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Improving the accuracy of manufacturing of hydraulic power cylinders using vibration-proof cutting tool

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Abstract. The article introduces new results on designing multilayer cutting tool holder. Experimental study of metal turning process workpieces shows efficient dynamic damping of oscillations. The coefficient of oscillations absorption and damping is increased due to large dissipative force of the material holder oriented in different deformation directions of holder material.

Key words: flat rolled stock, heterogeneity of structures, oriented deformation, adjustable anisotropy, multi-layered damping tool holder.

INTRODUCTION

Dynamic stability of the manufacturing system, reduction of vibration level generated in the process of cutting are prerequisites for stable chip formation. Meeting these requirements is crucially important for the automation of the process (Weitz, 2002). It is known that the vibration generated in the process of metal cutting leads to essential obstruction for automated manufacturing. Premature failure of tools, accidents of machines and facilities are some of potential consequences. Increased stability of the manufacturing system stability due to reduced level of self-oscillations is important issue for metal cutting industry. Main challenges are met when dealing with final machining of parts by automatic NC machines (Anastasiadis & Silnikov, 2002; Maksarov & Olt, 2008; Maksarov & Olt, 2010).

A number of fundamental research papers are devoted to studying of self-oscillations at metals cutting. The chip forming process at turning operation and the importance of manufacturing system stability at mechanical processing have been explained. Analyses of the methods and techniques that ensure stability of manufacturing systems confirm that these methods allow increasing stability of a manufacturing system in a varying degree and techniques. Several of those methods are applied successfully in practice at mechanical processing. Nevertheless, at present there is no universal method that allows effective suppression of vibration generated at turning.

In terms of dynamic stability the subsystem of the cutting tool is mainly affected by vibrations at final turning. Free damped oscillations, forced oscillation, parameter-induced oscillations and self-oscillations occur as a result of the impacts within the manufacturing system. Frequency equal to forcing frequency or frequency of the complicated periodical processes stipulated by nonlinear properties of the system are to be expected. Intensity of forced oscillations is especially high in resonant modes, which are inadmissible in cutting machines when performing final machining.

MATERIALS AND METHODS

At turning, in conditions of constrained cutting, the resultant cutting force P is composed of three mutually-perpendicular force components (Fig. 1). P_z is cutting force or tangential force tangent to the rake face and matching direction of the main motion; P_x is axial or feed force acting in parallel to the workpiece axis in direction opposite to feed motion; P_y is radial force directed perpendicular to the axis of the processed workpiece.

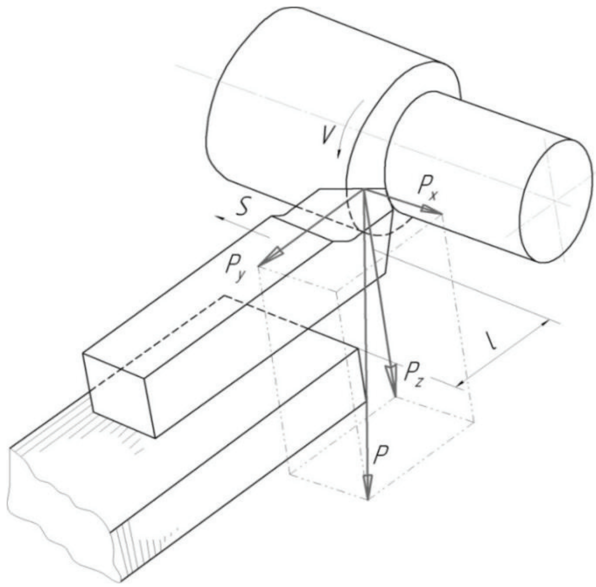

Figure 1. Diagram of cutting forces at turning, where: *s* is feed direction and *v* is cutting speed.

Development of a damping tool equipped with a multilayer holder with anisotropic properties is one of the most effective methods to ensure stability of the tool subsystem at final turning of cylindrical parts. Turning process with a tool equipped according to the suggested method show reduced level of self-oscillations occurring in cutting process due to designed disorientation in texture of anisotropic plates of a prefabricated multilayer holder. This allows effective dissipation of oscillatory wave energy at interfacial boundary between the holder plates. This method allows essential improvement in endurance of the tools cutting edge and extension of processing capabilities in regard to selection of effective cutting modes. Additionally ensuring compliance with demands of dimensional and geometric accuracy specification of processed surfaces.

The method suggests the using intrinsic anisotropy of holder plates by the method of pressure shaping. Plastic deformation of steels by hot rolling leads to change in direction of the structural constituents and inclusions along its direction thus forming mechanical deformation texture besides crystallographic texture. It is suggested to manufacture a cutting tool holder out of a pack of plates preassembled by planes parallel to the holder support surface; at that the plates are cut out of flat rolled stock with longitudinal, transversal and vertical orientation in plane regarding direction. After which they are assembled into a pack with the texture gain-boundary angle between the plates. Oscillations occurring in process of mechanical processing of the holder rod at low deformations are described by Hooke's law. Friction resistance at fixed connections between the plates and internal friction in the holder material must be considered. Inelastic effects of internal friction stipulated by available texture of the material and related to dislocations migration lead to irreversible hysteresis losses inside the metal at mechanical oscillations (Barmin, 1972; Ashkenazi, 1980; Borodkin, 1981; Anastasiadis & Silnikov, 2002). The holder plates should be oriented so that at transition from one plate to another one deformation is changed per $90 \pm 10°$ as related to action to the holder of the main tangential component of cutting force. Under action of cutting force in the upper layers of the holder mainly maximum tensile stresses σ_t occur while in the lower support layers compression stresses σ_c appear.

The Fig. 2 shows structure of a straight-turning tool holder with plates having oriented structure. The plate 1 is cut so that its surface has longitudinal orientation in regard to the direction of rolling. At that cross-section plane of the plate 1 is oriented transversally in regard to the direction of rolling. Plane of the plate 2 is oriented across the direction of rolling while its cross-section plane is oriented along the direction of rolling. Plane of the plate 3 is oriented vertically in regard to the direction of rolling and its cross-section is oriented in longitudinal direction. Accordingly all plates have different texture of deformation in their plane and cross-section, different physical and mechanical properties, including damping properties, as related to action of forces (cutting force components) (Weitz, 2002; Maksarov & Olt, 2010) loading the holder.

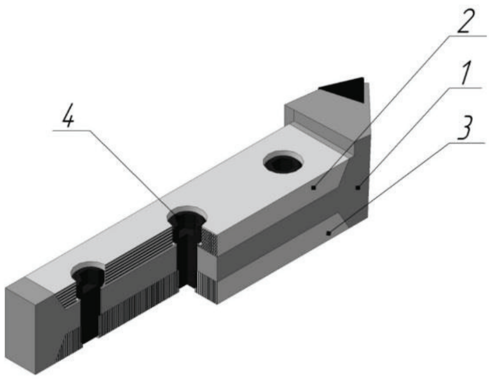

Figure 2. Structure of the straight-turning tool holder with plates having oriented structure.

At oscillations occurring in process of mechanical processing behaviour of the multilayer holder cross-section at low deformations is described by means of Hooke's law considering friction resistance at fixed connections between the plates and internal friction in the holder material (Vishnyakov, 1979; Vishnyakov, 1989).

In result of imperfect elasticity of metals the lines of stress deformation curve do not match at loading and unloading and form a hysteresis loop (Fig. 3). Its square area characterizes energy dissipated in one loading cycle. Internal friction is related to static hysteresis when shape and square area of its loop are not stipulated by temporary relaxation processes and therefore they do not depend on oscillation frequency, oscillation amplitude and material of the holder (Maksarov & Olt, 2008; Maksarov & Olt, 2010).

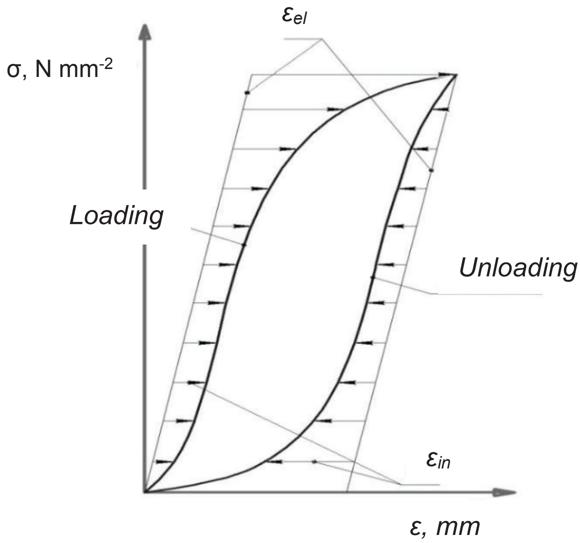

Figure 3. Hysteresis loop of stress σ deformation ε curve: ε_{el} is elastic deformation; ε_{in} is inelastic deformation.

While transiting the boundary between the plates the oscillatory wave changes its direction, and in result dissipation of vibration energy takes place. Dissipation of energy is insignificant at low value of the plate texture disorientation.

As is known, metals with a lattice of a space-centred cube have essential anisotropy of their properties (Vishnyakov, 1979; Vishnyakov, 1989; Glebov, 1990). Well-pronounced ductile-to-fragile transition is often observed in them, and this transition is defined by availability of fragile inclusions, temperature, conditions of load application and other factors. Annealing and recrystallization of flat rolled stock lead to redistribution of inclusions and change in texture. This change in texture leads to decrease in strength and viscosity in normal direction to a sheet.

RESULTS AND DISCUSSION

Table 1 is showing testing results of mechanical properties. Samples of flat rolled stock of steel BCт3 brand with thickness from 30 up to 40 mm (Glebov & Duchovni, 1990). The testing results provide evidence of significant anisotropy of mechanical properties, especially plasticity, Poisson's ratio and impact toughness.

Table 1. Mechanical properties of a steel sheet

Direction of rolling	Yield limit σ_y, MPa	Ultimate strength σ_u, MPa	Plasticity σ, %	Posson's ratio Ψ, %	Impact toughness RCU, J cm^{-2}
Lengthwise	237	402	35.9	63.3	42
Transverse	235	402	29.4	55.3	29
Crossed	322	402	7.0	11.8	16

Anisotropy of mechanical properties in materials may be high and it depends on stress-deformation profile at testing. Fig. 4 shows changes in conventional yield limit for low-carbon steel with 3% of Si depending on angle toward rolling direction where anisotropy reaches 30%.

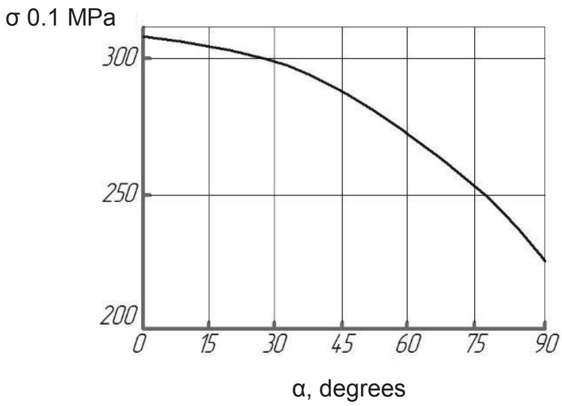

Figure 4. Change in conventional yield limit depending on angle towards the rolling direction.

Dependency of Young's modulus for chromium-molybdenum steel in the rolling plane on rolling direction upon hot deformation is specified in Fig. 5 (Miklyaev & Friedman, 1986). The figure demonstrates that difference in Young's modulus is 15% upon rolling and 10% upon annealing, which is related to deformation structure.

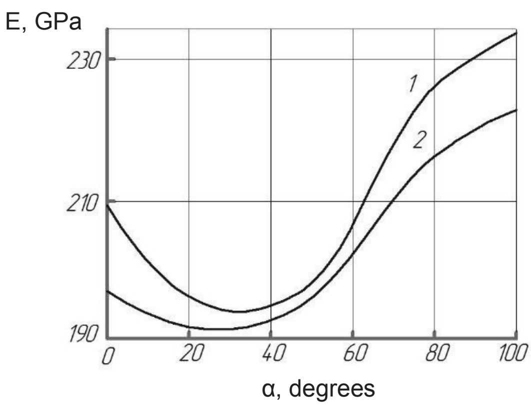

Figure 5. Change in Young's module depending on angle towards the rolling direction: 1 – upon rolling; 2 – upon annealing.

At static loading of the samples, at stages of elastic and elastoplastic strain, anisotropy of the characteristics is insignificant; it increases sharply at the yield pint and more towards bigger plastic deformation. In many practical cases mechanical texture causes anisotropy of the properties. Two mechanisms of considerable impact are possible:

- influence of crystallographic texture relative to anisotropy of elastic modulus and respective deformations;
- influence of non-metal inclusions relative to progressive increase of the surface area in process of alloy deformation and destruction considering that critical length of cracks, for example, for steel with yield strength of 1,700 MPa is 0.2–0.5 mm.

The Fig. 6 shows cracks with non-metal inclusions represented as elongated lines with sulphide and oxide inclusions. These inclusions have direct impact on the anisotropy of the impact toughness.

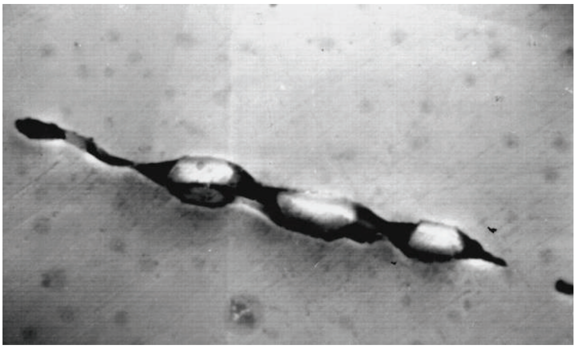

Figure 6. Non-metal inclusions: a, b – 100 times increase; c – 200 times increase.

In order to determine direction of texture in the holder plates and to assess anisotropy values, tests were performed to define mechanical properties of the material used for manufacturing of the designed multilayer holder.

The tests were carried out on a universal testing machine TIRAtest 2820. That is a measuring system capable of measuringforce and changes in linear dimensions of the metal samples for tension, compression and bending at static load modes.

The testing was performed on specimens made of hot rolled steel 45 (as per GOST 1577-93).

The samples were cut out of the surveyed flat rolled stock in three perpendicular directions (Fig. 7): lengthwise rolling (samples B), perpendicular rolling (samples C) and cross direction rolling (samples A).

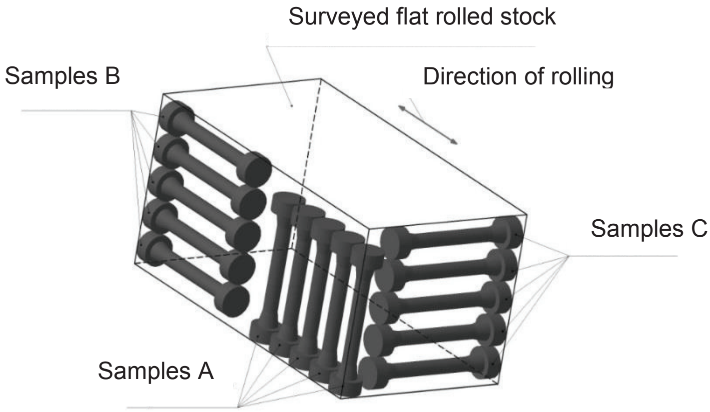

Figure 7. Points of the samples cutting out of the surveyed flat rolled stock.

The samples were made according to requirements of the standard GOST 1497-84, type V, number 7, with initial diameter of a sample of $d_0 = 5$ mm and initial design length of $l_0 = 5$ d0 = 25 mm. Turning of the samples was carried out according to the drawing (Fig. 8) with allowance of 0.5 mm at the surface with initial diameter of a sample of $d_0 = 5$ mm for heat treatment. Heat treatment was performed in the following sequence: tempering – heating up to temperature of 850° C, cooling medium – oil; temper drawing – heating up to temperature of 200° C, cooling medium – air. Hardness test for each sample was made by TP 5014 hardness tester. Then final turning of the initial diameter was made up to the size of $d_0 = 5_{-0.012}$ mm.

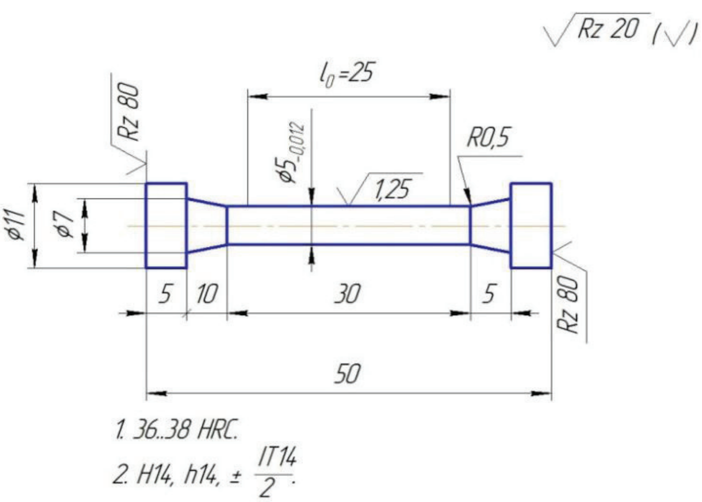

Figure 8. Drawing of a sample.

The Table 2 presents testing results for the samples of flat rolled stock received by elongation method.

Table 2. Average values of mechanical properties for the samples out of flat rolled stock

Rolling direction of a sample	Sample hardness, HRC	Ultimate strength $\sigma_{0.2}$, MPa	Tensile strength, σ_t, MPa	Plasticity σ_{av}, %	Poisson's ratio Ψ_{av}, %
A	37	1,281	1,350	0.71	6.29
B	37.2	1,219	1,334	5.03	28.38
C	36.8	1,212	1,365	2.36	18.8

CONCLUSIONS

For commercial steels anisotropy of their mechanical properties is stipulated mainly by structural heterogeneity. In addition there are influences from the quantity and morphology of non-metal inclusions.Parameters of microstructure have less significant effects.

It is shown that increaseing structural heterogeneity of a material its dampening quality also increases and this fact may be used to reduce self-oscillations. This principle is used for for increasing the performance quality of the manufacturing subsystem: cutting tool in process of high-speed turningoperation.

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