Special automatic control system for the accuracy of processing axisymmetric workpieces

O I Drachev¹, B M Gorshkov² and N S Samokhina²

¹Togliatti State University, Togliatti, Russia
²Volga Region State University of Service, Togliatti, Russia

E-mail: kaf_ekis@tolgas.ru

Abstract. The article discusses a special automatic control system for the machining process as applied to metal turning lathe. In processing, generalized information about the precision parameters of the processing system is gathered that makes affordable to integrate four control loops into its system. The first control loop stabilizes the tool post body. The second control loop stabilizes the workpiece axis during cutting. The third control loop stabilizes the cutting edge and the fourth one stabilizes the tool-workpiece.

1. Introduction
The development is applied to machine-tool manufacture, especially to metal turning lathes, and can be used on automated metal turning lathes with adaptive systems.

There is a known method for automatic control of the processing of the workpiece that the position of the workpiece axis and the tip of the tool is automatically adjusted relative to an artificial gage length. To do this, measure the increment in the diameter of the workpiece to be machined and the position of the tool tip towards the artificial gage length and in the function of their measurement, a signal is generated to control the position of the tool tip and the axis of the workpiece on a predetermined artificial gage length [1]. However, the layout markings do not allow measuring the diameter and shape of the workpiece to be processed during the cutting. Furthermore, they do not control the dimensional depreciation and the mine hole wear, the elastic OX and OY axes’ travels of the tool tip and the frequency of chip formation. Lack of information does not allow to control the cutting process and the position of the "tool-carriage" and "workpiece-carriage" forming subsystems [2-10].

2. The relevance and purpose
The article discusses the technological process of processing axisymmetric workpieces. Serious technological difficulties arise in manufacturing during machining, their main reasons are as follows: significant elastic compliance and low vibration resistance, as well as different flexibility of the technological system elements. The deteriorating effect of these factors in the in manufacturing of parts of the "shaft" type leads to a violation of the processing datum surfaces, errors in the shape and size of parts, limitation of cutting conditions and, ultimately, to the decrease in the operational reliability of finished parts.
An experience of the individual, preproduction and manufacturing production of the shafts analysis showed that traditional methods of processing low-rigid long-length axisymmetric workpieces are counterproductive.

Consequently, improving the machining during the axisymmetric parts manufacture is an important task that increases the production efficiency and the quality of engineering products.

Improving the accuracy of machining workpiece accuracy enhances the operational properties of the metal turning lathe and devices and leads to the machining allowances decrease. That, in turn, reduces the labor intensity manufacturing parts and assembling machines, increasing their reliability.

The purpose of the work is increasing the accuracy, productivity and expand the technological capabilities of the metal turning lathe, using a special computer aided system machining accuracy.

According to the special computer aided system machining accuracy, the value of the dimensional depreciation, the tool back and surface where is the point of separation of the chips, the current diameter’s value of the workpiece in the plane traversing through the tip of the tool are measured additionally separately and simultaneously. The elastic cross and cross-rail travels of the tool tip control the change the slicing frequency of the chip formation process and separately generates a control signal proportional to the increment in the diameter of the workpiece from the dimensional depreciation. In the function of changing the elastic mechanical system the position of the support-prism relative to the artificial gage length is controlled, maintaining the relative position of the tool tip and the axis of the workpiece constant. In this case, simultaneously, as the function of changing the elastic mechanical system of the tool tip during the cross and cross-rail travels the feed rate changes, keeping the position of the tool tip and the workpiece axis at a given level. When the surface depreciation is reached, the decrease in feed upon reaching of the surface depreciation of the critical state is limited.

3. The key discourse. Special ACS operations

The technology of machining using a special automatic control system for the turning process is as follows: the value of the dimensional depreciation, the tool back and surface where is the point of separation of the chips, the current diameter’s value of the workpiece in the plane traversing through the tip of the tool are measured additionally separately and simultaneously; The elastic cross and cross-rail travels of the tool tip is measured and the change in the slicing frequency of the chip formation process is controlled. Separately, a control signal is generated in proportion to the increment in the diameter of the workpiece from dimensional depreciation and mechanical compliance of the elastic mechanical system as a function of increment in dimensional depreciation; The position of the self-centering rest (SCR) relative to the artificial gage length is controlled; At the same time, simultaneously, as a function of elastic displacements of the cross and cross-rail tool tip travels the amount of feed is changed and its decrease is limited when the surface depreciation is reached the critical state.

The figure 1 shows a functional flow diagram of a special automatic control system for the workpieces machining of the shaft type.

During processing the generalized information about the precision parameters of the technological system (TS) is collected that makes it possible to integrate four control loops into its system.

The first stabilization loop of the tool holder body includes the tool holder stabilization sensor 1, fixed on the tool holder body 2 structure, relative to the artificial gage length 3, differential-input amplifier 4, initial position sensor 5 of the electrohydraulic gear 6.

The second stabilization loop of the workpiece axis during the machining consist of the SCR 7, SCR initial position sensor 8, SCR indexing mechanism 9, SCR differential amplifier 10, SCR electrohydraulic gear 11, ultrasonic sensor 12 fixed on the tool, impulse generator 13, amplifier detector 14, modulator electrode 15, assembly test recording of the artificial gage length 16.

The third stabilization loop of the tip of the tool consist of, mentioned in the second stabilization loop, the ultrasonic sensor 12, impulse generator 13, amplifier detector 14, modulator electrode 15,
dimensional depreciation unit 17, differential amplifier 18, electrohydraulic gear 19 of the tool, initial tool indexing mechanism 20, initial tool inspection sensor 21 (cutting depth indexing mechanism).

Figure 1. Functional flow diagram of a special automatic control system for the workpieces machining of the shaft type:
1 – tool holder stabilization sensor; 2 – tool holder body structure; 3 – artificial gage length; 4 – differential-input amplifier; 5 – initial position sensor; 6 – electrohydraulic gear; 7 – SCR; 8 – SCR initial position sensor; 9 – SCR indexing mechanism; 10 – SCR differential amplifier; 11 – SCR electrohydraulic gear; 12 – ultrasonic sensor; 13 – impulse generator; 14 – amplifier detector; 15 – modulator electrode; 16 – assembly test recording of the artificial gage length; 17 – dimensional depreciation unit; 18 – differential amplifier; 19 – electrohydraulic gear; 20 – initial tool indexing mechanism; 21 – initial tool inspection sensor; 22 – cutting force contour sensor; 23 – amplifier detector; 24 – block for generating a control signal as a function of elastic displacements of the cutter tip; 25 – dimensional depreciation unit on the surface; 26 – speed of the line feed indexing mechanism; 27 – speed control indexing mechanism; 28 – driver amplifier.

The fourth stabilization loop of the cutting force includes the sensor 22, amplifier detector 23, modulator electrode 15, control signal former in the function the tip of the tool elastic cross and cross-rail travels 24, dimensional depreciation unit on the surface 25, speed of the line feed control signal former 26, speed of the line feed indexing mechanism 26, driver amplifier 28.

During machining, the information on the precision behavior of the technological processing system (TPS) is read and summarized. The complex of the simultaneous four control loops operation shows the effect of simultaneous information directly from the tool zone about the current value of the machined workpiece diameter and sectional shape, its elastic travels, about the quality of the processed surface, about the dimensional depreciation and face wear of the tool, for example, the mine hole wear, the cross Y, X, Z axis travels of the tool tip and slicing of chip formation. Before the start of turning, the first stabilization loop of the tool holder housing position is switched on, while the contactless sensor 1 is rigidly fixed to the body structure 2 relative to the artificial gage length 3 (the latter is installed on the machine bed and can be replaceable and adjustable in the radial direction of the workpiece). In the case of the body structure 2 travel relative to the artificial gage length 3, the indexing mechanism I generates an electrical signal proportional to the amount of the tool holder travel, with account for to the differential-input amplifier 4, where this signal is compared with the
indexing mechanism 5 signal, amplified and fed to the electrohydraulic gear 6. The latter travels the body structure 2 in the desired line, stabilized it relate to the artificial gage length 3 along the entire length of the workpiece.

The tool holder body structure stabilization 1 of along the entire path of its travel makes it possible to create an artificial reference and measurement base for the control loops of the tool tip and workpiece axis, eliminating all errors introduced by the guides and lead screws. In the second stabilization loop of the workpiece axis, before the process of cutting, the SCR 7 is set relative to the tool holder body structure, while the position of the control sensor 8 included in the feedback of the second control loop corresponds to the nominal diameter of the workpiece and parallelism to the axis of the working surface of the artificial gage length 3. The signal from the sensor 8 is compared with the indexing mechanism 9 signal and fed to the differential-input amplifier 10, the output of the latter is connected to the electrohydraulic gear, which controls the position of the SCR 7.

During cutting, the output signal from the sensor 12, proportional to the current diameter of the workpiece to be machined in a plane passing through the tip of the tool along the normal to the machined surface of the workpiece through the control unit where this signal is divided into a signal proportional to the increment in the diameter of the workpiece being machined from tool depreciation and the signal proportional to the value of the diameter increment due to the bending deflection of the workpiece. The latter feeds to the input of the differential amplifier 10, where a control signal is generated in proportion to the increase in the diameter of the workpiece being processed as a function of its resilient flexing in the cutting area and is fed to the electrohydraulic gear 11, while changing the position of the SCR 7 relative to the artificial gage length 3 so that the axis of the workpiece is parallel to the artificial gage length 3.

The sensor 12 emits flexing waves under the influence of the ultrasonic pulse generator 13 oscillations to the workpiece, receives the reflected flexing waves, converts the flexing oscillations into electrical ones and supplies them to the differential-input amplifier 14, then to the elastic travels registration unit 16 and then to the amplifier 10. The plate pulse indexing mechanism 15 ultrasonic generator 13 and amplifier detector 14 are coupled to the input.

The second stabilization loop work of the workpiece axis make it possible to compensate for the workpiece axis travel due to the action of cutting forces and to minimize vibrations arising during processing, as well as to increase the vibration resistance of the “workpiece-support” system.

The blocks related to the second control loop are also involved in the work of the third stabilization loop of the cutter tip (12, 13, 14 and 15). While the cutting the sensor 12 signals from the ultrasonic pulse generator 13 to the workpiece being processed, and the reflected from the workpiece signals pass through the sensor 12 and go to the amplifier detector 14, the output of which is coupled to the tool 17 depreciation unit that registers the tool dimensional depreciation and gives signal proportional to the amount of the dimensional depreciation. The output unit 17 signal is fed to the input of the amplifier detector 18 which generates a control signal proportional to the size of the tool dimensional depreciation, and it is fed to the input of the electrohydraulic gear 19. The latter corrects the tool tip position according to the set from the cutting depth indexing mechanism 20. The position of the tool tip is set from the tool holder body structure 2 and is controlled by the position sensor 21 that included in the feedback of the electrohydraulic gear. The operation of the second and third control loops allows maintaining a constant relative position of the tool and the axis of the workpiece.

The mine hole tool wear at the point of chip separation along the leading surface, the elastic cross and cross-rail travels and the change in the frequency of the chip formation process slicing are measured by the fourth control stabilizing cutting forces loop. At the same time in the function of changing the elastic cross and cross-rail travels of the tool tip tool (due to the increase in cutting forces from depreciation), the cross feed of the tool is controlled, maintaining the stable position of the tool tip and the axis of the workpiece at a given level and limiting the decrease in feed when the mine hole wear reaches a critical state and reaching the frequency of the chip friction in advance of its predetermined value. In this control loop, the detecting head 22 is mounted on the tool along the normal to the main cutting edge. Both in the second and in the third control loops, the measuring
signal is generated by units 13 and 15 and also by a separate amplifier detector 23. The output of the latter is simultaneously connected to the unit 24 for generating a control signal as a function of the elastic Z-axis cross and X-axis cross-rail travels and to the control of the tool depreciation the mine hole wear unit 25 and the slicing frequency of the chip formation. The output signal from unit 26 is compared with the signal 27 the error signal is fed to the input of the driver amplifier 28 that controls the electric gear of the cross-rail feeds of the tool. While compensating for increased cutting forces by reducing feeds limits the cutting process in terms of productivity, then the mine hole wear and the slicing frequency of chip formation register these minimum feeds and stop the machining process.

The simultaneous four-controlled loop system operation make it possible to measure displacement in three directions, stabilizing the tool tip along the XYZ axes taking into account dimensional depreciation and the mine hole wear by controlling the position of the tool tip and also the control in the Y-axis direction is carried out by a separate servo drive as well as control of the cross feed in the X- and Y-axis directions. ACS makes it possible: To measure the diameter of the workpiece to be processed in the plane traversing through the tip of the tool along the normal and the workpiece surface; To measure the shape of the workpiece in the cross and cross-rail sections during processing; To roughness degree control of the machined surface and the surface in the cutting plane of the workpiece; To control the position of the workpiece axis, stabilizing it relative to the artificial gage length with a predetermined accuracy.

4. Results and conclusion

The developed technology for processing low-rigid shafts based on the automatic control technological system of the RV 104 lathe turning system, as well as the control systems and units for it, was implemented at OJSC “Azotremmash” in Togliatti during manufacturing of low-rigid shafts for pumping and compressor equipment of chemical units. Typical shafts produced had a length to diameter ratio of more than 40 and a centerline tolerance of 0.015 to 0.025 mm (runout 0.03 to 0.05 mm), which is less than 10 microns per linear meter of shaft length.

The existing technology, based on the factory TPD recommendations, provided for at least six turning passes using a standard travelling rest and three stabilizing operations carried out in the turning intervals and also the possibility of correction by bending. The diameter of the workpiece was 1.5-2 times larger than the diameter of the shaft so that it was possible to gradually "select" the turning operations for arising permanent technological deformations of the shaft axis bending and bring them to the specified straightness tolerance. According to the factory technology, the duration of the production cycle reached 57 hours, and the operations of the heat setting and flexible straightening took up to 80% of the cycle time. In addition, based on practically accumulated experience, to output one shaft with a given accuracy along the straightness of the axis, a deliberately increased batch of defective products was launched. This batch was launched as batch for shafts in which the length-diameter ratio 85 that reached a ratio of 11:1. New turning technology using an ACS at two, most three passes using a self-centering travelling rest, solves the problem of accuracy and productivity. At the same time, using the developed installation and calculation methods, a forecast of permanent technological deformations of the bending was carried out for each pass, the over dimension was distributed, the processing modes and tool parameters were appointed.

When the shafts were manufactured according to the factory technology, the change of permanent technological deformations of the bending was unstable and unpredictable that led to a large number of defective products. During the low-rigid shafts manufacturing, according the new technology, the maximum values of the permanent technological deformations of the bending were steadily decreasing. This led to the fact that additional bending corrections were excluded and also was ensured the specified accuracy of the shaft along the straightness of the axis.

The use of the proposed method on the RV 104 lathe when processing non-rigid workpieces makes it possible: To increase the processing accuracy by 6-8 times in the cross and cross-rail sections, depending on the cutting conditions and parameters of the control systems; To increase the processing productivity by 5-8 times by increasing the cutting conditions without reducing the requirements for
processing accuracy; to reduce the production cost of shafts by 3.2 times due to the elimination of energy-consuming heat setting operations; To reduce the number of turning passes and defective products; To reduce material consumption by 1.8 times due to the use of workpieces with a diameter as close as possible to the diameter of the finished shaft; To reduce the energy-consuming processing by 82 times; To reduce the duration of the technological cycle by 2.4 times; To extend the operational life of the shafts in the units by 1.6 times due to the achieved accuracy and its preservation in the future during normal operation. This is due to the fact that the dynamic characteristics of the TS system are not decisive during processing. Artificially built-in control loops and their transient index determine the behavior of the TS.

The ACS of the mechanical shafts processing in which the length-diameter ratio 85 from structural and corrosion-resistant steels for pumping and compressor equipment of chemical units was designed and implemented at OJSC “Azotremmash”, which made it possible to ensure the specified accuracy in the straightness of the shaft axis.

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