Improving lathe dynamics by workpiece - support subsystem control

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Abstract. The article discusses the design of the lathe, the peculiarity of which is the equipment of it with three automatic control systems (ACS) of the workpiece-support subsystem. The first ACS ensures the stability of the workpiece axis during machining by controlling the self-centering supports (SCS). The second ACS controls the dynamics of the spindle assembly. The third ACS controls the axial clamping of the rear center, which enables machining low rigid small, long shaft-type workpieces for turning, grinding and milling spline slots. The use of ACS increases the accuracy, quality of machining and vibration resistance of the Lathe-Device-Tool-Workpiece (LDTW) system, which is achieved in all operations through automatic control of tool positions and the workpiece. In addition, the residual stress on the machined surfaces is reduced by introducing high-frequency vibrations into the cutting area at all operations.

1. Introduction
Many modern units, machines and devices use responsible, low-rigid shaft type parts (LRP). The ongoing growth in the production volume of LRP is caused by the improvement of strength calculations, the optimization of shapes of details and designs, the constant decrease in metal consumption of products and the increase in the output of precision machines.

The disproportions in the design parameters of the LRP create serious technological difficulties in production, the main reasons for which are as follows: a) significant elastic and plastic deformations at all stages of processing, assembly and operation of parts; b) low vibration resistance and different pliability of elements of technological systems; c) significant influence of technological heredity on the reliability of work; d) warping of workpieces caused by non-uniform residual stress introduced at all stages of processing; e) low thermal resistance of parts. The negative effect of the above factors in the manufacture of LRP leads to the violation of technological bases, errors in the shape and size of parts, surface defects, limited applicable cutting modes, and ultimately to a decrease in the operational accuracy and reliability of LRP [1-15].

2. Relevance
The traditional ways of processing are inefficient for manufacture of low rigid parts, therefore questions of their manufacturing in practice are solved by limiting the processing modes, adding operations of manual finishing, which does not guarantee the required quality of products. That is why
improvement of technological processes of LRP production is an important task that increases the efficiency of production and quality of engineering products.

3. Automatic control systems
The article deals with the new design of lathe type machines. There is a subsystem workpiece support controlled by three independent automatic control systems (ACS). The first ACS controls the axis position of the workpiece to be machined using self-centering supports [2-3]. The second ACS controls the dynamics of the waveguide spindle [6-10]. The third ACS controls the force of axial compression of the rear headstock [1-2].

The lathe equipped with three ACS for machining long axisymmetric parts is illustrated in drawings (Fig.1-3). The lathe equipped with ACS for stabilizing the axis of axisymmetric long parts (Fig.1) contains the main bed 1 and a rigidly fixed bed 2, equipped with supports 3. The distance between the supports is the ratio of the shaft length to its diameter. On bed 2, there are longitudinal supports 4, on which transverse supports 5 with stepping drives 6 are mounted. On the upper base of the transverse supports 5, SCS 7 are fixed, which are equipped with stepping drives 8. SCS 7 are equipped with an automatic control loop, which includes the tool position sensors (not shown in the figure ...) along the length of the workpiece, the outputs of which are connected to the inputs of the computing device 9, and the output of the latter is connected to the inputs of stepping drives 6 of transverse supports 5 of the small bed and inputs of stepping drives 8 of the SCS 7.

Figure1. General view of the lathe equipped with a workpiece axis stabilizing ACS

Clamping spherical rollers 10 are placed on rotary levers 11, the latter are installed on fixed axes 12, which are fixed on the ends of the levers 13 of the SCS 6.

The lathe works as follows. By moving the longitudinal supports 4 and transverse supports 5, the SCS 7 are set in the required position for the Fig. 2 processing of a specific shaft. The shaft
workpiece is installed in the SCS 7. The turning work is further exercised by cutting tool in the toolholder.

The automatic control circuit ensures continuous contact of the rollers with the base surface of the workpiece by timely actuation of the clamp 8 stepper drives when the cutting area under the support is moved. At the same time, the workpiece is clamped on the machined surface by rollers from one edge by means of swivel levers 11. Then, at the exit of the cutting area from under the SCS 7 in step drive 8, lever 13 is pressed to the machined surface.

The developed ACS stabilizes the shaft axis of the workpiece during the cutting process and increases machining accuracy due to high rigidity and alignment of the bases. The base is the outer diameter of the workpiece.

The second ACS controlling the waveguide spindle is illustrated in the functional diagram, (Fig. 2). The vibration machining unit includes the installation of the workpiece 1 in the spindle of the lathe 2 with the elastic element 3, having screw grooves 4 with irregular step, giving it rotation $\omega$ and the simultaneous sending $v$ of the tool 5 along the workpiece 1. When the cutting tool 5 cuts into the workpiece 1, it is twisted, which is accompanied by simultaneous longitudinal deformation. Due to periodic relaxation processes associated with chip fragmentation in the area of chip formation, in the elastic element 3, complex torsional longitudinal vibrations from workpiece 1 are generated, the latter is sprung by the rear center 7.

![Figure 2. Functional diagram for automatic headstock spindle control.](image)

The control circuit contains sensors VAE 8 and 9 in tangential and longitudinal positions, which are connected via amplifiers 10 and 14, 11 and 15 to the adders 13 and 17, to which are connected setters of longitudinal and tangential component of vibration 12 and 16. Further; the circuits through the converters 18 and 19 are connected to the switch 20, which is connected to the supply 21, speed 22 and electric converter 23 force drive 6, pull 24 elastic element 3 with screw grooves 4.

Diagnostics of cutting process and oscillations of nonlinear system billet-elastic element can be carried out with the use of vibroacoustic emission (VAE) in the axial and tangential positions, and rigidity control of the elastic element in the cutting process in the function of change of excitation frequency, and the form of oscillations is determined in the function of change of axial and tangential component of VAE.

Adjustment of the elastic element rigidity allows shifting the resonance frequency, controlling the amplitude and form of oscillations at different processing modes.
Control of vibrations by cutting speed allows to achieve a certain frequency of excitation, providing resonance or anti-resonance nature of oscillations.

The use of diagnostic data allows to increase processing efficiency due to the stabilization of the shape of the workpiece-elastic element oscillation in the frequency function.

Carrying out processing at various points of the amplitude frequency characteristic (AFC) of nonlinear system workpiece-elastic element allows to carry out the most effective operations differing in nature due to the selection of frequency and amplitude of oscillations.

Carrying out processing on rough operations on the pre-resonance branch of the AFC allows to crush chips as effectively as possible due to resonance with excitation of mainly longitudinal component of oscillations.

Finishing operations on the resonance branch of the AFC ensure minimum roughness due to the minimum amplitude of oscillations using predominantly torsional oscillations, which provides maximum accuracy due to the introduction of a tangential cutting contour that dissipates disturbance not in the radial but in the tangential direction.

Selection of the working area at the AFC taking into account changes in the processing frequency allows to stabilize the vibration processing mode by eliminating frequency jumps from the upper branch of the AFC to the lower one.

The third automatic control system of accuracy of machining of long pieces by means of control of axial force of pressing is carried out as follows Fig.3.

**Figure 3.** Functional diagram of the ACS of axial clamping force.

The workpiece installed in the SCS and fixed in the chuck of the front headstock is pressed by the rear dynamometer assembly 2 with the dynamometer center mounted in it 3, one end of which rests on the workpiece, and the other, on the elastic element 4; its movement along the axis X is controlled by the first primary converter 5, the latter is rigidly fixed on the case of the dynamometer rear center relative to the elastic element 4 with an initial gap of $\Delta x$. When the workpiece is lengthening due to temperature expansion from the cutting process, the dynamometer center moves along the X axis and deforms the elastic element 4. The deformation of the elastic element is recorded by the primary converter 5, with the help of the output signal of which changes are made to the transfer coefficient of the first scaling amplifier 6 in the function of the static and dynamic resilience of the rear dynamometer center 3 in the specified coordinate system. Temperature deformations registered and transformed into electrical signals in the direction of the X axis by the converter 5 are fed to the first scale amplifier 6, where the output signal of the converter 5 is normalized by changing its transmission coefficient. Thus, the signal at the output of the scale amplifier 6, functionally connected with the axial temperature deformations of the workpiece, controls the value of the axial clamping force of the workpiece in the given range from the setter 7 axial force, i.e. the given axial clamping force by the rear center is preserved during the whole processing process regardless of geometrical and physical-mechanical parameters of the workpiece and temperature modes of processing. The signal from the
setter 7 and block 6 is compared in the comparator block 11, and the differential proportional signal goes to the amplifier 8 of power and further to the electro-hydraulic drive 9, the latter moves the dynamometer rear center 3 relative to the rear headstock 1 by the value proportional to the deformation of the workpiece from the temperature elongation, thus supporting the force of axial clamping of the workpiece set by the setter 7.

Axial clamping force control does not allow the creation of residual axial stress regardless of the temperature deformation of the workpiece during cutting. The rear headstock ACS allows to obtain parts with a given machining accuracy taking into account the influence of temperature deformations by compensating the latter at the turning, grinding, etc.

4. Conclusion
The use of automatic control systems by the workpiece - support subsystem for the processing of long, low-rigid shafts allows [4-5] to increase the coefficient of use of machine equipment and reliability of finished products by improving the strength surface characteristics of the parts. Experimental studies were carried out on workpieces $1 - 1.500 \text{ mm}, d = 32 \text{ mm} \text{ of} 40X \text{ steel}$. The processing was carried out without and with CAA at the following cutting modes: $n = 1,440 \text{ rpm}, S = 0.11-0.22 \text{ mm/rev}$, without the system, in two passes with cutting depth $t_1 = 1.5 \text{ mm}$ and $t_2 = 2.8 \text{ mm}$; with the ACS $t = 3 \text{ mm}$ per pass. The cutter material was T15K6. The cutter geometry was standard. Auto oscillations on the given machining modes did not occur due to the high rigidity of the workpiece fixed in the SCS and the absence of axial clamping forces.

The use of the proposed unit allows to increase processing productivity by 3-4 times, to obtain roughness $Ra 0.8$, longitudinal accuracy to $10 \text{ mcm/m}$ in the diameter range of $30-60 \text{ mm}$, and length range of $1.5-4 \text{ m}$. To remove residual deformations of the finished product during operation.

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