RING-SHAPED PARTS FORM ACCURACY IMPROVEMENT IN LATHE MACHINING USING COMPLEX SELF ADJUSTING EQUIPMENT

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Annotation

The structure of complex self adjusting equipment for multi edge machining is described. The equipment consists of both the adaptable clamping subsystem and adaptive type machining subsystem. The analytical model is presented to predict form errors of the cylindrical ring-shaped parts in turning machining using self adjusting tool accessories together with clamping system. To improve the machining accuracy the clamping chucks are proposed with clamping forces balancing distribution over the ring-shaped parts external surface.

Key words: *form accuracy; self adjusting accessories; ring; clamping force; elastic deformations.*

Introduction

The edge cutting turning process is followed by the elastic deformations and vibrations making unfavourable effect on the accuracy parameters, machining surface quality characteristics as well as tool life and machine tool service capability. In the process of machining the bending and torque vibrations occur that depend on the presence and mutual influence of technological cutting conditions, external perturbing forces and elastic deformation characteristics of manufacturing machining system. The ring-shaped parts dimensional processing in the turning manufacturing operations is associated with the bending deflection of machining surfaces under the action of cutting forces and clamping with the next forming of the concerning machining errors. The main problem in these circumstances is the insufficient rigidity of the machining part as well as of the overall manufacturing system. In such cases the machining part deformations as a result of the work piece positioning are equable with the machining tolerance. In this way the achievement of the ring-shaped parts form accuracy parameters of the machining surface stands as the complex technological and manufacturing task. Thus the machining errors minimization receiving is possible using only the correct chosen methods and techniques of technological manufacturing preparation. These ones are to decrease the main errors that are to be occurring in the different stages of the manufacturing process development.

Research actuality and investigation goal

In contrast to the single edge machining the ring-shaped parts multi edge lathe turning is among the most effective methods of the macro- and micro machining errors decreasing as well as liquidation of the inadmissible vibrations in metal cutting. The scientific papers by S.Nagornyak (1992) and I.Lutsiv (2012) deal with the research base of the multi edge equipment using self adjusting mechanisms and the adaptation process of the multi edge accessories investigations and design. The S.Astakhov (2012) paper is discussing the problem of the dynamical stability improvement of the thin wall pipes multi edge heads turning concerning the clamp holder axis rigidity distribution. It is clear that by using the feed change as the control parameter it is possible to organize the exceedingly delicate and sensible control mechanism of the elastic displacements. At the same time the feed variations related to the feed direction (X axis) do not effect negatively on the surface quality. Taking into consideration that the machine tool unit vibrations are subordinate to the minimum of potential energy principle and are directed toward the minimum rigidity axis’s it is reasonable to direct the oscillations along an axis X.

For another thing the form accuracy in the ring-shaped parts machining in a great measure is defined by the clamping system parameters in regard to the machine tool work pieces registration and positioning. The clamping device unbalanced rigidity regarding its clamping elements discrete positioning relatively to the clamping configuration effects the variations of radial components deformations that negatively affect on the machining surface form accuracy. The problems of the non regular rigidity compensation in regard to the clamping chuck rotation angle in long and short thin wall parts machining using the active single tool systems with piezo drive are discussed in the U.Heisel and S.Kang (2011) paper. The Y. Kuznetsov (2988) and V. Voloshyn (2010) papers deal with the received research results of static and dynamical investigations of the force and power characteristics of clumping chucks as well as of the system “clamping chuck-work piece” system rigidity and accuracy.

To decrease the influence of clamping forces and to achieve the necessary roundness tolerance the standard ways of this problem solving exist: the clamping force distribution by increasing the force exertion points number; the clamping force distribution by increasing the contact area square; clamping force regulation. But each of these ways demand the defining of the clamping elements optimal number as well as the clamping force value in each of the clamping element angular position to avoid the part cranking while providing the deformations in the admissible limits.

Therefore the improvement of the ring-shaped parts machining accuracy by using the complex self adjusting multi edge machining equipment consisting the adaptable clamping and adaptive type work piece machining subsystems stands as the actual research problem.

The research subject is the complex self adjusting manufacturing equipment for ring-shaped parts machining consisting the multi edge tool accessories and jaw clamping devices.

The research goal is to develop the analytical model to define the form errors and to predict the finish configuration of the ring parts in their inner machining using the complex manufacturing self adjusting equipment.

Research techniques

Self adjusting complex multi edge machining equipment consists of both the adaptable clamping subsystem and adaptive type machining subsystem (fig. 1) that are connected with each other and have to perform the main function that is to provide the precision and qualitative machining.

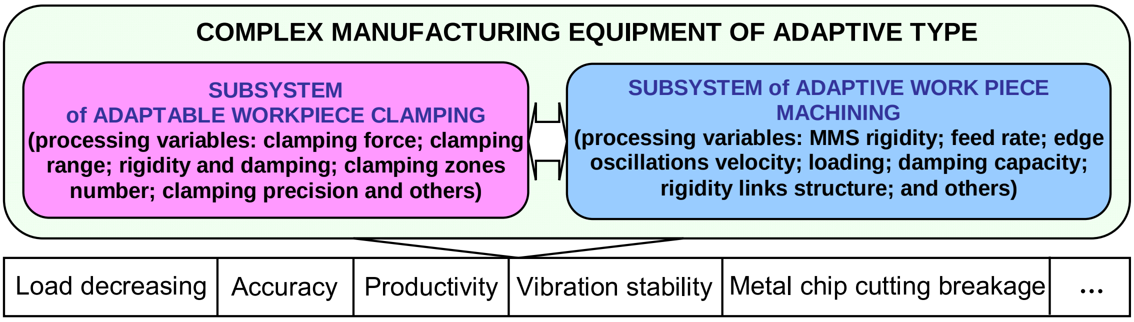


Fig. 1. Elements of complex self adjusting lathe machining equipment

Forming of the cylindrical ring-shaped parts dimensional deflections is a result of following effects: elastic deformations under the clamping force action; deformations under the cutting forces action; residual deformations of the machining process. Complex adaptive manufacturing equipment using is one of the techniques to minimize the elastic deformations as well as deformations under the cutting forces action in internal surfaces machining of the ring shaped parts (fig.1). To realize the given problem the equipment mentioned above consists of the multi edge tool accessories of adaptive type and corresponding clamping devices with regulation possibility suitable for formation of equally balancing clamping force distributed (fig.2).

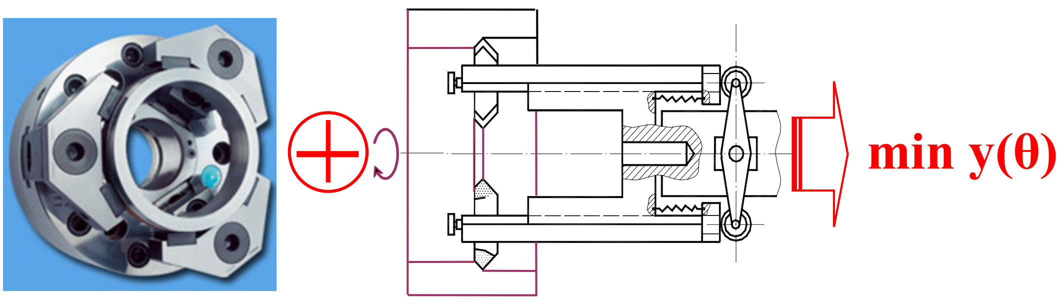


Fig. 2. Complex manufacturing equipment for ring shaped work pieces machining

To define the effect of elastic deformations and deformations under the cutting forces action in inner surfaces machining of ring shaped parts using complex adaptive manufacturing equipment the theoretical simulation of the ring-shaped parts dimensional errors forming is proposed. This model is based on the theoretical approaches of ring-shaped work pieces deformations calculating (Matin, 1988) in external clamping forces loading (fig. 3) as well as internal loading under the cutting forces acting in self adjusting multi edge accessories machining (fig. 4).

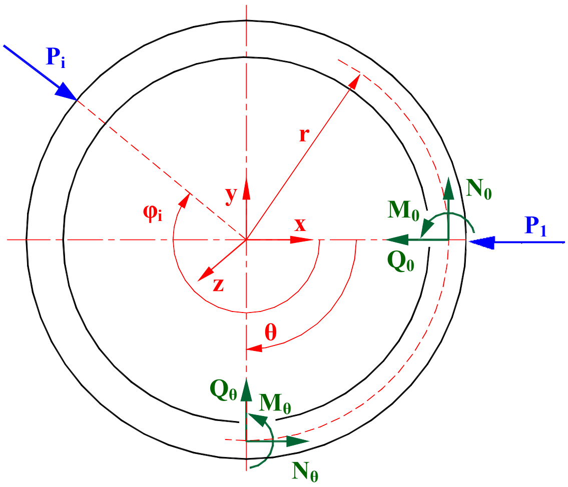


Fig. 3. Clamping element loading in ring-shaped work piece clamping

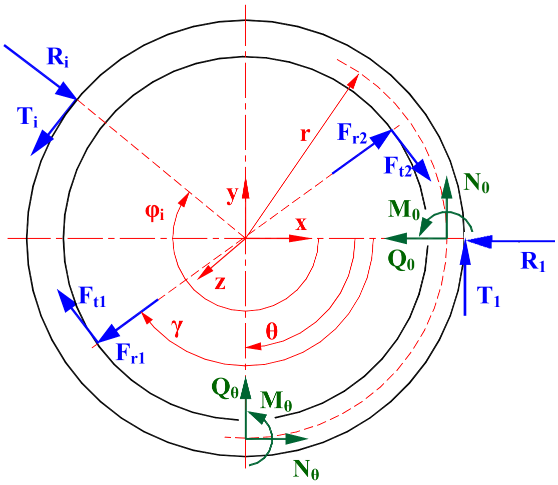


Fig. 4. Cutting forces and response reaction forces on clamping elements in two edges machining

Basing on the analysing of the force factors action diagram in work piece clamping the following dependences are obtained to evaluate the internal forces values in the ring cross sectional area θ=0 as well as in any other cross sectional area that is determined by the θ angle:

$$N_0 = \sum_{i=1}^{n} \frac{\varphi_i}{2\pi} P_i \sin\varphi_i; \qquad Q_0 = \sum_{i=1}^{n} \frac{\varphi_i}{2\pi} P_i \cos\varphi_i; \qquad M_0 = -rN_0 - \sum_{i=1}^{n} \frac{P_i r}{2\pi} P_i , \tag{1}$$

$$N_\theta = N_0 \cos\theta - Q_0 \sin\theta + \overline{N}_\theta; \quad Q_\theta = N_0 \sin\theta - Q_0 \cos\theta + \overline{Q}_\theta;$$

$$M_\theta = N_0 r (1-\cos\theta) + Q_0 r \sin\theta + M_0 + \overline{M}_\theta \quad (2)$$

in which P_i – is the i-th chuck jaw clamping force; φ_i – is the angle of clamping force application; r – is the ring mid-radius, $\overline{N}_\theta, \overline{Q}_\theta, \overline{M}_\theta$ – are the external loads vectors that are determined by the clamping forces P_i, applied in the φ_i point.

The equilibrium equation in two edge ring shaped work piece machining (fig. 3) can be expressed in terms of cutting forces components F_{r1}, F_{r2}, F_{t1}, F_{t2} as well as clamping elements response reactions forces P_i and T_i:

$$\begin{cases} \sum F_x = \sum_{i=1}^{n} R_i \sin\varphi_i + \sum_{i=1}^{n} T_i \cos\varphi_i - F_{r1}\sin\gamma - F_{r2}\sin(\gamma+\pi) - F_{t1}\cos\gamma - F_{t2}\cos(\gamma+\pi) = 0 \\ \sum F_y = \sum_{i=1}^{n} R_i \cos\varphi_i + \sum_{i=1}^{n} T_i \sin\varphi_i - F_{r1}\cos\gamma - F_{r2}\cos(\gamma+\pi) + F_{t1}\sin\gamma + F_{t2}\sin(\gamma+\pi) = 0 \\ \sum M_z = -F_{t1} r_{in} - F_{t2} r_{in} + \sum_{i=1}^{n} T_i r_{out} = 0 \end{cases} \tag{3}$$

The given system of equations is statically indeterminate. Thus to solve it the supplementary equations basing on the Castigliano theorem are formulated in regard to the ring deflections under the extra response forces action (fig. 3). According to the Castigliano theorem the ring deviation under the external load force can be obtained by the derivation of mathematical expression for the strained ring deformation U concerning the corresponding external loading:

$$\frac{\partial U}{\partial P_j} = 0, \quad \frac{\partial U}{\partial T_j} = 0, \tag{4}$$

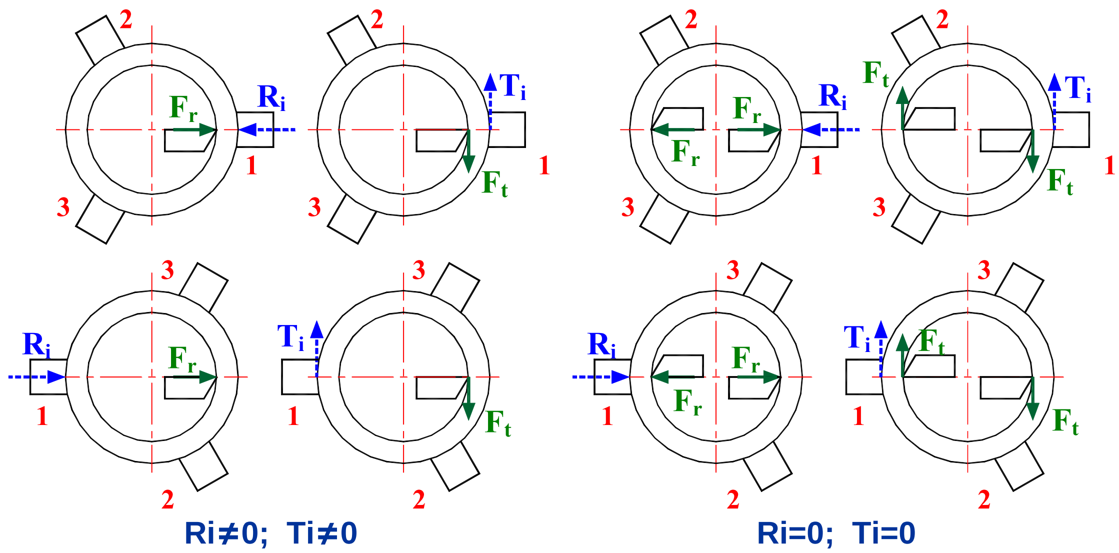
in which P_j and T_j is the extra force with j = 4,…, n index; U is the deformation energy of strained ring under the external loads P_i, and T_i.

In a case of the thin bent beam the internal normal and transverse forces can be neglected. In this way the strained ring deformation under the internal bending torque can be derived as the following dependence:

$$U = \int_0^{2\pi} \frac{M_\theta^2 r}{EI} d\theta = 0\ , \qquad (5)$$

in which $I_z = \frac{wt^3}{12}$ – is the mass moment of inertia about an axis z for the rectangular cross section with a width w and thickness t; E – is the transverse modulus of elasticity.

The fig. 5 illustrates certain jaws positions in regard to the radial and tangential cutting forces components. As the fig. 5 shows the response radial forces of the jaws in a case of the two edge machining are not to be in an action as in contrast with the single edge machining (fig. 5,a). But this is only possible under the condition that the adaptive two edge accessories provide the equality of the cutting forces components $F_{r1}=F_{r2}$. The same is to be applicable to the tangential jaw response forces under the condition of the cutting forces $F_{t1}=F_{t2}$ values equality providing.



a) b)

Fig. 5. Conditions of jaws extra radial R_i and tangential T_i response forces forming in the machining process using the single edge (a) and two edge (b) tool accessories regarding the jaws positions

Research results and recommendations

As a result of the developed model simulation the ring-shaped cylindrical parts final configurations are presented in the machining conditions using multi edge self adjusting accessories with different edges number. The table 1 exemplifies the simulation results obtained according to the theoretical model in the three-jaw chuck ring clamping of the external diameter of 70mm, internal diameter of 58mm and width of 20mm under the clamping forces of $P_1=P_2=P_3$=2500 N.

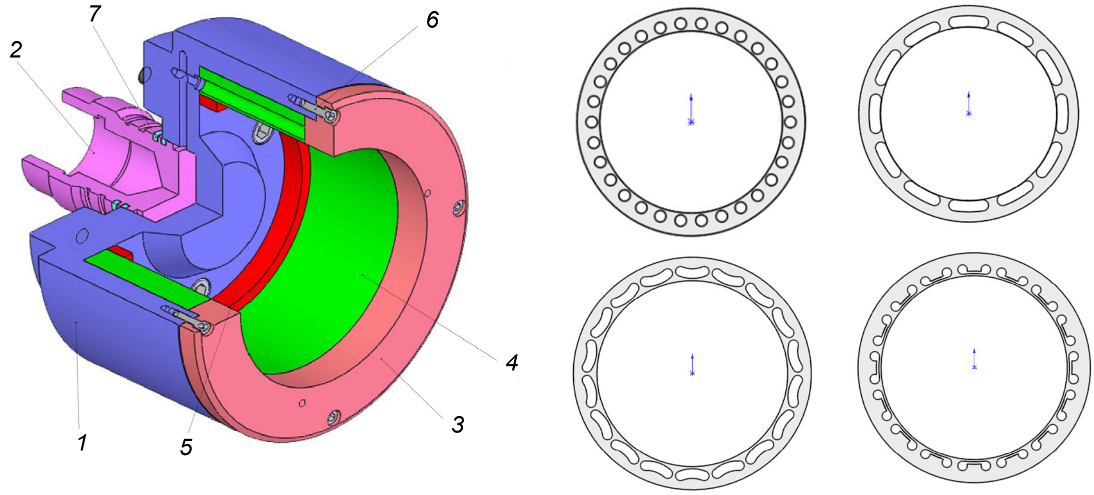
Table 1.

Configuration deflections from the theoretical one in ring different points under the total clamping force P_Σ=7500 N of the three-jaw chuck

	Angular position, grad					
	0	30	60	90	120	150
$y_p(\theta)$, mkm	-15	1,5	13,5	1,5	-15	1,5
	180	210	240	270	300	330
$y_p(\theta)$, mkm	13,5	1,5	-15	1,5	15,5	1,5

The total machining error in the ring clamping is of 28,5 mkm. As a result of analysing the final ring configuration after the machining using the multi edge self adjusting accessories as well as the clamping elements prediction model it is possible to find the minimal number of jaw chuck clamping elements as well as admissible clamping forces range guaranteeing the necessary ring shaped cylindrical parts roundness tolerance and providing their reliable clamping in the machining process.

It is possible to decrease the form errors under the clamping forces or to eliminate those at all using principally new designs of the clamping devices. Their operation is based on the principle of force closure around the circumference. Such clamping schemes are realized in hydraulic clamping devices (fig. 6,a) with shell member and bush clamping elements (fig. 6,b) designed in Ternopil Ivan Puluj National Technical University. The developed clamping devices can be well compounded with the machine tool clamping drive (hydraulic or electromechanical) and as the research results prove (Lutsiv, 2013, Voloshyn 2013) are to make the clamping force over the overall ring work piece surface and to provide the clamping regulating in the necessary range.



a) b)

Fig.3. Clamping device design scheme (a) and design structural variants of bush clamping elements (b): 1 – device box; 2 – inner piston; 3 – flanged piece; 4 – bush clamping element; 5– ring; 6 – screw; 7 – seel

Conclusions

1. The analytical model to evaluate the ring shape cylindrical parts form errors in machining using two edge self adjusting tool accessories is developed. The model makes possible to take account of clamping forces multi point application from the clamping device as well as cutting forces action in the single edge and two edge tool accessories.

2. Basing on the analysis of the extra radial and tangential response forces on the jaws forming in a single and two edge self adjusting machining it is proved that the extra response loads on the jaws under the equalized cutting forces while two edge tool self adjusting accessories using are not to be into action.

3. To decrease the form errors from the clamping forces or to eliminate them at all it is recommended to use the developed hydraulic clamping devices with bush clamping elements and clamping loadings balancing distribution over the ring work piece surface.

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