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Burnishing Systems: a Short Survey of the State-of-the-art

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Abstract. The modern technological solutions allowing to implement a new technology of surface plastic deformation are considered. The technological device allowing to implement the technology of hyper productive surface plastic deformation or wide burnishing (machining time is up to 2-3 revolutions of workpiece) is presented. The device provides the constant force of instruments regardless the beating, non-roundness and other surface shape defects; usable and easily controlled force adjustment; precise installation of instruments and holders toward the along the worpieces axis; automation of the supply and retraction of instruments. Also the device allowing to implement the technology of nanostructuring burnishing is presented. The design of the device allows to eliminate the effect of auto-oscillations.

1. Introduction

Surface plastic deformation (SPD) is a set of technologies for modifying the surface and near-surface layers of workpiece by plastic deformation. In the world literature, unlike the Russian Federation, this set of technologies is called “burnishing”, by the name of one of the main technologies. The peak in the development of PPD occurred in the 1980s, and at present SPD technologies continue to develop. The main directions of development are concerned with the transition to advanced digital and intellectual production technologies for the transition to a new technological way.

In this paper, several technological solutions allowing to implement modern SPD technologies are considered. The choice of these technologies is specified by several factors: mandatory industrial approbation and use in batch production, as well as the presence of a key difference in the mechanics of the process. These characteristics make it possible to distinguish these technologies as the best available, which contributes to the priority of their choice in the production development. The implementation of the following technologies is considered: the technology of hyper productive SPD (wide burnishing) and the technology of nanostructuring burnishing.

2. Hyper productive surface plastic deformation processing or wide burnishing (WB)

The most prevalent technology in the industry, including aerospace industry, from among the SPD technologies is a ball burnishing [1], however in spite of high numerical values of microgeometry parameters it is difficult in application. The purpose of developing a wide burnishing was the creation of a technology with processing time up to 3-4 revolutions of workpiece in a mass production. This required increase of force during processing from 150-300N (standard burnishing) to 2500-3000 N.

The issues of thermal stress and compensation of the transverse direction of the burnishing force have a special importance for these technological parameters.

The problems of increased thermal stresses [2] and their modeling [3] were considered earlier. It was found that with an increase in speed and pressure on the treated surface, the average temperature

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rises up to 8-9 times, but even under extreme processing conditions of high-strength cast iron with globular graphite, the temperature did not exceed 400 °C. The revealed dependencies made it possible to establish technological limitations of the processing on two factors: to prevent negative structural-phase transformations, and to reduce the intensity of tool wear.

To eliminate the appearance of a force directed across the axis of the worpiece and causing its deformation, a new design of the device for burnishing was developed [4]. Providing a proportional distribution of the processing force makes it possible to create residual compressive stresses.

The constructions of devices allowing processing without deformation are known before and the instruments are coaxial. However, the presence of defects in the shape of the workpiece and the basing leads to an uneven compression of the instrument against the surface [5]. As a result, the quality of the treated surface deteriorates and the uneven wear of the processing instruments increases significantly during processing. Double-lever devices are known [6], as equipped with two instruments, which of them is loaded with a separate spring. This devices allow to compensate the beating and non-roundness of the workpiece, but also have a uneven loading of instruments and their uneven wear.

There are Double-lever devices with two instruments loaded by a single spring located between the opposite ends of the levers [7].

The devices do not allow quickly, conveniently and accurately adjust the force of tools pressing to the workpiece. The device is moved to the working position by moving the entire device across the workpieces axis, with a spring-loaded stop applied for the device centering, which contacts the workpiece during processing and, therefore, can degrade the surface roughness and creates additional friction forces. The accuracy of centering of such a device is small. The device does not allow processing the workpieces with a change in size along the axis, for example, acclivous cones and other shaped parts due to the pressing force of the instrument will not be constant.

None of the mentioned devices is possible to set the coincidence of the axes of the working part of the indenters (their location in one plane perpendicular to the axis of the worpiece). Meanwhile, it is necessary that the traces of the indenters represent a regular two-screw line with steady pitch, it will ensure an even distribution of roughness along the length of the product. The use of all these devices in automated machines is difficult. The known dependences for determining the state of a plastically deformed surface layer with taking into accounting the thermal effect of plastic deformation, present the need to provide this solution [8].

The developed device provides a constant pressure of the instruments, regardless of beating, non-roundness and other changes in the shape of the surface. It is also provides a convenient and easily controlled force adjustment, precise mutual installation of instruments and holders in the direction along the worpieces axis as well as automation of the supply and retraction of processes.

The goal is achieved by the fact that the device consist of a body and double-levers hinged on the body, as well as holders with instruments fixed to one end of the levers. The second ends of the levers are equipped with hinges, to which are respectively connected the rod and the body of the hydraulic cylinder installed between them and combining the functions of the feed and pressing of the instrument. The rotation axes of the levers are located at a distance equal to the diameter of the workpiece, symmetrically with respect to axis and the working surfaces of the instruments due to eliminate the component of the working force deforming the workpiece in a plane perpendicular to the line connecting the instruments.

For precise mutual installation of instruments and holders in the direction along the axis of the workpiece, the holders and the ends of the levers are provided with guides for rectilinear movement, the holders are movably mounted along the axis of the workpiece and each of them is provided with at least one adjusting screw and also a screw for securing it in an adjusted position. For precise adjusting of the holder the adjusting screws can be made micrometric. Figure 1 presents the side view of the proposed device.

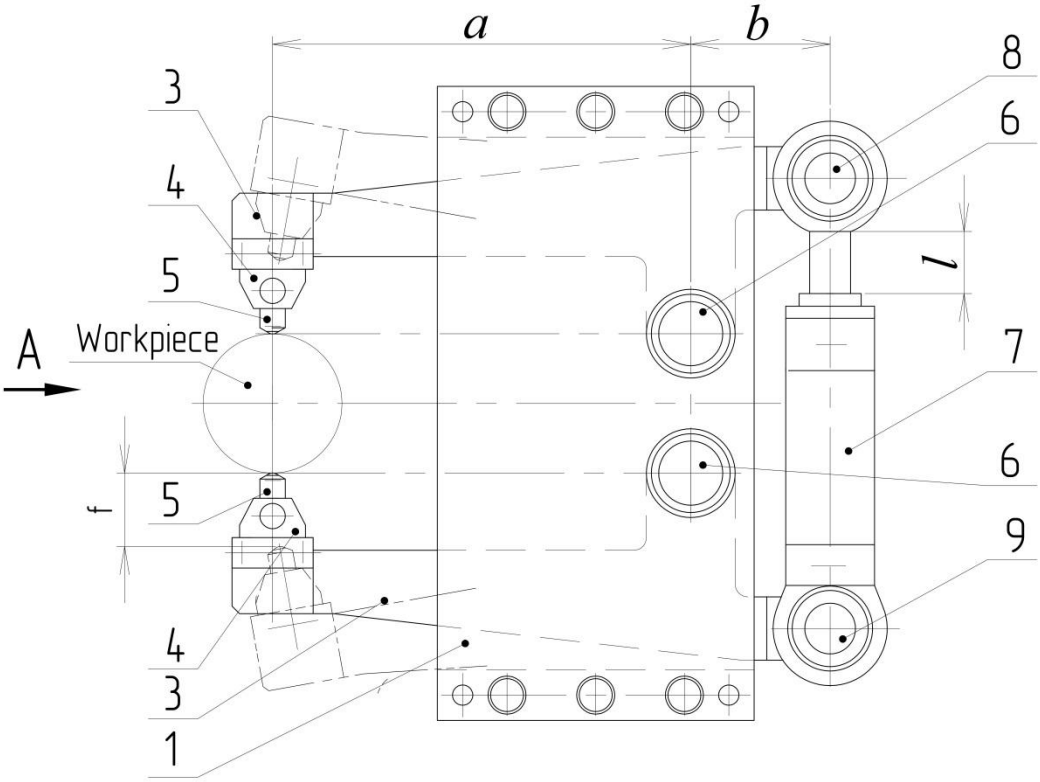


Figure 1. Design of the device.

The body of the device consists of two plates 1 and 2, connected together, for example, by screws (figures 1 and 2). Between the plates 1 and 2 two double-levers 3 (the upper and lower) are situated. The instrument holders 4 and instruments fixed in them, for example diamond burnishers - indenters 5 are situated at the one end of the levers. Each lever 6 is supported by a hinge in the body. The other ends of the levers are provided with hinges 8 and 9. The rod and the body of the hydraulic cylinder 7 are connected with these hinges respectively, which perform the functions of supply-retraction and pressing instruments to the workpiece. The hinge axes 6 are located at a distance equal to the diameter of the workpiece, symmetrically relative to its axis and instruments work surfaces.

To provide instrument retraction by a given amount f, the stroke of the hydraulic cylinder l is defined from the relation:

$$2\frac{b}{a}f < l \qquad (1)$$

This feature is provided for two tasks:

Replacing the burnishing instrument;

free setting trajectory of workpiece.

At the end of the carrying the instrument lever 3, there is a rectilinear motion guide, for example, "dovetail" type or rectangular groove "B", as shown in Fig. 3. In this groove the shank of the instrument holder 4 is placed with the possibility of moving along the workpieces axis. The instrument (indenter) 5 is fixed in the holder with a screw 10. From the ends the groove B is closed by two slats 11 fixed to the lever 3 by screws 12. The adjustment screws 13 are screwed into the slats 11. It may be used only one adjusting screw, but then it is necessary to fix its head from the movement in the slat 11 and screw it into the hole made in the holder 4. For precise movement of the holder 4, the adjusting screw can be made micrometric. The instrument holder 4 is fixed to the lever 3 with screw 14.

The body of the device is mounted on a working unit designed to move along the axis of the workpiece. Then, the device is set as the common axis of the working surfaces of the instruments 5 in a retracted position crosses the axis of the workpiece. The body of the device is secured in this position. The screws 14 holding the holders 4 are loosen, and by manipulating the adjusting screws 13, the holders are moved along the axis of the workpiece, ensuring that the axes of the working surfaces of the instruments match. In the same way, it is possible to fine adjust the initial position of the processing instruments.

Then, the holders are again fixed using the screws 14. By adjusting the pressure in the part of the hydraulic system of the machine to which the hydraulic cylinder 7 is connected, set the required amount of pressing force of the instruments to the surface of the workpiece (the pressing forces determine the working burnishing force). After the starting the cycle, the product starts to rotate, hydraulic fluid is supplied to the hydraulic cylinder, and the levers are reduced by pressing the instruments on the work surface. Due to the placement of the hinge axes 6 at a distance equal to the diameter of the workpiece and symmetrical relatively its axis and the working surfaces of the instruments, the pressing forces are transferred to the workpiece strictly perpendicularly to the surface. Then the device is moved along the axis of the workpiece and processing is performed.

If the workpiece surface has beating (or this beating is due to inaccuracy in unit for fixing the workpiece), the instruments with levers move relative to the axis of rotation, while the piston also moves inside the hydraulic cylinder. This, however, does not lead to changes in the pressure of the instruments, since it are not determined by the position of the levers, but by pressure value in the working cavity of the hydraulic cylinder. Therefore, the proposed device allows processing not only the surfaces of straight circular cylinders, but also parts with significant non-roundness, and also cones, for example, simultaneously processing the neck of the shaft for sealing and facet before it. At the end of the processing, the machine control system (or the operator itself) gives the command to retract the levers and return the device to its initial position. The hydraulic cylinder 7 separates the levers 3, and the part can be removed.

Thus, the hydraulic cylinder 7 in the device performs two functions: the supply and retraction of the tool (idling), as well as the creation of a working force and keeping it constant, regardless of the beating and changings in the dimensions of the processed surface. It seems promising to use this type of device in titanium alloys processing.

The implementation of this device significantly improves the stability of the wide burnishing processing, increases the durability of instruments, improves the quality of the machined surface; It allows to process parts with significant beating and non-roundness of the surface, and also shaped surfaces and cones.

3. Nanostructuring burnishing

In this technology, an enlarged roller of the pushed metal is formed, due to indenters with increased coefficients of friction and heat resistance, which ensure a high level of shear deformations. This effect contributes to the process of dispersing the structure of the surface layer [9]. However, the growth of the roller can lead to destabilization of the dynamic system of burnishing and the appearance of self-oscillations. It should be noted that when implementing the technology of green (dry) burnishing performed at increased temperature loads, the author also encountered this effect, also called “Moire effect” [10]. In this case, finite element modeling allowed to identify patterns of changes in the stress-strain state and to reveal mechanisms of formation of a nanostructured layer [11, 12]. To eliminate the effect of self-oscillations, the following design of the burnishing tool was developed.

The indenter is designed to improve heat transfer and reduce the mass with a cone shaped blind hole with an end of a circular shape (to reduce the possibility of stress concentrators). The design of the indenter ensures that it performs the function of the plunger (pressing to the body). When the low-boiling liquid is poured into the case (for example, alcohol or acetone), the indenter is cooled down

and it is possible the speed increase of burnishing (i.e. performance). The presence of the bush provides damping of self-oscillations arising when the burnishing speed is increased.

The burnisher consist of the following elements: body 1, indenter 2, set of disk springs 3, nut 4, rubber seal 5, low-boiling liquid 6, rubber bush 7. Body 1 is arranged vertically. The indenter 2 with a rubber bush 7 mounted on it is installed in the body 1. A set of disk springs 3 is installed in the body 1 and low-boiling liquid 6 is poured. A rubber seal 5 is fitted onto the nut 4.

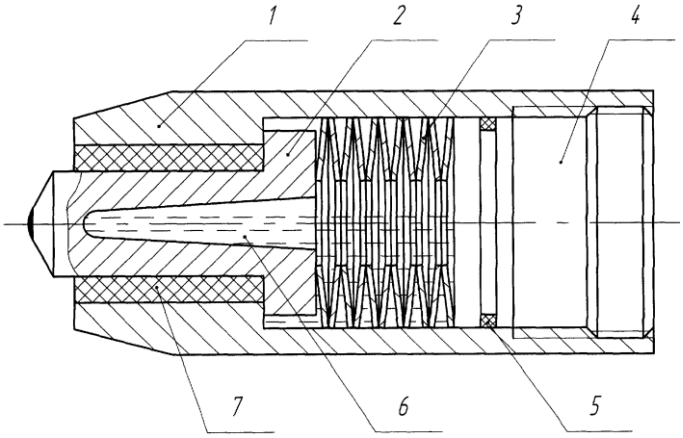


Figure 2. Burnisher design [13].

By screwing the nut 4 into the body 1, the set of disk springs 3 is pressed to the required burnishing force. The tare set of disk springs 3 is pressed by nut 4 to the required burnishing force. After the contact of the indenter 2 with workpiece the instrument is inserted into the workpiece until the indenter 2 abuts against the body 1. In this moment, the indenter 2 stops abutting the body 1 and begins to receive the force of the pre-pressed disk springs 3. When the burnisher moves, the indenter 2 is cooled down with low-boiling liquid 6, and the rubber bush 7 damps the self-oscillations of the indenter 2.

Thus, the considered device due to design features allows to implement the technology of nanostructuring burnishing in a wide range of operating modes. At the same time, increased friction provides the nanostructural burnishing can be estimated in terms of contact phenomena [14, 15].

4.Conclusion

The development of burnishing technologies in direction of operational characteristics increasing of the processed parts must be accompanied by appropriate technological support. The development of new SPD technologies is associated with new distinctive features (for example, hyper productivity) and constraints. The presented technical solutions can be used not only in the implementation of the SPD technologies for which they are intended. For example, the authors' experience shows that the phenomena arising in nanostructuring burnishing also arise in green (dry) burnishing, and the general approach described in this publication can be applied to solving problems of minimizing the probability of manifestation of these phenomena. The presented device allows to implement constant pressure at wide burnishing regardless of beating and non-roundness. The device in the case of nanostructuring burnishing that allows to eliminate the effect of self-oscillations, which directly affects the parameters of the microgeometry of the processed parts is presented.

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