Phasechronometric performance data processing for lathe operation parameters monitoring

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Abstract. The article describes the problems of processing measuring phase-chronometric information in order to obtain information about the turning process. Similar techniques are used to monitor the current state of the cutting tool, optimize cutting conditions and control the correct operation of the machine. Also, a methodology for determining the parameters of the machine using the Pearson correlation coefficient.

1. Introduction
Modern machining technologies have embraced digitalization for a long time already. The analysis of the existing cutting-edge developments, for example, those described in DMG MORI TECHNOLOGY EXCELLENCE, the magazine of a leading machine manufacturer, demonstrates the relevance of continuous development and implementation of new solutions for obtaining additional performance data to optimize equipment operation. Among the most relevant directions of such developments today are systems of cutting tool wear monitoring, methods for optimizing cutting parameters to improve machining performance at a required accuracy, as well as diagnostics of abnormal equipment operating modes (improper workpiece fastening, exceeding the maximum cutting power, etc.). The solution to these problems is primarily associated with innovative digital performance data processing techniques.

2. Method
Based on continuous measuring of time intervals between the phases of a machine or mechanism working cycle, the phase-chronometric method [1-3] is considered as a tool for obtaining additional machine performance data (Figure 1).
This method measures $\delta t_1$ ... $\delta t_i$ time intervals corresponding to the rotation (displacement) of the machine running gear making the cycle, the machine spindle in the considered case, by a certain $\Delta \varphi$ angle (working cycle phase). Phase chronometry application history shows that the machine performance data can be obtained by measuring the time intervals of machine spindle rotation phases during processing. The rotation chronogram, being a graphic representation of $\delta t_1$ ... $\delta t_i$ time sequence (the chronogram formation diagram is shown in Figure 2), contains information on the operation of all machine components, including the tool status.

This approach fundamentally differs from the amplitude measurement methods (vibration diagnostics, etc.), currently used in machine engineering, primarily by the accuracy of obtained performance data. Since frequency and time can be measured with the highest accuracy using modern devices, phase-chronometric systems are characterized by a relative measurement error of approximately $10^{-2}$ to $10^{-4}$ percent. Measuring channels of diagnostic systems applied today are not able to reach this level of accuracy.
However, application of the phase-chronometric method in machining is associated with certain difficulties, including rotation chronogram processing issues. Time interval fluctuations are associated with the operation of all machine components, and here lies the advantage of phase chronometry. But, at the same time, identification of individual effects, for example, cutting tool wear, is a complicated task. Multi-factor mathematical models of the turning process are very time consuming and are virtually not applied in any diagnostic criteria identification methods. For this very reason, this study describes the processing of experimental data.

3. Results

To test the described phase-chronometric data processing method at the first stage of research, a testing rig has been assembled with an electric motor being a machine model. Previous studies [4] defined that rotation chronograms change under any external influence (for example, when switching from idle spindle to cutting). External influences have been modelled by introducing an unbalance and periodic shock effects on the electric motor shaft. Qualitative changes of chronograms have been recorded and explained [5]. Further, the Pearson correlation coefficient has been used to switch from qualitative to quantitative estimates. Its application allows greater stability and persistency of rotation parameters of the idle run chronogram. Additional manifestations occur on graphs only under external influences, while typical idle run fluctuations are preserved (Figures 3, 4).

![Figure 3. The chronogram of rotation at idle, 15 Hz.](image1)

![Figure 4. The chronogram of rotation for imbalance.](image2)

The stability of idle run parameters has been confirmed by calculating the Pearson correlation coefficient [6,7] for 11 series against each other: 1 and 2 series, 2 and 3 series, etc. Each series contained 10,000 values (2 shaft revolutions). The result is shown in Diagram 5:
Figure 5. Pearson correlation coefficients, rotation at idle.

The values demonstrate a high correlation level being close to unity.

Let us also consider the cross-correlation (Figure 6) of the idle run and testing rig operation with artificially introduced unbalance (load displaced relative to the shaft's longitudinal axis). The results considerably differ from those shown in Figure 5.

Figure 6. Pearson correlation coefficients, rotation with imbalance.

The correlation degree decreases proportionally to the disturbances observed in Figure 4 compared to Figure 3.

Since the Pearson correlation coefficient applies only to data with normal distribution, an analysis has been performed by finding the mean absolute deviation (Figure 7). The obtained mean absolute deviation value equals 0.018, which confirms that the Pearson coefficient can be applied for the considered case.
4. Conclusion
Such a processing method can be used for more complex technical systems, including lathes. The following performance data processing procedure can be proposed for complex systems. The data processing algorithm is calibrated using the calculated idle run correlation coefficients. Further deviations of the idle run parameters from the calculated Pearson correlation coefficients for the previous series data relative to the current series indicate external influence on the machining system. The degree of external influence can be determined using neural network algorithms.

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