Technical diagnostics of gear hobbing technological system on diagnostic signs of deviations of tooth profile of gears

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Abstract. The article reveals the main provisions of technical diagnostics of gear hobbing machine system with CNC on the diagnostic parameters of the profile of the sides of the teeth. The scheme of embedding diagnostic processes in the cycle of improving the quality of manufacture of gears. The developed scheme is universal and applicable to any gear processing operations. It consists of several successive steps – the evaluation of indicators relative to the limit values, the identification of the technological structure of the profile errors and the identification and analysis of diagnostic deviations of the profile of the lateral surface of the teeth, indicating. Each step of the improvement cycle is necessary to determine the negative factors of the process leading to a deterioration in the quality of manufacture of gears. Application of technical diagnostics profile diagnostic indicators allows to detect deviations of the technical condition of machine components, adjustment or tuning machinery. Diagnostic indicators are identified for the most significant technological components of non-conforming errors of the profile of the sides of the teeth of the gear wheel. The advantage of this quality improvement scheme is that it is more efficient than traditional methods of statistical quality management.

Keywords: technical diagnostics, gear processing operations, profile errors, lateral surfaces of teeth.

1. Introduction
As a rule, technical diagnostics of machine systems consists in instrumental collection and analysis of information on various indicators of the technical condition of the machine system to determine the degree of compliance of its components with passport data.

In production conditions, methods for estimating the geometric accuracy of machine modules are widely used. Measurements are performed by traditional mechanical indicators, modern electronic or laser systems (Renishaw laser system (C-ALS)) [1,2]. According to their measurements, geometric deviations of machine modules, beating of mobile rotational modules are estimated. Another type of technical diagnostics is the evaluation of the performance of modules on vibration indicators. They are recorded by vibrodiagnostic complexes measuring the parameters of the vibration spectrum at selected measurement points or by strain gauges [3]. Special diagnostic methods are also used, allowing for a combined assessment of the technical condition of the geometric accuracy and positioning accuracy of the movable machine modules in idle conditions. This evaluation is performed by the coordinates of the trajectory change of the high-precision disk fixed in the spindle of the machine (system F. Ballbar
QC20-W). Technical diagnostics is carried out according to the equipment inspection schedules. Depending on the obtained values of indicators planned equipment maintenance – replacement of quick-wear parts of equipment of small, average or capital repair of equipment for the restoration of rails, replacement of lead screw, ball screws and other moving parts of the machinery. Note that compliance with the passport data of machine modules does not guarantee the quality of products. For example, the machine system corresponding to the passport data can be a source of inappropriate products in the event of deviations of quick-change clamping equipment or adjustment parameters, individual for different batches of parts. Thus, the planned procedures of technical diagnostics are not integrated into the processes of improving the quality of production.

Figure 1. Measuring and Computing Center Klingelnberg P 65 gear profile indicators (sheet 1). 1 – data measured gears, 2, 3 the profilograms and the table of the quantitative indicators of the profile of the teeth of the toothed wheels 4, 5 is a field of profilogram and the table of quantitative indicators of the profile longitudinal direction of the teeth of the toothed wheel, 6 – scale field profilogram in the longitudinal direction 7 – scale field profilogram in the transverse direction.
Production of complex engineering products is associated with the simultaneous provision of a complex of interrelated indicators of accuracy of machine parts elements. To reduce their variations, other methods of quality management are used, the application of which is possible by systematic measurements of the volume of output [4]. These methods include probabilistic and statistical analysis, various types of control maps, assessment of technological accuracy, etc. The result of their application are conclusions about the mood and stability of the process of formation of the measured indicator. If process index inconsistencies are detected, the actual cause of their nonconforming values remains undisclosed. To identify index inconsistencies, there is a need for unplanned additional studies, including the use of technical diagnostics. Thus, the methods of product quality management are not related to the processes of planned technical diagnostics [5,6]. Many modern studies are aimed at providing various individual indicators of the process of tooth processing and parameters of cutting tools by constructing models of varying degrees of compliance with the actual processes of shaping [7,8], without paying attention to the modeling of key indicators of the accuracy of the processed side surfaces of the crown depressions.

The errors of the involute profile are [9] error involute profile: the total error $F_{\alpha}$, directions profile $F_{H\alpha}$, the shape of the profile $f_{\alpha}$ and the errors of the longitudinal profile of the lateral surface of teeth: the total error $F_{L}$, longitudinal direction $F_{H\beta}$, shape of the longitudinal profile $f_{\beta}$.

The measurement of the geometric parameters listed above is performed by specialized coordinate measuring machines. The result of the process of measuring machines is a standard Protocol for measuring geometric accuracy indicators, the requirements for which are contained in the normative document (Figure 1).

A mandatory requirement of the standard for the measurement Protocol is the presence of profiles of the side surfaces of the tooth cavities in the end section and along the length of the tooth [9]. The Protocol also contains quantitative data on the amount of errors. The measured values of indicators are used by enterprise control services to assess the suitability of manufactured gears, but not for the more popular tasks of gradually reducing variations in the measured error values. The reduction of variations in the values of indicators is associated with their use for the purpose of organizing timely technical diagnostics of machine tools for gear milling.

2. Theoretical part

Consider the content of levels that allow for timely development of corrective and preventive measures to improve the efficiency of the process of technical diagnostics of gear milling machines. At the first level, standard measurements of manufactured products are performed. Product conformity assessment and accumulation of measurement protocols are performed. If the product is suitable and all indicators correspond to the maximum set, then level 2 is not used. If discrepancies are detected, the metrological structure of the measured errors of the profiles is constructed in accordance with the content of the second level (figure 3). The metrological structure is determined by the nesting of metrological indicators. The nesting of indicators can be estimated by the contribution of error values from one level to another. For example the contribution of longitudinal profile errors to the total side surface error can be found as a percentage based on the following relationship:

$$K_{L} = \frac{F_{\Sigma L}}{F_{\alpha} + F_{H\alpha} + f_{\alpha}} \times 100$$

where $F_{\Sigma L}$ – is the total error level of the profile on the side surface. Micrometer.

$F_{\alpha}$ – profile error; microns.

$F_{H\alpha}$ – angular error, mkm.

$f_{\alpha}$ – form error, mkm.

A signal for the implementation of the third level, which identifies diagnostic signs of deviations of the nodes of the gear milling machine. The signal for implementing the third level of analysis is that the contribution coefficient exceeds the threshold value. The threshold value is 70%. At the third level of analysis, the geometric parameters of the profilograms are analyzed, which reveals the most likely
operating negative technological factors that lead to deviations of the profile from the nominal position.

The advantage of the scheme for embedding technical diagnostics and quality improvement processes is to perform corrective actions only in case of violation of the metrological indicators structure, indicating the urgent need for their implementation.

![Figure 2](image)

*Figure 2.* levels of analysis of standard protocols for CNC gear measuring machines to reduce variations in profile error values in gear milling operations.

The scheme of embedding technical diagnostic procedures in the process of improving the quality of products is carried out taking into account the technological structure of the accuracy indicators is shown in figure 2.

It consists of several successive steps-the evaluation of the profile relative to the limit values, the identification of the technological structure of the profile errors by calculating the contribution factors of the components (figure 3) and the analysis of the profile on the diagnostic indicators signs of deviations of the tooth profiles. Each step of the proposed scheme consistently leads to finding inconsistencies and negative factors of the technological process in accordance with the degree of their importance. The improvement cycle is universal and applicable to both roughing and finishing operations.

Let us consider in more detail the content of the individual steps of embedding technical diagnostics procedures in the processes of product improvement. The implementation of the first step is to find inconsistencies profile indicators specified values. If they are detected, the second step of the scheme is activated. It consists in the calculation and evaluation of the significant coefficients of the contribution of errors.

The content of corrective actions is revealed by the presence of diagnostic signs of deviation from its nominal position in the profiles of the side of the tooth. The causes of the diagnostic features of the profile are known and well-defined technological factors [10]. For example, the presence of periodic waves involute profile indicates beating tool mandrel. In this case, the diagnostic features are the step and frequency of the wave sections of the diagram. The positive slope of the middle line of the profile indicates the presence of an anterior angle that distorts the profile of the cutter tooth in the main plane and leads to thinning of the tooth. Diagnostic signs in this case is the angle and sign of the angle of inclination of the middle line of the profile. To confirm the presence of the identified diagnostic features, graphical run-ins with changed tool profiles or trajectories are performed.
The identified and frequently occurring diagnostic signs are entered into the database of the corresponding working gear hobbing workplace. Additional features are contained in the reference data, manufacturers gear machining systems. The database is constantly updated and updated with the identified diagnostic indicators, which allows more effective corrective and preventive actions to improve the quality of manufacture of gears.

The authors have developed similar methods for other types of parts, based on the identification of diagnostic quality indicators of automotive components, which have shown high efficiency of product improvement [11].

3. Practical implementation

Let's consider an example of a practical application of the technique on the example of processing an oblique gear on a CNC gear milling operation.

On the first level of evaluation of conformity of values of the limit values identified disrepair of production in terms of error variances forms the involute profile error and the direction of the profile.

Then, at the second level, the metrological structure of indicators was determined, which revealed that the threshold level of 70% was exceeded for the profile shape error from 80 to 100 % for all six measured side surfaces of the teeth (figure 4A).

For deviations of the longitudinal profile, the threshold values are exceeded in terms of the direction error to values from 100% to 110% for four of the six measured side surfaces of the teeth (figure 4 b).

Exceeding the threshold values leads to the need to use a mechanism for identifying diagnostic indicators based on the profilograms available in the standard measurement Protocol.

In accordance with the diagnostic features given in [9], the following diagnostic feature was identified from the longitudinal profile profilograms – different angular inclination of the longitudinal profiles of the teeth of the toothed crown. The reason for this feature is a deviation from the perpendicular axis of the gear mandrel in different angular positions when rotating the table of the gear milling machine feed line of the worm cutter. The deviation can be eliminated by carrying out adjustment work to reconcile the position of the mandrel with hour-type indicators.

The reasons for the tooth thinning is the presence of front corners in the teeth of the milling cutter. The cause of undulation can be complex. This may be the presence of runouts of the cutter teeth on the mandrel, runout or contamination of the mandrel during adjustment, backlash in the feed mechanisms of the cutter.
Figure 4. Graph of changes in the profile error significance coefficients in the metrological structure of tooth profile errors a) the significance of the involute profile errors, b) the significance of the profile direction errors.

Figure 5. Profilograms of profiles a) of the involute profile, b) of the longitudinal profile.
Profilogram the involute profile (figure 5 a) revealed several diagnostic features: reduction in head-gear tooth on the left side, the waviness profile as on both the sides of the valleys, the inclined shape of the tooth profile on the left and right side.

The reason for the inclined shape of the tooth profile is the deviation of the cutter sharpening. It is possible that the mill is made or reworked with an error in the pitch of the helical line.

Thus, the reduction of variations in profile deviations is possible only after the above-mentioned reasons for the occurrence of diagnostic signs are eliminated.

4. Summary

The proposed method of identifying the content of corrective and warning actions allows for systematic identification of corrective actions to effectively improve the quality of cylindrical gears. The application of the method described in the article requires the company to introduce additional functions for the personnel of technical control services, as well as for the Adjusters of CNC gear milling machines. Introduction of registration of data of standard measurement protocols in a single information system, as well as maintaining a database of diagnostic features of profiles. The introduction of the method encourages the company to constantly improve the level of product quality in key operations of gear milling.

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