Simulation modeling of dynamic characteristics of machining in NI LabView software environment to improve processing technique of a rod component

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Simulation modeling of dynamic characteristics of machining in NI LabView software environment to improve processing technique of a rod component

V V Maksarov, A E Efimov

Saint-Petersburg Mining University, 21 Line, St. Petersburg, Russia, 199106

E-mail: maks78.54@mail.ru; efim-aleks-evgen@mail.ru

Abstract. The paper considers a problem of providing required surface roughness of rod component during processing by means of forecasting dynamic characteristic of machine works with computer modeling taking into account transitional process. The role of the transitional process is performed by a modified structure in the surface layer of the blank created by preliminary laser effects; it is introduced into the computational model by means of a switch. To analyze the influence of preemptive structural change in the processed material onto the dynamic characteristic, a two-loop computational model describing delays in cutting force changes has been adopted. From the results of computational modeling in NI LabVIEW 2013 software environment, it has been discovered, that during the processing a stable suppression of arising self-vibration takes place when going through the modified structure zone. A positive effect in suppression of self-vibration is also supported with experimental research, thus providing a method of attaining preplanned surface roughness and allowing to remove the finishing operation from the current process to improve productivity and extend the modes of mechanical working. The article was prepared according to the State task (the project's number № 9.10520.2018/11.12)

1. Introduction

During the operation, components of mining machinery are subjected to both high dynamic loads and intensive wear, which are largely dependent on specifics of operating conditions of mining enterprises. Besides, individual parts of the components come under significant alternating forces that lead to an abrupt increase in friction between contacting surfaces. Deterioration of operating conditions is aggravated by aggressive environment, which includes excess of dust and moisture.

On the other hand, operation of mining machinery in a mine is significantly harsher than on the surface. Mine waters contain acids and alkalies. Their contact with covered machine components and parts facilitate development of corrosion. In addition, dust in mine air aggravates the mechanical wear of mating surfaces, causing damages in the form of chips, burrs, scratches and cracks. Presence of such negative factors leads to unplanned stoppage, meaning evident economic losses due to dismantling and reinstalling the broken-down part, as well as downtime.

A hydraulic cylinder rod of powered support may serve as an example of such components. The issue leading to selection of this very part is the following. When manufacturing a critical part, it is necessary to ensure conformance with high requirements in accuracy within the tolerance as per IT8 and roughness $R_a = 0.63$ micron [1, 5]. In a typical process, these parameters are formed sequentially in turning operations.
The finishing circular grinding brings these values to requirements with the aim of subsequent chrome plating and polishing. However, alongside the positive sides of this operation, there are also disadvantages. The main one is a charging effect in finishing treatment of the item by grinding. Operating such rod under heavy loads may lead to destruction of a protective layer and subsequent wear of a sealing system and containment failure of the cylinder.

Thus, to minimize failures in the critical component and to improve safety of mechanized support operation at the breakage face, the current process needs to be changed. So, it is proposed to completely remove the circular grinding from the rod manufacturing process. In its turn, provision of necessary surface roughness parameters is attained by modeling dynamic characteristics (vibration amplitude) of the machine work in the NI LabVIEW software environment [1, 2]. Use of computerized calculations allows selecting such parameters of the machine work that provide suppression of self-vibration and required surface roughness values are attained.

2. Method of preliminary local laser effects

Currently, rods of hydraulic cylinders are produces of steel Grade 45 and 40Cr. As it is known, these steels easily undergo structural transformation under high temperatures. Consequently, positive effect in suppression of self-vibration is attainable by applying a method based upon local laser effects (LLE), see Figure 1 [1, 3]. The nature of the proposed method is in modification of a localized surface area of a blank by laser heating following a specific trajectory with the view of further machine works. Lathe turning will lead to introduction of the cutting tool into the area with the local modified layer. Such a process will be accompanied by changes in the shear angle and grain elongation vector, thus leading to abrupt changes of the stress-deformation state of chips coming off the area with the modified structure. Exceeding the strength characteristics will lead to formation of a crack and further separation of the facing from the removed layer, thus suppressing the self-vibration.

Let us consider this method in more detail. Laser heating of localized surface area of the blank proceeds under flash heat conditions. Under this form of exposure, the temperature in the processing zone changes from the critical point with phase change $A_{c1}$ to the temperature $A_{c3}$ and higher. Cooling of the heated area proceeds into the depth of material [3]. As a result, a layered structure is formed, different from the bulk of metal in its mechanical properties, see Figures 2 (a) and (b).

Determination of depth of the modified layer is an integral part of this method. In a case where the impact depth exceeds the tolerance value, the tool hits on the layer with increased hardness. It leads to cleaving of the cutting edge along the front surface, contributing to inferior surface roughness. To avoid this defect, a modeling of thermal processes in LLE was conducted in COMSOL Multiphysics software environment, see Figures 2 (c) and (d).
Figure 2. Parameters of modified structure in 40Cr and 45 grade steels, where: (a) and (b) are experimental determinations of depth; (c) and (d) are virtual determination of depth

3. Modeling dynamic characteristic of machining

The next stage is aimed at finding out the influence of the modified area in the surface layer of the blank onto dynamic characteristic of machining. A two-loop process has been selected as a calculation model. The structure of such a mechanical system appears as a Tool subsystem [6]. The subsystem pattern includes two generalized coordinates along which reduced masses are applied, as well as positional and dissipative forces. Selection of such a system is defined, primarily by a theory based upon delay in changes of the cutting force $P$ and friction force $Q$ during the turning, due to inertia of the chip formation process [2, 4].

However, when selecting a dynamic system and composing the motion equation, it is necessary to impose the following limitations onto the model. When describing the behavior of the mechanical system, we disregard the blank subsystem, deeming it as absolutely rigid. As for the mathematical description of chip formation, it is reduced to approximation of discrete nature of the chip formation onto a continuous mode. Then, taking into account all these assumption, the system of linear differential equations for assessment of the dynamic characteristic takes the following form (1).

In the given system of equations (1) there are two formulas that cover the tool motion along the two directions $x$ and $y$, and two more describe the delay process in changes of cutting and friction forces due to chip formation, represented as coefficients: $l_P$ is the value of delay $P$; $l_Q$ is the value of delay $Q$; $f$ is the friction force. Suppression of the amplitude of vibration in such a system may be performed by introducing changes due to entering the modified area into the modeled process. Such changes in modeling will concern both transition of mechanical properties from the raw material of the blank $K_m$ to the modified layer $K_m'$ and parameters covering the chip formation process from $l_P$, $l_Q$, $f$ to $l_{P1}$, $l_{Q1}$, $f_1$. A switch represented through time $t$ will allow accounting for and introducing the aforementioned changes into the machining being modeled. Solving the system of linear differential equations together with the transition process is performed in the NI LabVIEW 2013 SP1 software environment by means of transfer functions in operator form.
\[
\begin{align*}
T_{x2}^2 \ddot{x} + T_{x1} \dot{x} + x &= Q \\
T_{y2}^2 \ddot{y} + T_{y1} \dot{y} + y &= P \\
T_P \dddot{x} + P &= -k_x \cdot x - T_{ky1} \ddot{y} \\
T_Q \dddot{y} + Q &= P - T_{ky2} \ddot{y}
\end{align*}
\]

where \(T_{x2}, T_{y2}\) are time constants; \(T_{x1}, T_{y1}\) are damping time constants; \(T_P, T_Q\) are constant components of friction and cutting forces; \(k_s\) is the transfer factor of the closed loop; \(T_{ky1}, T_{ky2}\) are damping time on cutting speed oscillation constants.

To determine the vibration amplitude of the closed two-loop process system, it is necessary to know the values of parameters stated in the system of formulas (1). These parameters are expressed in terms of values of reduced mass \(m\), rigidity \(c\), dissipative force \(b\) during the transformation and are given in the dimensionless form. The values of factors responsible for mechanical properties in transition from raw metal \(K_m\) to the modified layer \(K_m'\), are calculated from the experiment, while the delay values \(l_P, l_Q\) and friction force \(f\) are tabulated values taken from references [6]. Having determined the necessary parameters of the process system and properties of both raw and modified layers, it is necessary to substitute them into a generated virtual instrument to calculate vibrations arising in machining. Following the modeling of such process, the oscillogram has allowed registering the suppression of self-vibration process amplitude, see Figure 4 (a).

All the following stages of modeling that registered reduction in vibration amplitude during the machining were produced on JET GH-2040 ZH machine, see Figure 4. A blank with the modified layer was placed into a three-jaw chuck and rigidly pressed with the poppethead. Registration of vibration suppression was performed with a vibration diagnostics unit produced by Prüftechnik MT GmbH. For that end, two vibration transmitters were connected to the cutting tool, along the \(x\) and \(y\) axes. The results of the experiment were registered on the oscillogram of the vibration diagnostics unit. In figure 4 (b), a signal recorded in channel \(y\) is given as an example. This oscillogram shows, that the machining of raw metal \(T\) is accompanied with increase of the vibration amplitude to \(A_{x1}\). After that, when reaching the modified area \(T_m\), a motion is registered that may be characterized as a reduction of logarithmic damping constant and appearance of parametric vibration \(A_{x2}\). Following the same principle, a stable suppression of self-vibration process takes place throughout this stage of machining.
Figure 4. Oscillogram of vibration accelerations in machining 45 grade steel in the modes $V = 150 \text{ m/min}, t = 0.3 \text{ mm}, S = 0.15 \text{ mm/rev}, l_m = 0.275 \text{ mm}, h_m = 0.75 \text{ mm}$, where: modeling results are shown under a) and under the experimental readings from channel y are under b); $T$, $T'$ show raw metal machining; $T_m$, $T_m'$ show modified layer machining; $A_{x1}$, $A_{x1}'$ are amplitudes in regular machining; $A_{x2}$, $A_{x2}'$ are amplitudes after machining with the modified layer; $\lambda = (\ln \frac{A_1}{A_{1+n}})/n$ is the logarithmic damping constant, $A_1$ and $A_{1+n}$ are amplitudes of vibrations delayed by a given number of periods, $n$ is the number of full-wave oscillations.

Figure 5. Dependency of the self-vibration process amplitude $A$ during the acceleration process for surface roughness $R_a$ when machining a blank in Grade 45 steel with LLE and without it.

Following each machine works of the blank that had been previously treated by LLE method, surface roughness was measured with a profilometer, model SurfTest SJ-210. After the testing, a graph has been plotted that reflects the dependency of the surface roughness $R_a$ on amplitude $A$ of the self-vibration process when lathe turning the LLE-treated and untreated blanks, see Figure 5. From the graph it is evident, that there is a positive trend in suppression of amplitude of the self-vibration process that causes reduction in surface roughness values.
4. Conclusion

From the whole complex of the research outlined above, that included both computer modeling and laboratory experiments, the following conclusion may be made. Firstly, the modeling stage of the closed two-loop process scheme with considerations for a transition process due to localized modified layer of the blank has confirmed reduction in self-vibration amplitude during machine works, which is a direct consequence of adequacy of the model. Secondly, the modes that showed reduction of vibration were tested in practice. The results of the experimental research allowed finding a good convergence with the values from modeling and establishing a positive trend to reduction of self-vibration amplitude in machine works of the LLE-treated blank. Summing up, one may confidently say that the process of rod manufacturing may be improved by introduction of the LLE method. This, in its turn, will allow removing the grinding operation from the process and achieving the required values of surface roughness $R_a = 0.63 \mu m$ by suppressing the self-vibration level in machining the LLE-treated blanks.

References

[1] Maksarov V, Olt J 2016 Cutting process simulation on the basis of Rheological properties of. 26th DAAAM International symposium on intelligent manufacturing and automation. pp. 229-237

[2] Olt J, Liivapuu O, Maksarov V, Liyvapuu A and Tärgla T 2016 Mathematical modelling of cutting process system. Springer Proceedings in Mathematics and Statistics. 178 173–186

[3] Grigoriants A G Technological processes of laser processing. (Moscow: BMSTU)

[4] Olt J, Maksarov V 2015 Development of chatter-resistant system of cutting tool. Annals of DAAAM and Proceedings of the International DAAAM Symposium 26. «Proceedings of the 26th DAAAM International Symposium, DAAAM 2015». 223-228

[5] Timofeev D, Maksarov V, Khalimonenko A 2014 Machining quality when lathing blanks with ceramic cutting tools. Agronomy Research. 12(1) 269-278

[6] Elyasberg M E 1993 Oscillations of metal-cutting machines Theory and practice. (SPb.: OKBS)