COMPUTER SIMULATION OF CLAMPING JAWS WITH ELASTIC COMPENSATING LINKS FOR THIN-WALLED PARTS CLAMPING

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Annotation

The paper deals with the study of clamping jaws with elastic compensating links which have the properties of adaptation to the clamping surfaces of thin-walled work-pieces and ensure the accuracy of their centering. Basing on the method of finite element analysis using a CAD/CAE system, the dependences of the deformations of the jaw clamping section depending on its wall thickness and force loading on the plungers were obtained. According to the computer simulation results the locations of concentration of the maximum equivalent stresses in the clamping jaw with an elastic compensation link and their values are determined.

Keywords: adaptive clamping jaw, thin-walled part, centering accuracy, stress-strain condition, elastic deformations

Introduction

The shape accuracy of the thin-walled working parts after turning is largely determined by the parameters of the clamping system. Most often, jaw chucks are used for basing and fixing thin-walled work-pieces during turning operations, allowing clamping thin-walled work-pieces of different size. They are advantageous in terms of machining cost and readjustment time. Clamping thin-walled work-pieces with cylindrical base surfaces of different diameters by clamping jaws with a fixed geometry of their clamping surface leads to different contact conditions. When clamping such work-pieces with commercially available power-operated lathe chucks, there is sometimes a problem of insufficient centering accuracy, despite the previous fine machining of “soft” clamping jaws. Therefore, the development and study of clamping jaws with elastic compensation links, which have the properties of adaptation to the clamping surfaces of thin-walled working parts as well as ensuring the accuracy of their centering is an urgent scientific and engineering task.

Research goals and objectives

Taking into account the requirements for the turning process of thin-walled working parts, much attention should be paid to the clamping elements used to equip the turning chucks. The main requirements for the design of such clamping elements are: adaptation (ensuring full contact) to the surface of the part, high centering accuracy, sufficient clamping stiffness, rapid readjustment [1-3]. The paper [4] deals with the results of local strains in the contact zone of traditional and segmental clamping jaws when fixing the thin-walled work pieces of the ring type in the turning chucks. This study allows defining more precisely dependences for the calculation of torque and clamping forces to prevent local damages in the contact area. The strategy of reducing deviations from the roundness of turned rings when they are clamped with a three-jaw chuck is given in [5]. This strategy is used first for the external clamping with traditional jaws, and then - segmental jaws for the inner clamping. The finite element method is used here to simulate the ring deformations. Adaptive system to compensate the errors taking place when clamping the thin-walled cylindrical work-pieces is given in the paper [6]. The operational element of this system is designed in the form of the mechatronic holder with integrated sensor and piezoelectric drive for the turning tool displacement. As well, in the paper [6] the developed models of cutting depth control in various angular positions of the thin-walled work piece are also resulted taking into account deformations of the work piece and the tool. To actively compensate the displacement of the work piece during clamping on lathes the papers [7, 8] develop a new method of accurate positioning using an active chuck. This technique provides that the position of the work piece is determined by two tactile displacement sensors. The clamping chuck consists of built-in piezoelectric actuators that compensate the eccentric displacement and decline errors. The corrected position of the work piece is fixed by a friction lock caused by the tensile force.

Many scientific investigations in the leading technical universities as well as in the companies that are engaged in manufacturing of clamping devices deal with the development of devices design with adaptive properties and also in research of their characteristics [7-11]. To ensure the adaptation of the clamping jaw to the work pieces of variety of diameters, different principles are used [9-11], in particular: mechanical (sliding pins; plates; flexible segments, etc.); thermal (low-melting materials and low-melting metals); magnetic (magnetic powders, magneto-rheological fluids); hydraulic (liquid and granular media (granules)).

The analysis of numerous designs of adaptive clamping elements, based on the mechanical principle of adaptation, shows the presence of elastic links in them.

Based on the mentioned above, increasing the accuracy of centering of thin-walled work-pieces with cylindrical base surfaces can be achieved by developing clamping jaws with elastic compensation links that have adaptive properties.

The object of the study is the clamping jaws with elastic compensation links that ensure the accuracy of centering of the thin-walled work-pieces with cylindrical base surfaces.

The objective of the study is to increase the accuracy of centering of thin-walled work-pieces with cylindrical base surfaces due to clamping jaws with elastic compensation links and evaluation of their stress-strain condition at different design and power parameters.

Research techniques

One of the basic approaches in creating clamping jaws with adaptive properties, which is proposed to use, is the deliberate deformation zones introduction into their design [10, 11]. This concept allows synthesizing clamping jaws with elastic compensation links, to ensure the fitting of their contact surface to the clamping surface of a thin-walled work-piece and making moving it to ensure the accurate centering.

Using this approach, the design of a clamping jaw with elastic compensation links for clamping thin-walled parts with cylindrical base surfaces (Fig. 1), which contains a hydraulic medium, is synthesized.

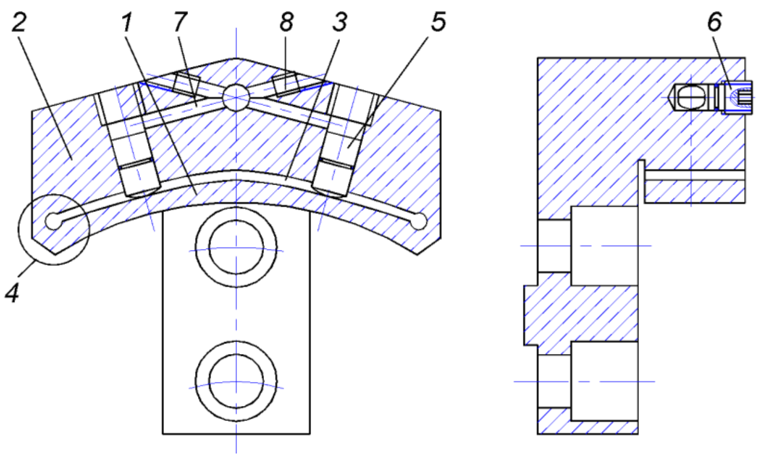


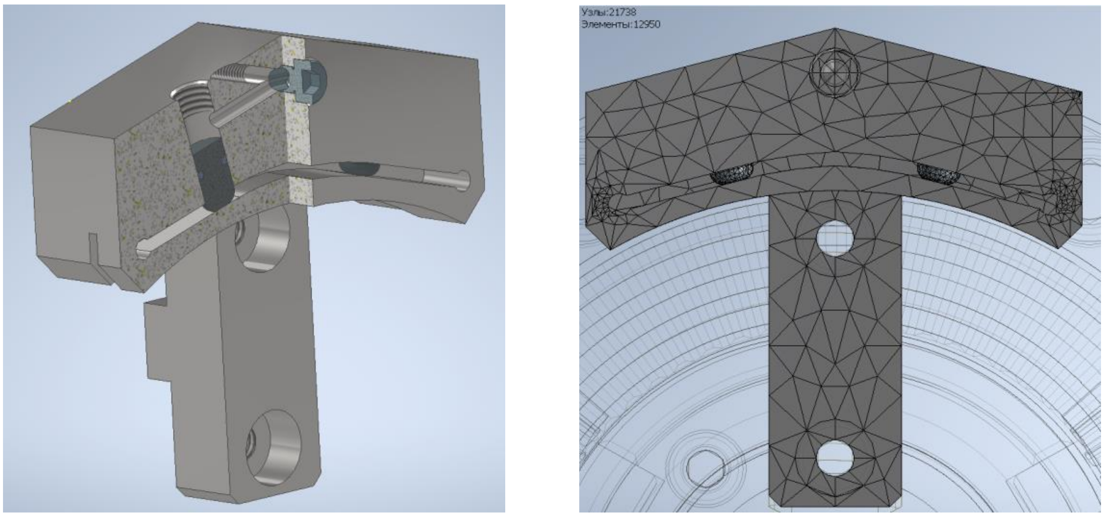
Fig.1. Clamping jaw with elastic compensation links for clamping thin-walled parts with cylindrical base surfaces

Its characteristic feature is to ensure uniform distribution of pressure on the clamping surface due to the elastic connection of the clamping section 1 with a base section 2. The cavity 3 is made almost along the entire width of the clamping jaw and is tangential to its radial movement. The clamping section 1 is connected to the base section 2 by means of solid body hinged joints 4, which gives it elastic properties in the radial direction and has a favorable effect on ensuring a uniform pressure distribution on thin-walled work-piece. The moving drive of the clamping section 1 is made hydraulically, so that a constant tension is created between the sections of the clamping jaw. Actuation of the clamping section 1 is carried out by the piston plungers 5 under the pressure of the liquid, which is created by the screw 6 located at the end of the clamping jaw. This allows easy access to the clamping jaw even when the work-piece is clamped. Precise hydraulic adjustment is provided by turning the screw 6 with a wrench. When turning the screw, the hydraulic fluid is displaced into the channels 7 and acts on the piston plungers 5. Piston plungers 5 press on the inner area of the clamping section 1.

The stroke of the plungers leads to the desired expansion of the clamp radius by a small amount when clamping by section 1. The hydraulic system for moving the clamping section 1 allows ensuring its precise adjustment, which leads to the precise centering of thin-walled work-piece, as well as to the fitting of the jaw contact surface to its clamping surface. Screw caps 8 of the hydraulic channels 7 are used to fill in and pump the hydraulic system.

Due to the complicated design of the proposed clamping jaw it is necessary to solve problems related to the quantitative assessment of the stress-stain state of the clamping section as well as an influence of structural and power parameters on it. Therefore, the method of finite element analysis using CAD/CAE system is chosen.

Using the method of 3D parametric modeling, a solid model of a clamping jaw with an elastic compensation link (Fig. 2,a) was created for a clamping chuck with a body diameter of 200mm. The calculation model was prepared by creating a finite element grid. The grid was developed on a 3D model of fairly accurate hexahedral and tetrahedral finite elements. The grad dimensions were chosen to be variable. In the areas of solid-body hinges, a finite element grid was developed with a smaller size to increase the accuracy of modeling. The finite element grid is checked and its convergence is adjusted. Fig. 2,b shows the resulting finite element grid generated by the program.



a) b)

Fig.2. Solid-body clamping jaw model with elastic compensation link (a) and its model consisting of a finite element grid (b)

The initial conditions of modeling are found. Structural alloy steel with a tensile strength of 980 MPa and a yield strength of 785 MPa was selected as the material of the clamping jaw. A kinematic boundary condition of the “fixation” type was chosen for the base section of the clamping jaw. The condition of the plunger contact with the inner surface of the clamping section is accepted such that the faces can be moved in any directions relative to each other (with the possibility of both partial breakage and sliding). In order to study the force effect from the plungers on the stress-strain condition of the clamping jaw, a load was applied to them in the form of a static boundary condition of the type “normal force”. This power load varied from 100N to 1000N. Finite element modeling was performed in a static setting; the model was considered linear-elastic.

Results of static finite elements analysis

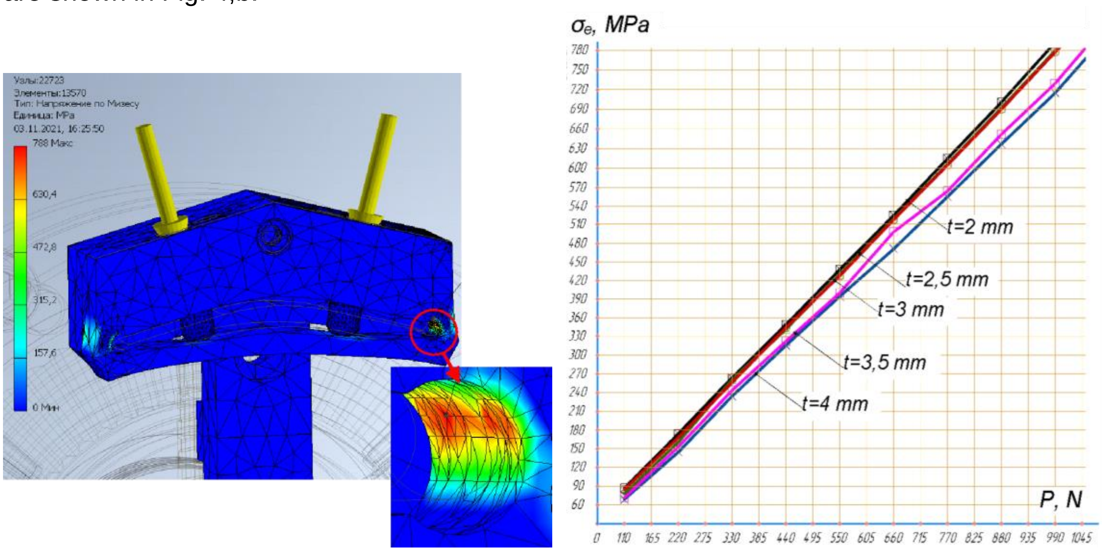
The results of modeling of clamping jaw with an elastic compensation link by the method of finite element analysis are equivalent stresses, which values were calculated basing on the Richard von Mizes hypothesis of the shape changing energy, as well as deformations. According to the simulation results, the locations of the maximum equivalent stresses σ_e in the clamping jaw with elastic compensation link and their values are found. Analysis of patterns of equivalent stresses σ_e distribution over the volume of the clamping jaw (Fig. 3,a) shows that their largest values will be in the area of the solid-body hinge joints. The maximum equivalent stresses σ_e in the area of the solid-body hinge joints of the clamping jaw, obtained by computer simulation at different force loadings P on the plunger and different values of the wall thickness t of the jaw clamping section are shown in the Fig. 3,b.

The simulation results show that with the force load *P* on the plungers increasing from minimum to maximum, the maximum equivalent stresses σ_e also increase, i.e. there is a direct proportional linear dependence between these parameters. In this case, for the clamping section wall thickness from 2 to 4 mm at the same force load *P* on the plungers, the maximum equivalent stresses σ_e differ by a small value (from 10 to 16%).

Analysis of the simulation results showed that the clamping section under clamping force loadings in the range of 100…1000N operates in the elastic deformations zone.

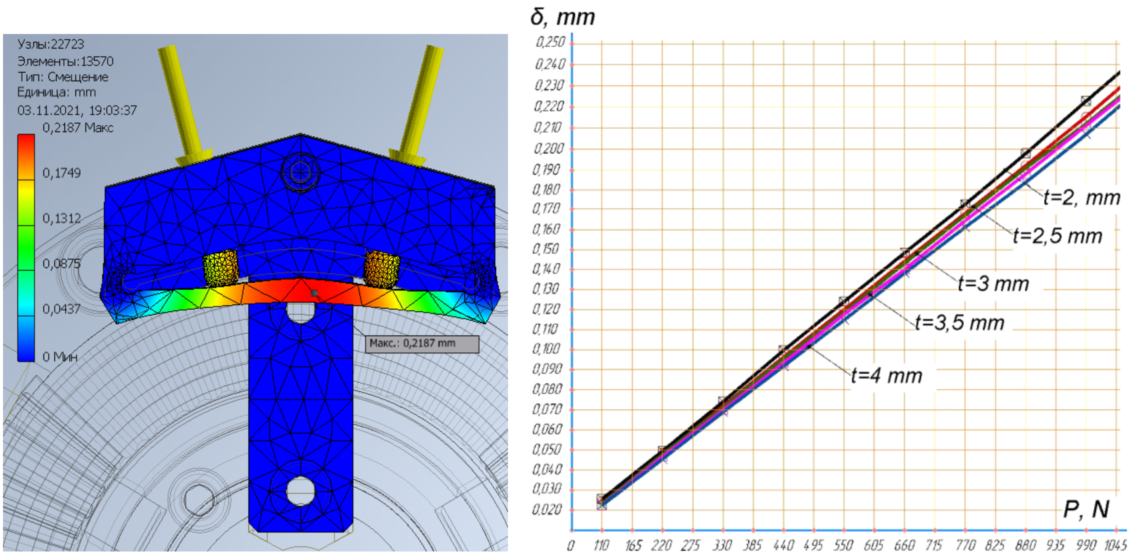
The study was also conducted dealing with the deformations of the jaw clamping section depending on its wall thickness *t* and the force load *P* on the plungers. Analysis of deformation patterns (Fig. 4,a) shows that the largest displacements δ occur in the area of the central part along the vertical axis of symmetry of the clamping jaw.

The maximum displacements in the area of the central part along the vertical axis of symmetry of the clamping jaw, obtained as a result of computer simulation at different force loadings *P* on the plungers and different values of wall thickness *t* of the jaw clamping section, are shown in Fig. 4,b.



a) b)

Fig.3. Pattern of stress distribution on the volume of the clamping jaw (a) and graphical dependences of the maximum equivalent stresses σ_e in the area of the solid-body joints on the force *P* on the plungers and the wall thickness *t* of the clamping section (b)



a) b)

Fig.4. Deformations pattern of the jaw clamping section (a) and graphic dependences of the maximum displacements δ on the force *P* on the plungers and wall thickness *t* of the clamping section (b)

The simulation results show that with the force loading *P* on the plungers increasing from minimum to maximum, the maximum displacements of the jaw clamping section also increases i.e. there is a direct proportional linear dependence between these parameters. With an increase in wall thickness from 2 to 4 mm at the maximum force loading P=1000 H on the plungers, the maximum displacements δ decrease by 7%.

The maximum displacements δ in the area of the central part along the vertical axis of symmetry of the clamping jaw under the force loads of the plungers in the range of 100…1000N and wall thickness of the clamping section from 2 to 4 mm are in the range of 0.023…0.0235mm. Such values of displacements allow providing the corresponding values of correction at a clamping of thin-walled work-pieces with cylindrical base surfaces for ensuring accuracy of centering at finishing turning.

Conclusions

1. Using the developed method, a mathematical description of the jaw clamping section deformation depending on its wall thickness and force loadings on the plungers is obtained. This model is to be used to determine the correction values to ensure accurate centering of thin-walled work-pieces with cylindrical base surfaces.

2. The study was performed by the finite element method of a clamping jaw with an elastic compensation link, on the basis of which the displacements and equivalent stresses were determined. Their values were calculated basing on the Richard von Mizes hypothesis of shape changing energy. The results of the study show a directly proportional linear dependence between the loads acting on the plungers and maximum equivalent stresses and deformations. It is found that the locations of concentration of the maximum equivalent stresses are on the zone of solid hinge joints of the clamping jaw.

3. The simulation results show that the jaw clamping section under the force loads of the plungers in the range of 100…1000 N operates in the zone of elastic deformations. It is determined that the maximum displacements in the area of the central part of the clamping jaw vertical axis of symmetry section from 2 to 4 mm are in the range of 0.023…0.0235 mm. These values allow ensuring the accuracy of centering of thin-walled work-pieces with cylindrical base surfaces, due to the elastic compensating links of the clamping jaws.

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