MODELLING OF STRESS CONDITION OF SURFACE LAYER BY ULTRASONIC STRENGTHENING PROCESSING

A. Polovinkin, V. Makarov

Abstract
Effective way of improvement of operational properties of the details made of different marks steels and alloys is hardening their superficial layers, including with use high concentrate energy sources. In this paper results of research of process of ultrasonic strengthening finishing processing with use of a finite elements method are submitted. Mathematical dependences of interaction of the concentrator with a surface of workpiece and as results of experimental researches are submitted at hardening heat-resistant steels which used at manufacture of gas turbine engines.

Keywords: SPD - superficial plastic deformation, USFP - ultrasonic strengthening finishing processing, the concentrator.

1. INTRODUCTION
One of fundamental problems of machine-building manufacture is necessity of martempering quality, a heightening of productivity, increase in longevity and reliability of machines wares. These indexes in basic are ensured on finishing operations at the expense of quality management of a surface stratum and reaching of tall operating performances of work pieces in a completing stage of their manufacture. Reaching of tall operating performances of workpieces is ensured owing to application of strengthening machining. One of directions of a development of ways of strengthening is creation of an opportunity of control in parameters of a surface layer (depth, degree and uniformity of strengthening, and as microgeometry of a surface) in a wide range. At SPD the ultrasonic instrument speed-torque characteristics are improved such as strength and hardness that is consequence of growth of a density of dislocations raise. In hardened steels to this process transition of residual austenite in martensite is added, that as considerably raises their speed-torque characteristics. In heat-resistant steels and alloys there are interphase microstresses and, presumably, there is a seal of structure. The given kind of processing has external similarity to process of smooth by rolling. Difference consists that the concentrator makes compulsory fluctuations with the certain amplitude and frequency in a direction of a normal to a processable surface (Fig. 1). The concentrator has frequency of fluctuations 20 kHz. Such frequency of fluctuations is created by means of transformation of a current with frequency of 50 Hz the generator of semi-conductor type which is connected to the ultrasonic head established on the machine tool. In the case of the ultrasonic head it is located magnetostrictor due to which mechanical fluctuations with similar frequency are achieved. Thus process of hardening grows out short-term bangs. An interval of time of bang 5•10^{-5} sec. During the certain part of the period contact between the tool and a processable surface is absent, and at the moment of contact instant pressure are much higher than average, as results in the much greater plastic deformation, than at usual smoothening or running. On open joint-stock company «Perm engine company» researches of influence of parameters of modes of processing USFP on quality of a superficial layer of the samples made of heat resisting alloys have been carried out. It has experimentally been established, that the range of district speed lays within the limits of 20 - 25 m/minutes. At decrease of district speed improvement of quality of a surface is insignificant besides productivity of processing whereas the increase over 35
m/minutes results in occurrence of vibrations is reduced. As on a roughness of a processable surface essential influence is rendered with size of submission of the tool. The range of feeds be found within the limits of 0,05 - 0,5 mm/rev.

that speaks necessity of overlapping of traces of the tool. Usually than below size of feed, the less height of microroughnesses of manufactures surfaces. However at very small values of submission quality of a surface worsens owing to the big frequency rate of the appendix of loading (great strengthening) besides productivity is reduced.

At ultrasonic strengthening finishing processing in a superficial layer there is compressing residual pressure. Definition of sizes of this pressure is necessary to estimate a degree of hardening of a superficial layer and to reveal, what level of internal pressure is critical, that is at what pressure there is a fatigue failure of a superficial layer of a processable detail.

2. RESEARCHES

2.1 The mathematical description of single bang and force of impact.

For forecasting an intense condition in a zone of interaction of the concentrator and a detail the mathematical model of individual shock interaction is developed. The technique is based on use of contact task Hertz for elastic and plastic deformations in view of energy of shock waves that allows defining shock forces, deformations and pressure at упругопластических deformations in a zone of contact. Technological parameters of USFP are: energy of bang \( E \), a dynamic component of loading \( P_{D} \), a statistical component of loading \( P_{S} \) frequency of bangs, feed, and diameter of the concentrator. Basing on the law of preservation of a pulse and the law of preservation of quantity of movement at ideally plastic and ideally elastic bang it is possible to write down [2]:

\[
F_{S} \cdot T = \int_{0}^{t_{bang}} F \cdot dt = \int_{0}^{m_{j}} V \cdot dm
\]

Where, \( F_{S} \) - average force of bang, \( T \) - the period of fluctuations, \( \int_{0}^{t_{bang}} F \cdot dt \) - a pulse of shock force of the concentrator about processable a surface.

The task in finding \( F_{S} \) is in essence reduced to definition of time of contact of the tool with a detail which at unknown persons \( F_{S} \) and \( T \) depends only on speed in the beginning of bang and physicomechanical properties of a material of a detail. Processable materials usually have elastic-plastic properties. Therefore as a first approximation it is possible to interpolate values of time and force of bang between the calculated sizes of absolute - elastic and absolute - plastic impact in view of factor of restoration of speed \( K \).

The factor of restoration of speed \( T_{0} \) is determined by experimental way by known techniques. After mathematical transformations we receive dependences of time of bang \( \tau_{bang} \) and force of bang \( F_{b} \):

a) \( K=0 \)

\[
\tau_{b} = \frac{T \cdot F_{S}}{F_{S} + 4 \sqrt{AR\sigma} \cdot F_{S}}
\]

and

\[
F_{b} = F_{S} + 4 \sqrt{A}R\sigma F_{S}
\]

6) \( K=1 \)

\[
\tau_{b} = \frac{4.53T \left[ (\sigma_{1} + \sigma_{2}) \cdot F_{S} \cdot T \right]^{2}}{4.53T \left[ (\sigma_{1} + \sigma_{2}) \cdot F_{S} \cdot T \right]^{2} + T \left[ 4A^{3}R\omega \right]}^{3}
\]

and

\[
F_{b} = F_{S} \left[ 1 + \frac{T}{4.53} \left( \frac{4A^{3}R\omega}{(\sigma_{1} + \sigma_{2})^{2} \cdot F_{S}^{2} \cdot T^{2}} \right)^{3} \right]
\]

During bang on cooperating bodies the shock waves of compression having spherical front
(Fig. 2) are distributed. It is considered, that the pressure arising from action of shock force, are in regular intervals distributed on spherical front. For the any moment of time \( t \) when the wave of deformation will be distributed in strengthening body, the volume of a body as a hemisphere will be filled by a shock wave. Weight of the deformed volume of a body the following dependence:

\[
m_D = \rho_i \cdot \frac{3\pi}{2} \left(V \cdot t\right)^3
\]

where \( \rho_i \) - density of a hardenable material; \( V \) - speed of distribution of a shock wave.

According to the received results energy of elastic deformations is equal each separate zone to kinetic energy of a wave. However it is necessary to take into account, that at imposing several waves of compression and a stretching this balance is broken that are differently summarized energy.

At reflection of a wave from a free surface of a body the wave of compression develops with the reflected wave, the firm deformable body unloads from energy of deformations, and due to it kinetic energy of particles is doubled.

At reflection of a wave from a rigid barrier, on the contrary, energy of deformation is doubled due to unloading particles of a body from kinetic energy.

Full unloading and doubling of deformations can occur only for bodies of the simple form, such as a core.

For bodies of the difficult form increase in energy of elastic deformation due to energy of a wave occurs only in part.

The important conclusion is that the size of the returned wave energy is proportional to energy of elastic deformation.

2.2 Results of experiments.

The basic influence on endurance of details is rendered with superficial residual pressure of 1-st sort which are counterbalanced in volume of a body without the appendix to it of any external influences, these pressure therefore are considered. Residual pressure arise always when the part of volume or thickness of a body has tested the pressure exceeded a limit of fluidity as a result of external influences, with creation of residual lengthening or compression of metal while other part of the same body tested pressure within the limits of proportionality.

As it has been marked above experimental researches were carried out on heat resisting steels. Diagrams of residual stresses are resulted in figure 3 and 4.

Researches were carried out on samples of the cylindrical form:

The given samples have been established on a lathe. Preliminary made grinding a surface. Then cutting tool removed, and on its place established the ultrasonic head.

As carried spent replacement of the concentrator to determine character of change of residual pressure depending on its diameter.

To strengthening surfaces pressed the concentrator with various static efforts, that as is reflected on dependences.

For inspection of reliability mathematical and for comparison of the analytical solution of a problem about impact of a ball about a surface of a detail calculation with the help of numerical methods has been executed and comparison with experiment is manufactured.

The numerical solution has been executed software grounded on a finite element method.

At calculations the obvious circuit of an integration which provides data of the solution on a time is used.

The model (Fig. 5) will consist of a ball and a parallelepiped.
Fig. 4 Distribution of residual stresses of a surface layer after USFP depending on diameter of concentrator D and force of its hold-down tool P.

The bang of a ball occurs on a flat surface which is broken on volumetric finite elements. Materials of a ball and a rod correspond to the materials, accepted in natural experiments. At calculation properties of materials are used at temperature 20°C, at calculations outside elasticity piecewise linear approximation was used. Comparative results of experimental researches, certainly the element analysis, and analytical calculation on designed models as distribution of residual stresses are higher presented in figure 6. Comparison of obtained results displays their satisfactory coordination.

Fig. 5 Finite element model

CONCLUSION

On the basis of executed theoretical and experimental researches the technique of management is developed by process of a reinforcement of details of gas turbine engine.

The given technique can be used for definition of optimum conditions of a reinforcement of details.

Fig. 6 Distribution of residual stresses on depth of a surface layer.

REFERENCE