6. Заключение

Рассмотрена задача о вдавливании штампа, с учетом нелинейного закона трения. Для решения контактных задач с учетом трения, шероховатости упругого полупространства предложен метод с использованием регуляризации интегрального уравнения, кубатурных формул, введением разности значений искомой функции в разных точках и последующей интерполяции слагаемых для устранения особенностей.

Приведены числовые примеры, подтверждающие правильность и эффективность предложенного метода решения, из которых видно, что учет степенного закона трения, по сравнению с линейным, приводит к более равномерному распределению нормального давления по области контакта. Увеличение высоты приложения горизонтальной силы, приводит к большей несимметричности распределения давлений, что может привести к отрыву штампа от поверхности упругого полупространства.

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CONTROLLING THERMAL DEFORMATIONS DURING MECHANICAL SHAFTS PROCESSING

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This paper examines the basis of controlling the thermal deformations process during mechanical processing of long-length, low stiffness shafts. This article focuses on making manufacturing accuracy higher and keeping this accuracy during normal exploitation.

This high accuracy is available through the minimization of residuary axis stress force forming during the processing. A functional outline of the automatic accuracy control during mechanical processing is presented. Keeping the introduced recommendations and technological conditions, considering the stabilization of axis deformations of power perimeter and the correction of the machining depth allows stabilizing depth of stress-deformations state in the outer layer of part. This allows also to receive parts of the intended accuracy and to keep this accuracy during the exploitation.

INTRODUCTION

Working out modern technology of machining shafts-rotors, members of turbine compressors revealed the complexity of problems with high accuracy of manufacturing shafts with diameters of 38-50 mm and length of 3000-6000 mm made of stainless steel 10H17NWM2T, 08H13.

Machining process worked out earlier, e.g. turning on a RW-106 lathe with use of self-centring holders [1, 2] gave good results – vibration at a cross section along the entire length after one rough pass didn't exceed 0.012 mm.

Accuracy lengthways was 0.010 mm/m, which fills requirements described in structural documentation. It proves that stiffness of self-centring holders depends on the working pressure in holder's hydraulic cylinders, and if we take into consideration, that needling accuracy of semi-finished product and the stabilization of it's axis is obtained by the automatic controlling system, with the feedback according to working rolls location towards the working surface, so reduced stiffness of the semi-finished product in it's processing may be regarded as endless. Apart from that, basing of the semi-finished shaft on the outside diameter allows connecting technological, structural and measuring bases. However we didn't manage to keep an accuracy after processing on the machine tool. After 72 – 100 hours shaft deformation (bending the length in the centre) was 0.1 - 0.4 mm/m. Geometrical parameters also didn't meet rotor-shafts exploitation characteristics. That's why a decision to develop shafts processing technology with use of length stabilization arrangement of semi-finished product in the processing was taken.

LONG-LENGTH SHAFTS PROCESSING TECHNOLOGY

Engineering calculations for shafts with diameter of 40 mm and length of 3000, manufactured from 10H17N13MGT steel with coefficient linear expansion $\alpha = 18.5 \cdot 10^{-6}\, mm/m{\cdot}^0C$ were taken.

Lengthening the semi-finished product as a result of heating up in the machining process to $T = 70^0C$ were calculated according to:

$$\Delta l = \alpha \cdot L \cdot T^0 = 2{,}775 mm \tag{1}$$

Relative lengthening $\sum = \Delta l / L = 0{,}925 \cdot 10^{-3}$.

Axial force forming at lengthening the semi-finished product as a result of heating up, at propping with the rotational needle is:

$$F_o = S \cdot E \cdot \alpha \cdot \Delta T = 907425\, N. \tag{2}$$

Residuary stress force that can form were calculated according to following equation:

$$\sigma = E \cdot \alpha \cdot \Delta T = 182\, MPa, \tag{3}$$

where: S - cross section surface of the semi-finished product, $E = 2.1 \cdot 10^5$ MPa, ΔT - temperature difference (between the heated up semi-finished product and the environment).

The potential energy as the result of elastic stress force that apperas during heating up was determined using the relation:

$$P = 0{,}5F_o \cdot \Delta l = 1255 \cdot 10^3 \, Nmm. \tag{4}$$

If we consider the fact that axial residuary stress forces, which are summed with thermal stress forces, appear on the semi-finished product surface during the turning process, the deformation of the finished product is unavoidable.

The purpose of developed technology is to make manufacturing accuracy of rotor shafts higher during mechanical processing and keeping it during usual exploitation. It is achieved by minimization of residuary axis stress force arising during the mechanical processing.

This target is achieved thanks to fact that as an entrance parameter – the thermal increase of parts length which occurs during the machining is set. This parameter is registered and converted into the electrical signal, which is finally converted as a controlling signal of residuary axial stress force controlling servo in the semi-finished product. At the lack of controlling influences, residuary axial stress force cause deformations of the semi-finished product after mechanical process, and during the exploitation - disrupts of dynamics of finished parts work. To include the influence of the change in the dynamic flexibility of the technological arrangement, a flexibility of the semi-finished product is registered along three axis on the tool through the control of deformations of the tools needle. In addition an electrical signal connected with the thermal deformation of an semi-finished product is registered, and next tool's rest supporting axial force, which stabilizes axial resultant force that influences the semi-finished product is controlled. This force is enough for holding the semi-finished product in balance while machining force appears. In the function of the thermal volume change, growth of the working diameter is automatically corrected in range of the tolerance for the finished part by the machining depth, maintaining received diameter at the same time along the entire length, taking thermal volume change into consideration.

LONG-LENGTH SHAFTS AUTOMATIC PROCESSING ACCURACY CONTROLLING SYSTEM

Automatic controlling system for mechanical processing accuracy of long-length shafts include a tool rest, made as an non-contacting dynamometrical needle containing three preliminary converters registering static and dynamic needle movement along three axis X, Y and Z. The first preliminary converter is recording axial deformations toward X axis and additional thermal deformations of the semi-finished product through the resilient element of the tool rest. Needle dynamometrical deformation in YOZ plain is registered by two different (second and third) preliminary converters installed on OY axes and OZ towards the tool's rest. Those three converters are simultaneously connected to the two controlling circuits. The first circuit (stabilizing residuary stress force) contains second and third preliminary converter (needle dynamometrical deformation in Y and Z axis) – appropriately, both exits of these sensors are connected to input of the differential amplifier and the output of this amplifier is connected to the first calibrated amplifier. The second input of this amplifier is connected to the output of the first preliminary converters (measuring semi-product axial deformations) and it's output is connected to the first circuit of automatic residuary axial stress force controlling. This circuit contains (in order): comparison element, which second input is connected to the output of axial power regulator and the output signal is connected one by one to: power amplifier, electro-hydraulic drive and dynamometrical node.

Blocks of the first circuit are connected to the second circuit of automatic machining depth regulator (during processing), three preliminary converters, differential amplifier and the first calibrated amplifier which output is connected to the second controlling circuit - which contains: "insensibility zone" type block – which output with the machining depth regulator output is connected to the input of second comparing element, and it's output is connected to the third comparing element. The second input of the third comparing element is connected to fourth preliminary converter-controller (feedback loop of knife movement correction signal as a function of thermal semi-finished product lengthening). And finally output of the third comparing element is connected to the included blocks one by one: second power amplifier, small movements electro-hydraulic drive of the knife edge in Y axis (after location correction).

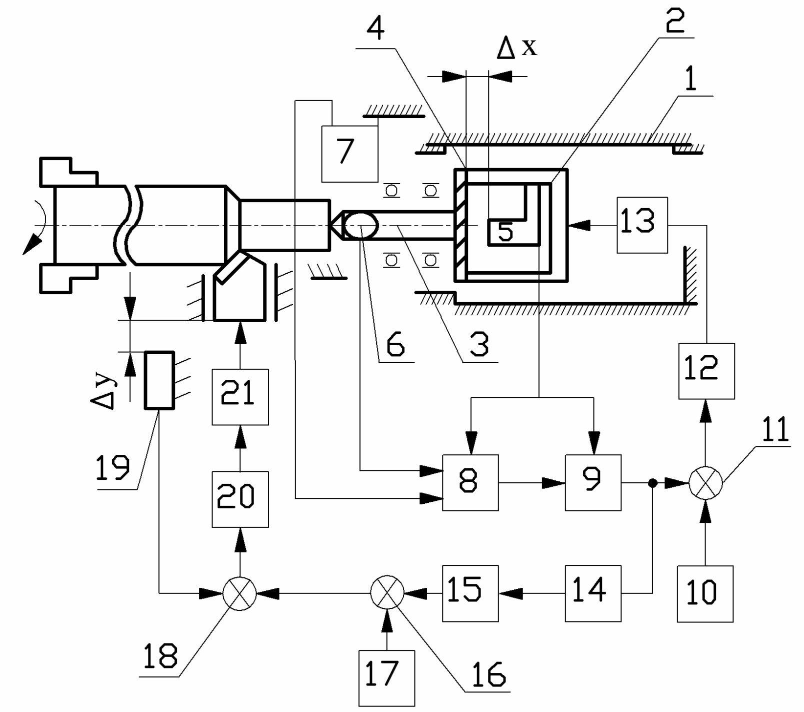

Fig.1. Functional outline of the mechanical processing accuracy controlling system

The key of this technology is to change the order of controlling the long-length shafts mechanical processing, while axial controlling force isn't influencing the semi-finished product, like during earlier known ways of processing [4, 5] - the semi-finished product was being squeezed or stretch using axial force while stabilizing this force, so that lengthening of the semi-finished product didn't form residuary stress force which will lead to deformations of finished products.

Known technical solutions are based on the technological inheritance of low stiffness parts and on resilience – plastic theory phenomenon occurrences in metal in the time of mechanical processing [5, 6]. Active control of the expanding volume of the semi-finished product during machining and controlling the axial hugging force does not allow residuary stress force to appear independently on the physico-mechanical and geometrical properties of semi-finished products.

Fig. 1. describes functional arrangement of mechanical processing automatic accuracy controlling system of long-length shafts. Controlling system includes: tool rest 1, which contains dynamometric node 2. Node 2 contains: dynamometrical needle 3, resilient element

4 taking the axial force, preliminary converters 5, 6, 7 installed appropriately along the X and Y axis, differential amplifier 8 which input signal comes from preliminary converters 5, 6, 7 and output is connected to blocks circuits; first calibrated amplifier 9, axial force regulator 10, comparison element 11, power amplifier 12, electric drive 13. Output signal of the first calibrated amplifier 9 is connected to the second channel of machining depth regulator, which contains second calibrated amplifier 14, “insensibility zone” type block 15, second comparison element 16, machining depth regulator 17, third comparison element 18, sensor 19 of the feedback of knife edge location, second power amplifier 20, electro-hydraulic drive 21 for radial knife movement.

The work of the mechanical processing automatic accuracy controlling system of long-dimension parts is fulfilled in following way. The semi-finished product is mounted in the handle and pressured with dynamometrical node 2 with fitted in dynamometrical needle 3 witch one end is leaning against the semi-finished product and second against resilient element 4, it’s movement is controlled by first small movements preliminary converter 5 which is fastened stiffly in the body of the dynamometrical needle according to resilient element 4 with initial clearance ΔX. During increasing the length of semi-finisher product as a result of thermal expandability while machining, dynamometric needle moves against X axis and deforms resilient element 4. Element 4 deformation is calibrated in harmony with it’s physico-mechanical characteristics and is diagnosing the axial stress force in the semi-finished product during the mechanical process. Resilient deformation of element 4 is registered by the first preliminary converter 5.

Shaping the useful signal in the aim of suppression the disrupting influences caused by thermal-force deformations of the rotational needle in the YOZ plane is realized by registration the static and dynamic deformations components through preliminary converters 6 and 7 and with differential amplifier 8 which output signal is changing the amplification rate of calibrated amplifier 9 in the static and dynamic change function of flexibility of the dynamometrical needle 3 in selected coordinates system. Thermal deformations in the X axis direction are registered by preliminary converter 5 and are converted in electric signals, directed to calibrated amplifier 9 which normalizes the output signal of preliminary converter 5 through the change in his amplification rate. In this way input signal on the calibrated amplifier 9, tied functionally with thermal (axial) deformations of the semi-finished product is controlling axial force leaning the semi-finished product in the adopted axial deformation scope of regulator 10. This means that the set axial needle leaning force maintains its value in the time of the entire process, independently on geometrical and physico-mechanical parameters and temperature conditions of processing of the semi-finished product.

The semi-finished product, while stretching is not additionally loaded with outer axis force resulting from the thermal expandability. Signals of regulator 10 and block 9 are directed to the comparison element 11, from which differencing signal proportional to controlling signal is pointed to the power amplifier 12 and then to electro-hydraulic drive 13 which is transferring dynamometrical needle 2 according to tool base 1 by a value proportional to the semi-finished product deformation caused by thermal deformation, supporting by the way semi-product leaning force set by regulator 10.
Additionally in function of formed controlling signal taken from calibrated amplifier output 9, a size of the machining depth of the semi-finished product taking thermal deformations into consideration is corrected (through knife influence). This change is set by voltage at the output of the machining drive correction regulator 17, through connected one by one: calibrated amplifier 14, "insensibility zone" block type 15, comparison element 16. While the size of controlling the correcting signal in the process of setting is achieved by change in

the amplification rate of the calibrated amplifier 14, and a size of insensibility zone is set so that the signal of controlling on it's output only then appears when the temperature of the semi-finished product rises directly in the time of processing up to 15^0-20^0 C against the surrounding environment temperature. Next, the controlling signal - correction of the knife edge taking thermal expandability of the semi-finished product into consideration, from output of the comparison element 16 is directed to input of the comparison element 18, where it is compared with feedback signal of knife edge location to preliminary converter 19, installed on machine tools base. Differential signal on the output of the comparison element 18, is directed to the input of second power amplifier 20 and next to the electro-hydraulic drive 21.

CONCLUSION

Assuring that abovementioned conditions and the operations order are met (considering also axial deformations stabilization of tool base circuit and correction of the machining depth) the stabilization of stress-deformations depth state of the outer layer can be achieved. This will also allow receiving parts with the demanded accuracy in lengthways and crosswise direction and to keep this accuracy during the exploitation.

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COMPARISON OF CUT OUT'S INFLUENCE ON THE HYDRODYNAMICS OF THE TWO-PHASE GAS-LIQUID FLOW IN HEAT EXCHANGER WITH SEGMENTALL BAFFLES*

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This paper presents DPIV techniques, applied for evaluation of hydrodynamic properties of two-phase gas-liquid flow. The process of the flow were performed in shell side of heat exchanger. Single image of the two-phase flow registered by digital video camera in grey scale reflects instantaneous concentration distribution of particular phases. The idea of proposed method of gray level fluctuations analysis is based on determination of the change of certain features which are results of digital image representation (that is image as a distribution function of gray level values).