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The System of Accuracy Control on Lathes

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Abstract: The article describes a new fault detection system for metalworking machine-tools of the second generation. The system includes 4 contactless motion sensors for shaping trajectory measuring and 1 spindle rotation angle fixing sensor. The developed “Lagrang” software processes the sensor signals, calculates and plots the geometric image of the machined surface of the workpiece in the cross and longitudinal sections. It also calculates reference circle according to DIN ISO 1101 and evaluates accuracy parameters of the machined surface in the cross and longitudinal sections.

Keywords: Shaping trajectory; geometrical image; accuracy parameters

1 INTRODUCTION

The experimental research of the shaping process on lathes has been carried out in MSTU “STANKIN” for 15 years so far [1-11]. At present a fault detection system of the second generation has been developed with the help of «Lagrang» software.

The experimental research was carried out in the real time and under real cutting conditions. A premachined bush made of steel C 35 which was fixed in a precision mandrel was used as a workpiece. The cutter with a carbide plate T15K6 with the sharpening angles $\phi = 45^\circ$; $\phi_1 = 45^\circ$; $\gamma = 6^\circ$; $\alpha = 6^\circ$ was used for the processing. Both roughing and finishing were carried out, the spindle rotational speed was measured $n = 60 \div 975$ rpm, the depth of cut $t = 0.1 \div 1.0$ mm, the feed $S = 0.1 \div 0.15$ mm per revolution.

2 EXPERIMENTAL UNIT

Fig. 1 shows the diagram of the experimental unit. The lathe spindle holds the precision mandrel 6, whose ovality and outrun are not more than 0.2 microns. The mandrel holds the workpiece processed with the cutter 3 fixed in the toolbox 7.

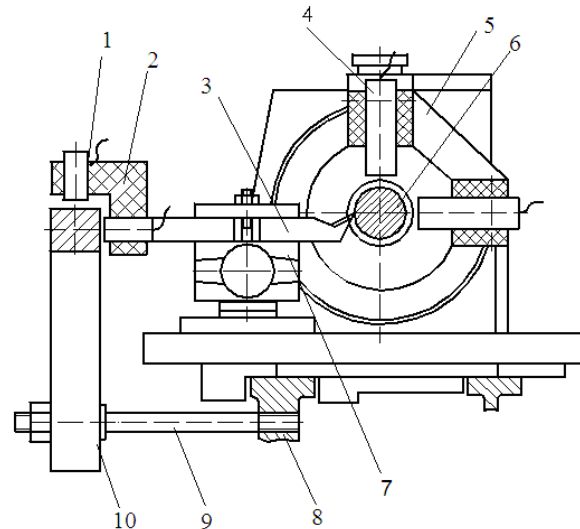


Fig. 1. The diagram of the experimental unit

The headstock and the bed 8 hold the bracket 5 with two eddy current probes 4, whose tips contact with the mandrel 6. The probe axes are mutually perpendicular, one of them lies in the plane passing through the tool point. The probe signals are transmitted to the computer by means of the interface. The precision ruler 10 is fixed to the lathe bed 8 with pins 9, and the toolbox 7 holds the bracket 2 with two probes 1. The latter contact with the ruler 10 and record the movement of the tool

point. The signals from these probes are transmitted via the interface to the computer as well. In addition, the angular movement sensor is connected to the spindle.

While cutting the workpiece the computer sends a

command to start recording the readings from the probes. Following signals were recorded: the signal from the basic point (БМ), the signal of the workpiece axis movement along X₃ and Y₃ and the signal of the tool point movement along X_p and Y_p (Fig. 2).

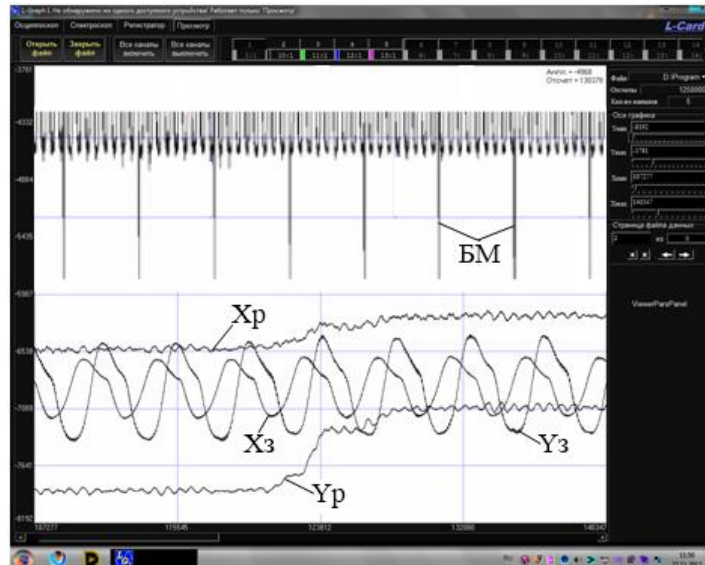


Fig. 2. The signals recording for the beginning of cutting

Three basic requirements were observed during the experimental research: a real cutting of a workpiece on a real machine-tool in the real time took place in the process of testing.

After the trajectory measurement data was sent to the computer memory, «Lagrang» program started processing it, which consisted in the following:

- 1) measurement array consisting of 40 revolutions of the spindle was taken;
- 2) 20 such arrays with equal intervals between them along the full length of the workpiece were taken;
- 3) movement data processing by means of mathematical statistics methods took place in each array;
- 4) averaged data was used to build workpiece axis trajectories (Fig. 3);
- 5) in the same way the cutting tool trajectory was built (Fig. 4).

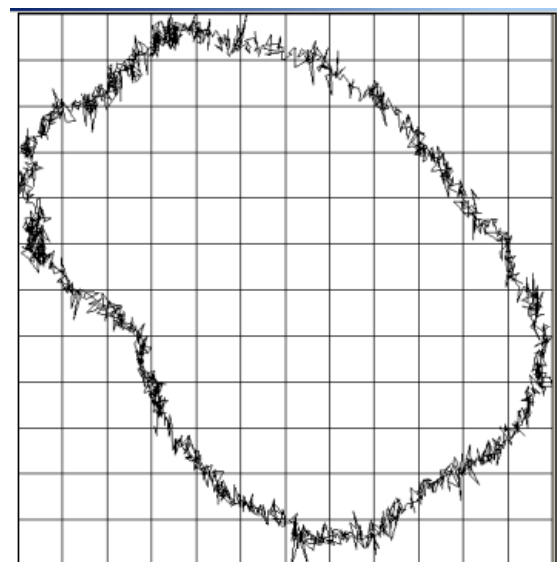


Fig. 3. Workpiece axis trajectory $n=975$ rpm, $t=0.6$ mm, $S=0.15$ mm/revolution

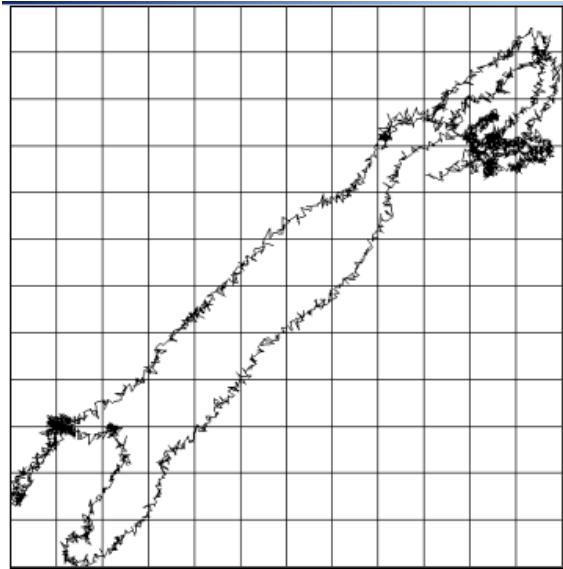


Fig. 4. The cutting tool trajectory $n=975$ rpm, $t=0.6$ mm, $S=0.15$ mm/revolution

3 THE METHOD OF GEOMETRIC IMAGE CALCULATION AND CONSTRUCTION

A formula for defining the distance between two points lying in one plane (Fig. 5) is used for mathematical modelling of the geometric image in the cross section:

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$$

Since the segment AP denotes an instant radius of the workpiece processed, the formula for it looks as follows:

$$R_{\Delta} = \sqrt{\left(\frac{D_{\Delta}}{2} - X_{\Delta i} + X_{p_i}\right)^2 + (Y_{\Delta i} - Y_{p_i})^2} \quad (1)$$

This equation is a generalized function of the geometric image in the process of lathe turning. After the workpiece axis trajectory (i.e. current X_3 and Y_3 , coordinates) and the cutter trajectory (i.e. current X_p and Y_p coordinates) are experimentally found according to the spindle rotation and substituted in the Equation (1), it is possible to define the shape of the surface being machined.

The «Lagrang» software evaluates and builds the geometric image of the machined surface in the real time (Fig. 6).

The flow-chart of the program is given in Fig. 7 and Fig. 8. The «Lagrang» software consists of 5 independent plug-in modules each of which can be used as an independent program which allows evaluating some parameters without launching the main program module. The software provides:

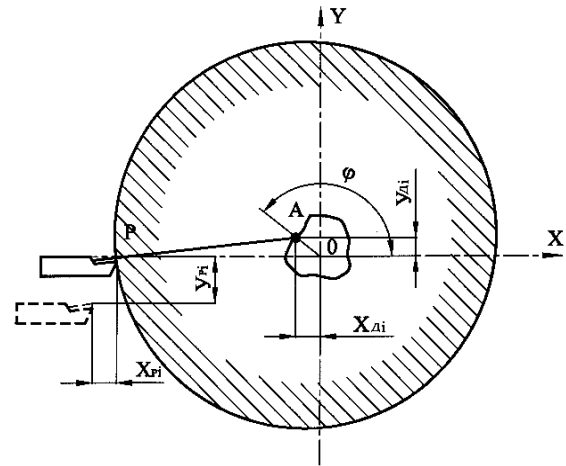


Fig. 5. Design model for defining the geometric image of the machined surface

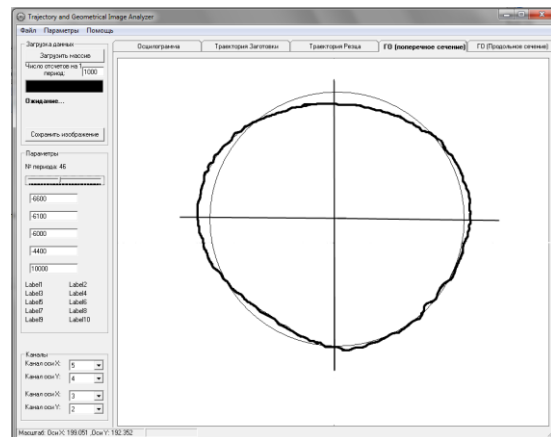


Fig. 6. Program interface of building the geometric image of the machined surface cross-section

- 1) the ability to import data from L – Graph program supplied with the analog-digital converter L – 761;
- 2) program setting;
- 3) imported data processing with the help of mathematical statistics methods;
- 4) building trajectories of the selected section as well as of all the 20 sections simultaneously along with the ability to view the current X and Y coordinates and radius-vectors;
- 5) the ability to evaluate and build a geometric image of the workpiece cross-section;
- 6) the ability to evaluate and build reference circle basing on the geometric image of the workpiece cross-section with the further definition of the regulated accuracy Fig. 5 of the machined surface.

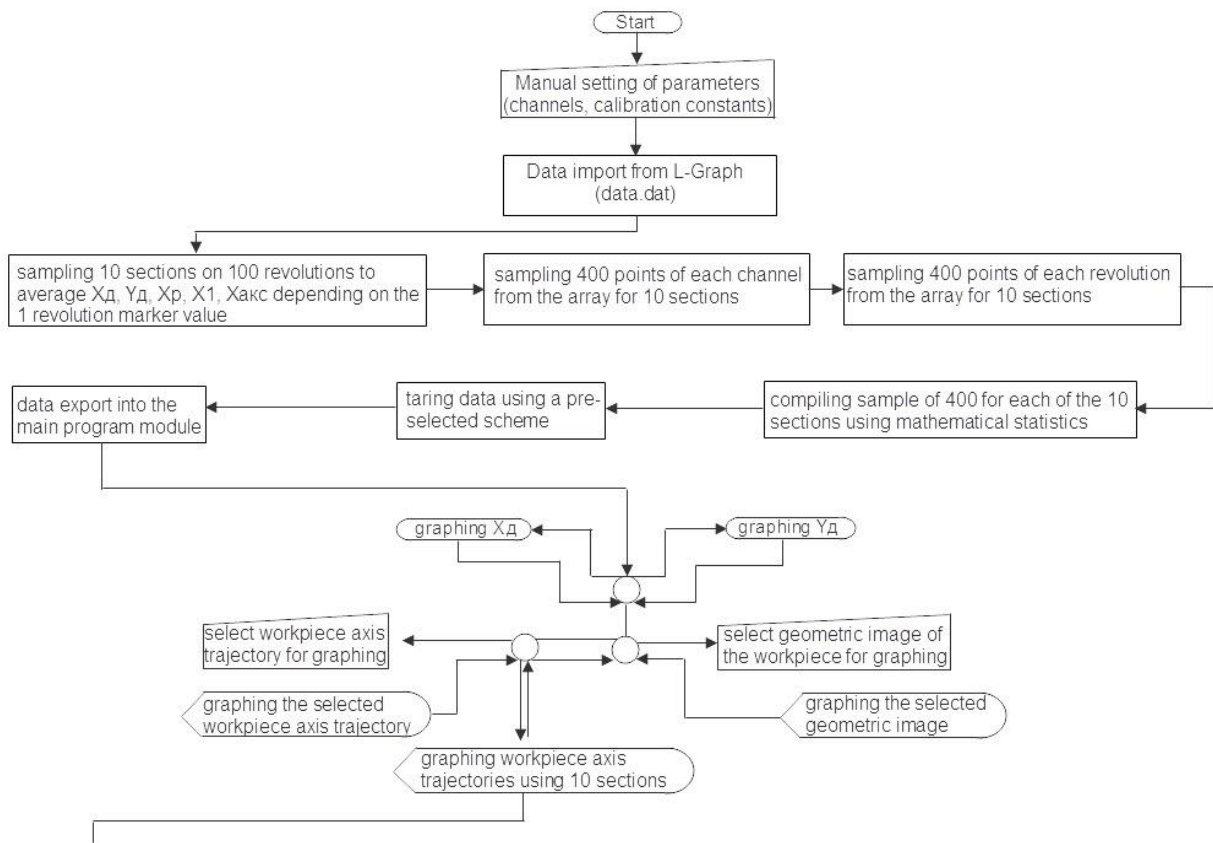


Fig. 7. Flow-chart of the «Lagrang» software

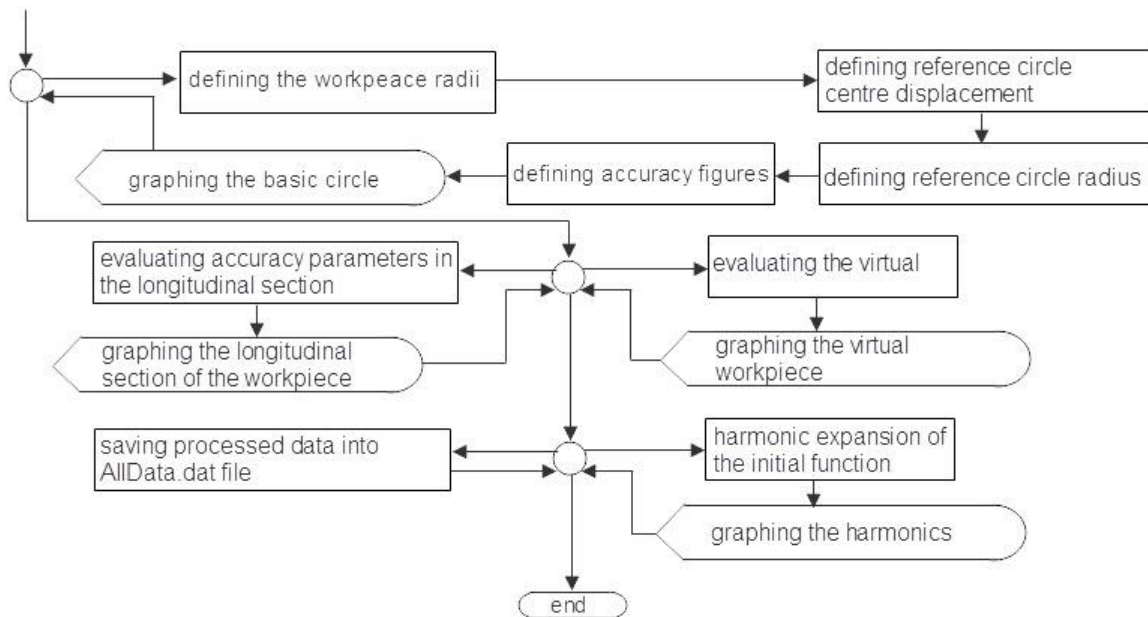


Fig. 8. Flow-chart of the «Lagrang» software (continuation)

The «Lagrang» software is designed in Borland C++Builder 5 programming environment. It was chosen due to its compatibility with most of the modern PCs. To simplify processing functions a programming mode using VCL (Visual Component Library) components was chosen, which eliminates the need of manual programming the elements of control.

A special function contained in an additional DDL library was used in order to import data file from L – Graph program. L – Graph program records the data as a binary code with a special structure onto the hard disk of the PC. It complicates simple data reading, therefore to simplify and to speed up the process of data loading a function of parameters definition from a special DDL library was used.

- 1) workpiece axis movement;
- 2) cutter movement;
- 3) workpiece axis movement trajectories;
- 4) geometric image of the cross section.

In order to evaluate the accuracy parameters the reference circle is needed. DIN ISO1101 [12-16] standard gives recommendations to use four methods of defining it: MZC, LSC, MIC, MCC. At present LSC is most widely used in machine building practice. According to it, the reference circle radius is defined as the circumference with minimum sum of squares of the distances from the reference circle to the geometric image profile. The centre of the reference circle is defined by formula:

$$a = \frac{2 \sum_{i=1}^n X_i}{n};$$

$$b = \frac{2 \sum_{i=1}^n Y_i}{n}.$$

where X_i и Y_i are the current coordinates of the points lying on the geometric image; a is the reference circle centre displacement relative to the geometric image centre along X ; b is similar displacement, but along Y ; n is the number of the points in the geometric image graph. In the experiment discussed $n = 200$.

The reference circle radius is defined by the formula:

$$R_{\text{в.с.}} = \frac{\sum_{i=1}^n R_i}{n}$$

where R_i is the current geometric image radius of the processed workpiece.

The maximum $\max(R_i)$ and the minimum $\min(R_i)$ values of the current geometric image radius are taken from the R_i array. Their difference makes up the deviation of circularity of the processed surface cross-section:

$$\Delta_{OK} = \max(R_i) - \min(R_i)$$

Thereafter the diameters of the geometric image are evaluated:

$$D_i = R_i + R_{(i+100)}$$

The cross-section sizing error is evaluated by the formula:

$$\Delta_{\text{ПП}} = \max D_i - \min D_i$$

where $\max D_i$, $\min D_i$ are the maximum and minimum values of the geometric image diameter.

4 RESULTS OF THE RESEARCH

Other accuracy parameters for the processed workpiece can be evaluated in a similar way.

Testing of the control workpiece processing, cross-section geometric image graphing and the sequential metrological measurement of the processed surface were held in order to estimate the system of accuracy control on lathes and the processed surface geometric image graphing efficiency.

After processing on lathe the control workpiece was subjected to metrological testing. A roundness measurement instrument of the accuracy class 2, model 290, designed at “KALIBR” plant, was used for recording out-of-roundness profile. The instrument has a limit of the admissible radial error of 0.12 microns. Fig. 9 shows an out-of-roundness profile of one of the sections. 1-5 filter was used. Comparison of the cross-section geometric image and the out-of-roundness profile for the same section shows that they have a close convergence. Maximum difference between the geometric image and the out-of-roundness profile lines in the radial direction after their superimposition is not more than 1,8 microns. Arithmetical mean value of the deviations is 1,4 microns.

The system described is defended by a number of patents [6-11].

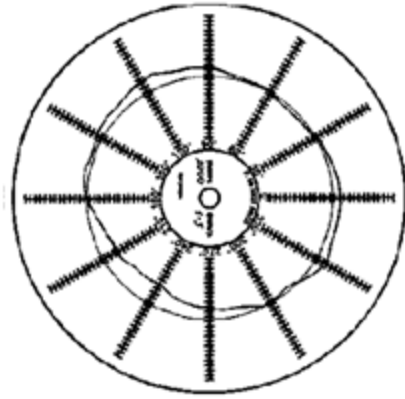


Fig. 9. Out-of-roundness profile of the control workpiece cross-section

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