Reducing the effect of centrifugal forces on the clamping force in the new design of a three-jaw lathe chuck

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Abstract. The article considers a simple and reliable design of a new three-jaw lathe chuck, characterized by high operational characteristics: high rotation speed, durability, calibrated clamping of products and a number of others. The abandonment of classical methods of construction enabled us to create a new effective design. In addition, this design only due to its principle, enables you to compensate for centrifugal forces at any rotational speed, and at the same time the lathe chuck has a standard size for installation on machines.

1. Introduction
Engineering is one of the main industries that ensures development of the economy. Continuous improvement and development of mechanical engineering is associated with the progress of machine tools, since metal-cutting machines are the basis for the manufacture of any new types of equipment.

In the conditions of large-scale and small-scale production, one of the most important tasks is technical and technological re-equipping of machine-building enterprises, further expansion of technological capabilities, and increase in productivity, accuracy, reliability and durability of machine tools.

One of the main components in the structure of the machine is the clamping mechanism (CM), which along with other mechanisms has a significant impact on the accuracy and productivity of part processing, since the used cutting conditions, the time spent on processing the part, the quality of processing and the accuracy of installation of parts depend on it.

Currently, many companies produce lathe chucks, for example, RÖHM GmbH (www.roehm.biz), MicroCentric Corp. (https://www.microcentric.com) and several others. A lot of papers is devoted to the selection of lathe chucks [1-3].

Currently, much attention is paid to improving the structure of manufactured machines and improving their mechanisms to achieve the following main goals [4-7]:
1) increased processing productivity;
2) improving the quality of workpieces;
3) reduction in processing costs.

Chucks for machine tools with CNC of the turning group must provide:
1) reduction of the time spent on changing workpieces, readjustment or replacement of jaws, changing chucks, as well as on the change-over of the machine from chuck to center work;
2) alignment of the workpiece’s axis relative to the axis of the machine’s spindle during processing, which places a demand on the chucks of stable accuracy of centering the workpieces, as well as of the rigidity of the chucks’ nodes;
3) clamping force, which guarantees during processing the unchanged position of the workpiece, achieved during basing, i.e., to prevent rotation and displacement of the workpiece under the action of moments and cutting forces;
4) reduction or even elimination of the influence of centrifugal forces on the clamping force of the workpieces with jaws;
5) sufficient size of the central hole for the possibility of processing in the chuck both workpieces and rod stocks.

2. Research method
Modern machines have high spindle speeds. With increasing rotational speed, the action of centrifugal forces, reducing the clamping force of the workpiece on their jaws, increases. The dynamic clamping force of the workpiece is determined by the following formula

\[ Q_{dyn} = Q_{cm} \pm F_c, H \]

where \( Q_{cm} \) - static clamping force;
\( F_c \) - centrifugal force, H;
The minus sign in the formula refers to the workpiece compressible on the outer surface, the plus sign - on the inner surface.

\[ F_c = mR\omega^2 = \frac{GR\omega^2}{g} = 0,102GR\left(\frac{\pi n}{50}\right)^2 \]

where \( m \) - mass of jaws, kg;
\( R \) - radius from the rotation axis of the chuck to the gravity center of the jaw, m;
\( \omega \) - angular velocity, rad/s;
\( G \) - jaw weight, H;
\( g \) - gravity acceleration, m/s²;
\( n \) - spindle rotational speed, s⁻¹, s⁻¹.

After the transformation, we get

\[ F_c = \frac{mRn^2}{100} = \frac{Gn^2}{1000} \]

Thence

\[ Q = 1,2KP_d \frac{mRn^2}{f, d_1} \]

where 1,2 is the coefficient taking into account the effect of radial and axial components of the cutting force;
\( K \) - reliability factor (\( K = 2.0...2.5 \));
\( P_d \) - main component of cutting force;
\( d \) - diameter of the processed surface;
\( d_1 \) - workpiece diameter at the jaw clamping point;
\( f \) - friction coefficient.

In practical implementations, to reduce the effect of centrifugal forces on the clamping force, a reduction in the mass of the jaws is achieved, but their reliability is reduced. In some designs, the centrifugal force is compensated for by incorporating into the bodies of chucks some counterweights connected to the jaws by a lever, but this complicates the design and reduces its reliability.
3. Practical implementation
A new design of a three-jaw self-centering chuck devoid of this drawback has been proposed [8-10]. The effect is achieved by combining a clamping jaw with the mechanism of its movement (hereinafter the jaw). Moreover, the clamping jaws themselves can be hardened and manufactured on CNC machines in one technological process together with a movement mechanism. The design of the lathe chuck is shown in Figure 1 (the top cover is not shown). The rigidity of the structure is ensured by fixing the movement along two coordinates. The movement along the third axis is carried out using the movement screw (is not shown), which can move the jaws both in manual mode and in mechanical (automated) mode. Moreover, the design of the lathe chuck in both modes is the same.

Figure 1. Three-jaw lathe chuck model.

Figure 2 shows a prototype chuck with a diameter of 250 mm.

Figure 2. Prototype lathe chuck 250 mm.

On the left, Figure 2 shows a standard Morse taper with a hollow sleeve located inside for automatic part clamping. This design enables one to process rod stock material.
The design of the lathe chuck is made according to Russian standards, but due to the design of the jaws it can be made 30-50% thinner. This will depend on the strength of the clamp required. In addition, this design can be implemented with a calibrated, predetermined effort [10].

4. Conclusions

With the abandonment of the classical model of a three-jaw lathe chuck, it was possible to increase the service life of the chuck while fully maintaining the normalized characteristics due to a significant increase in the contact area of the jaws and the body. During long-term operation, these sliding planes grind down evenly, moreover, they bed in over time and the centering accuracy can even improve.

This design is fully compatible with all machines. Such a disadvantage as a small stroke of the jaws (while the jaws do not protrude beyond the edge of the chuck) can be effectively used in automatic lathes.

The design of the jaws enables, in the presence of certain automation, to clamp parts from the electric drive of the machine.

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