such a case, stiffness of the whole unit additionally depends on joints – their stiffness and their features durability (effectiveness of connection).

Another desirable feature of the body elements – dimension invariability, which is defined in relation to temperature and time, is developed in the stage of design. It is carried out by selection of a material that fulfils the above-mentioned requirements, but also by taking into consideration other factors, resulting from, e.g. structural and operational assumptions.

The above presented features of every technological machine body are basic quantities, which determine accuracy of elements produced by these machines, thereby the quality of the whole machine, in which the body structure exists. Therefore, these quantities can be considered as diagnostic elements for designing and constructing the process stages, that is, elements of constructional diagnostic [7].

Second of the mentioned functional units, fixed headstock, is of great importance for the machine tool technological capacity. It is intended for transmission of the moment from the drive source to the work-piece or/and to the tool in the final fragment of the machine tool kinematic chain, and for setting the work-piece or the tool in rotary motion. It determines directly the kind of machining and its efficiency, which possible to be realised with the use of the particular machine tool, and indirectly – the quality of machined elements.

The tasks realised by the spindle unit determine quantities essential for its proper operation. In terms of the machine tool accuracy diagnosis, the following features should be considered as the most important ones:

- rotational speed of spindle,
- its motion accuracy, and
- stiffness of the unit.

The boundary rotational speed, which can be reached by the spindle, as well as accuracy of this rotational motion, largely depends on bearing nodes. The kind of applied bearings (sliding, rolling), type (hydrostatic, hydrokinetic, ball, roller, etc.), and the structural variation (transverse, angular, axial, one- or multiple-row) determine correct operation areas for the bearing nodes and, thereby, for the whole fixed headstock.

In the case of rotating shafts, their run-out is the function of the support stiffness and of unbalance, resulting, among others, from machining deviations. To minimise the unfavourable influence of radial and axial run-out on the machined element accuracy, the machine tool fixed headstock is supported by means of spindle bearings belonging to a group of special bearings. Compared to typical bearings, they are characterised by higher boundary rotational speed and stiffness. These features are obtained as a result of application of other materials (smaller density), and the greater accuracy of the bearing elements [3]. These features of machine tools are formed in the design stage, so it is possible to consider them as other elements of constructional diagnostics.

The necessary condition for machining with the use of machine too1s is the too1 movement in relation to the workpiece. Depending on the kind of machine tool, the movement is realised by the tool or work-piece. In special cases both movements occur simultaneously. This kind of kinematics makes the unit that moves the tool or/and work-piece so important for the machining process. The following diagnostic features can be accepted for assessment of the motion parameters:

- stability of speed (its uniformity),
- accuracy of unit movement along the assumed trajectory, and
- motion resistance.

The satisfactory level of these factor values can also be obtained by applying rolling guides. Apart from the above mentioned motion features, these guides are characterised by great stiffness. They also satisfy (greater than sliding guides) durability.

Analysing operation of the unit that moves tools or/and work-piece in terms of the whole machine tool diagnosis, it is possible to accept deviations of the real dislocation track from the nominal one as diagnostic signals. Operation of this unit and the fixed headstock has a very strong influence on the final effects of machining and the final product accuracy.

## 3. Diagnosis of the machine tools state

The state of the machine tool functional units has a direct influence on their machining capabilities, both in terms of the machined element accuracy and machining efficiency. Since the first of the mentioned aspects is particularly significant, great importance is attached to this scope of the machine tool investigations. In order to unify requirements to be fulfilled by machine tools manufactured by different producers, and enable their comparison, accuracy tests procedures have been standardised. They are contained in national norms, e.g.: [2] and international ones e.g.:[1]

For full diagnosis of the machine tool accuracy, one should specify standard features of their state. Primarily the following:

- geometrical parameters of the machine as the whole,
- accuracy of displacements of particular functional movable units of the machine tool,
- stereometric parameters of workpieces machined in specified conditions and their comparison with nominal values (these tests are so-called "test by work").

The two first groups of the above mentioned geometrical measurements involve examining dimensions, shapes, positions, and relative movements of the basic machine tool units and their component elements with reference to nominal lines and theoretical surfaces. Results of these investigations can undoubtedly make up a set of tools for machine tool quality assessment. For diagnostic purposes, these results are of smaller importance, because they are not always directly reflected by the work-piece accuracy, and deviations can add up or subtract, warping the assessment.

The third group of machine tool investigations – test by work – is of a different character. During these investigations, the test pieces are machined and then the machining effects are analysed. Consistence of the obtained values of geometrical constructional features is compared with their expected (nominal) values. The structural forms of the test pieces are different for particular kinds of machine tools, and their dimensions are not precisely specified. Norms often contain ranges of dimensions they should stay within.

Fig. 1 presents the shape and the most important dimensions of a test piece for test by work in a milling-machining centre. Indispensable measurements for checking geometrical features carried out for these kinds of objects are presented in Table 1.

There are more and more technological machines of this kind in stocks of machinery of plants in every branch of industry, because they combine machining capacity of several different types of simple machine tools. Therefore, the structure of a machining centre and trajectories of relative movements of tools and work-pieces are complex. The mentioned factors cause that the sample object is geometrically more complicated than for machine tools which realise only one basic type of technological operation (lathe, milling machine, grinder, etc.).

The tests should make it possible to measure all the dimensions important for accuracy assessment of machining realised by means of the centre. The measurement results should be useful for diagnostic inference concerning machine tools whose total machining capacity is equivalent to the capacity of the centre.

Table 1. Setting-up of measurements of machined fragments of the test piece
Tablica 1. Zestawienie pomiarów obrobionych fragmentów przedmiotu próbnego, wg [2]

| Item | Measured fragments of object | Kind of measurement |
|---|---|---|
| 1 | Central hole | • cylindricity<br>• perpendicularity of axis of hole to base A |
| 2 | External square | • rectilinearity of sides<br>• perpendicularity of adjacent sides to base B<br>• parallelism of opposite side to base B |
| 3 | Upper square (15°) | • rectilinearity of sides<br>• accuracy of angle 75° in relation to base B |
| 4 | External circle | • roundness<br>• collinearity of external circle and central hole |
| 5 | Slant surfaces (3°) | • rectilinearity of foreheads<br>• accuracy of angle 3° in relation to base B |
| 6 | Deepened holes | • position of holes in relation to base C<br>• collinearity of deepened holes and central hole |

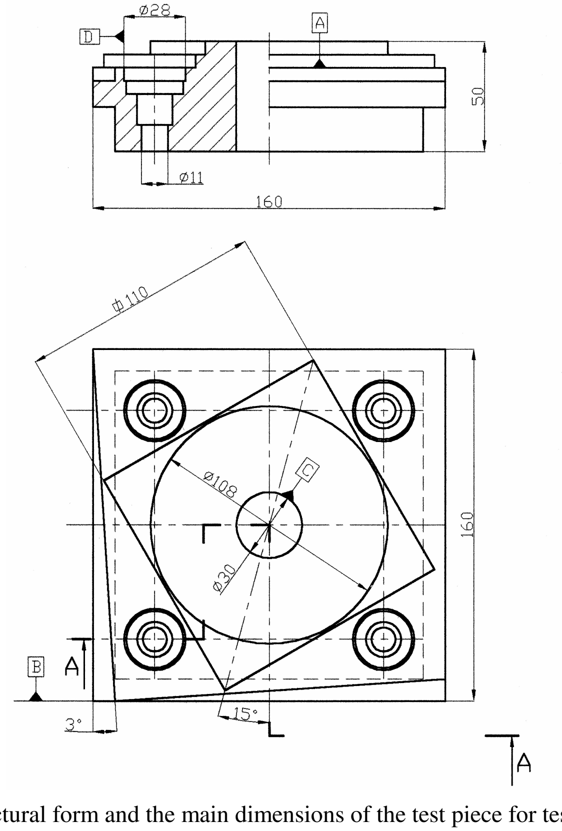


Fig. l. The structural form and the main dimensions of the test piece for testing the milling machining centres accuracy with marked processing bases
Rys. 1. Postać konstrukcyjna przedmiotu próbnego do badania dokładności centrów obróbkowych z zaznaczonymi bazami obróbkowymi [2]

Values of individual dimensions showed in Fig. 1 have different numbers for different dimensional variants of machine tools; their mutual relationships are also different. The mentioned standards also contain permitted values of deviations for dimensions obtained as a result of machining.

Conditions for machining test pieces for different machine tools are also given in the quoted objective standards. Moreover, Standard [1] contains information concerning preparation of the machine tool for tests, as well as the method of carrying out the measurements. This information, together with measurement results, is indispensable for assessment of the machine tool's current state, thereby for the accomplishment of the basic operational diagnostic tasks *(BODT)* [4]. Moreover, in order to make a prognosis of the machine tool for further operation, information on the course of occurring phenomena is necessary, which is the "history" of the diagnostic signal [6].

Results of machine tool accuracy investigations are considered in a bivalent system: good – bad. First case (good) takes place, when between measured (real) deviation $T_{real}$ and permitted deviation $T_{adm}$ there occurs the following relationship:

$$T_{real} < T_{adm} \tag{1}$$

In case the opposite situation occurs, that is, when:

$$T_{real} > T_{adm} \tag{2}$$

we have to do with run-time error, that is, a faulty object.

Results of these investigations can be used for diagnostic purposes. On the basis of the obtained results, it is possible to define the machine tool technical state [6]. In the first case, when condition (1) is fulfilled, the machine tool is in a good state; however, in the second state, according to condition (2), the machine is in a state in which realisation of the assumed tasks is not possible. This is true unless different causes of incorrect machining occur, such as, inappropriate features of the machined element, or the work-piece has inappropriate fastening. On the basis of the sample object dimensional deviations, it is also possible to assess the states of the machine tool's particular functional units. For example, after having machined the object on the machining centre, there have been found (Fig. 1) great deviation values of the perpendicularly of planes will reflect inaccuracies of the unit that moves the tool in relation to the work-piece, which can be caused, e.g., by excessive clearance in the machine tool guides.

Found deviations of the edge rectilinearity or the surface flatness (Item 5) will reflect wear of the guide elements.

Obviously, the discussed examples of diagnostic inference do not exhaust the diagnostic possibilities of application of accuracy tests results. Nevertheless, on their basis, it is possible to confirm, being familiar with constructional solutions applied in the tested machine tool, as well as its operation rules, and they are indispensable for effective diagnosis.

## 4. Prognosis of the machine tool state

It has already been said, apart from assessment of the machine's current (temporary) state, diagnostic activities should also involve predictions concerning two basic problems:

- time of the machine further efficient work, and
- time of next diagnostic investigations.

Because diagnostic assignment is a sequence of the following activities (see Fig. 2):

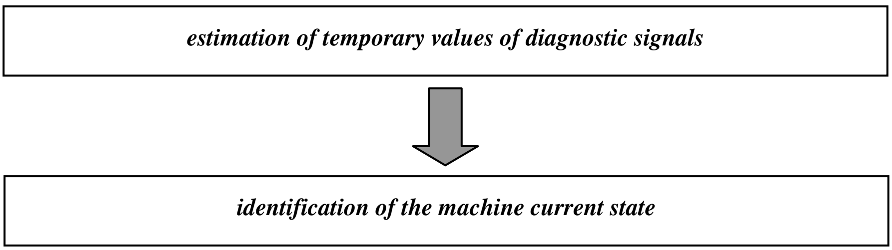


Fig. 2. Sequence of activity indispensable for realisation of *BODT*
Rys. 2. Sekwencja działań niezbędnych dla realizacji PZDO

Then, taking into consideration prognostic tasks for diagnostic purposes causes that the above mentioned sequence is extended by additional elements – Fig. 3:

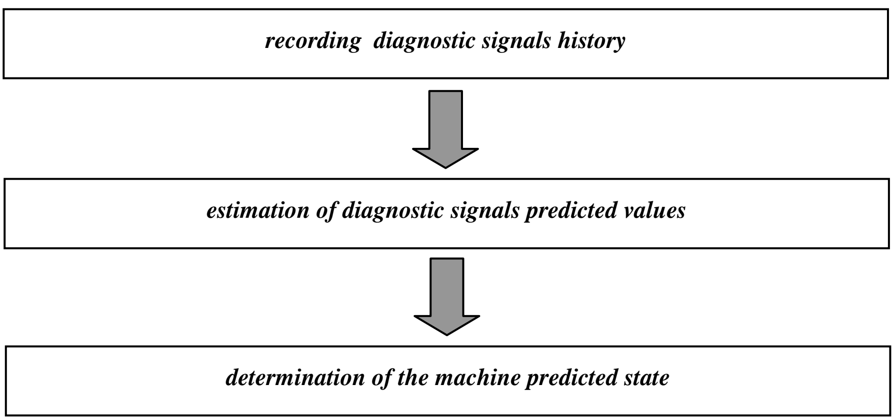


Fig. 3. Sequence of diagnostic activities in prognosis
Rys. 3. Sekwencja diagnostycznych działań prognostycznych

Realisation of the above-mentioned sequences is possible using the introduced investigations of machine tools accuracy. The first demands the realisation of one set of investigations; however, in the second case, it is necessary to carry out a cycle of tests with their established regularity, so that on the basis of the results analysis, diagnostic inference can be extrapolated on the basis of the analysis of results.

The algorithm of activities enabling the machine tool state prognosis, using BODT series, which in this algorithm are the elementary link, is demonstrated in Fig. 4.

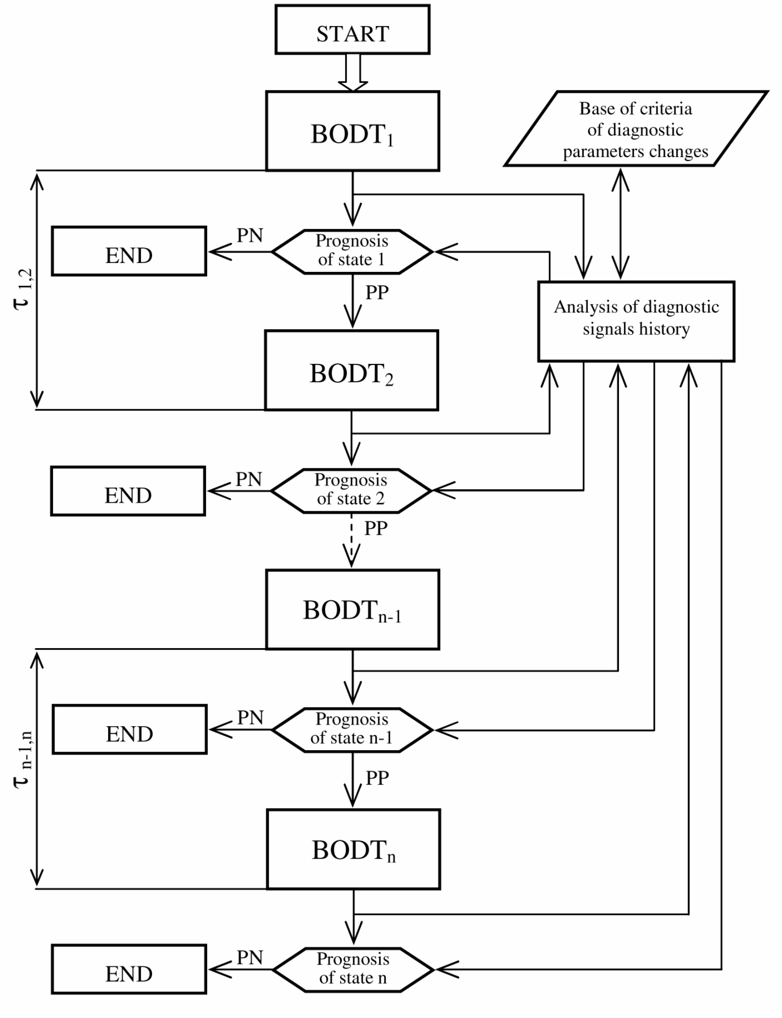


Fig. 4. Algorithm of prognosis activities using BODT (*PP* – positive prognosis, *PN* – negative prognosis)

Rys. 4. Algorytm działań prognostycznych z wykorzystaniem PZDO (PP – prognoza pozytywna, PN – prognoza negatywna)

Taking into account the variety of external loads acting on machine tools, it should be assumed that, for every kind of technological machines (lathe, grinder, etc.), the frequency of BODT is different. Moreover, on the basis of knowledge on mechanisms of typical wear processes, it is possible to conclude that this frequency in whole cycle should be different. It should be smaller in the initial stage of the process of machine tool operation and greater for its final stage. Therefore, the following relation occurs:

$$\tau_{1,2} > \tau_{2,3} > \ldots > \tau_{(n-2),(n-1)} > \tau_{(n-1),n} \qquad (3)$$

Time between the succeeding BODT is fixed on the basis of an analysis of the diagnostic signal history in which the criteria set of quantity changes, accepted as diagnostic signals, is taken into account. The time is fixed in such a way that, after appointed time $\tau_1$, the predicted values of monitored parameters do not exceed permitted values, so the first condition (1) is fulfilled.

If the value of a single analysed parameter slightly exceeds the permitted value, it is possible to shorten the time, so that the above mentioned condition will be fulfilled.

The prognosis is developed according to an established procedure and on the basis of an analysis of diagnostic signal changes. If after time $\boldsymbol{\tau_I}$, justified in terms of technology and economy, the value predicted for the parameter is higher then the permitted one, then the state prognosis is negative (NP) and the machine tool operation phase is finished (END). In such a case, a decision concerning its further destination is to be made – repair or dispose of it. In the opposite case, that is, for a positive prognosis (PP), the machine tool is continued to be used until the next BODT realisation.

## 5. Conclusions

The carried out considerations on the machine tool accuracy investigations prove their great usefulness (including prognosis) for operational diagnostics. The values permitted for deviations of the test piece geometrical constructional features that can be accepted as boundary values of the machine tool state symptoms can be found in standards. They make it possible to assess the machine’s current state and its usability for machining.

Uniform conditions for test cycles enable observation and comparison of the state changes in time, and this is one of factors necessary for the prognosis of the process of further operation. Together with criteria of changes of the observed symptoms, they can create the basis for holistic diagnosis. The developed procedures extend the set of diagnostic tools, which is of great significance, as machine tools make up a numerous and a very important group of technological machines.

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**Znormalizowane badania dokładności obrabiarek w prognozowaniu ich stanu**

S t r e s z c z e n i e

Podstawowym celem diagnostyki maszyn jest przede wszystkim określanie ich stanu, lecz także prognozowanie i genezowanie tego stanu. Wszystkie trzy wymienione fazy są niezbędne do racjonalnej eksploatacji tej ważnej grupy maszyn technologicznych. Z tego powodu ciągle poszukuje się nowych metod realizacji tych zadań. W artykule przedstawiono nową koncepcję prognozowania stanu obrabiarek skrawających na podstawie badań ich dokładności. Na podstawie cyklu znormalizowanych badań diagnostycznych tworzy się historię sygnałów diagnostycznych, niezbędną w fazie prognozowania stanu. Jednakowe, stałe warunki badań pozwalają obserwować i porównywać zmiany stanu maszyny w czasie i na tej podstawie prognozować dalszy proces jej użytkowania. Przedstawiono algorytm działań, które umożliwiają opracowanie prognozy stanu. Zaproponowana w pracy procedura rozszerza zbiór narzędzi diagnostycznych (w zakresie prognozowania) dla obszernej i niewątpliwie ważnej grupy maszyn technologicznych, jaką tworzą obrabiarki skrawające.