Simulation model of dynamic processes during friction hardening of the flat surfaces

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Abstract – Simulation model of dynamic processes during frictional hardening the flat surfaces of assembly parts was developed.

Key words – conference, conference proceedings, paper layout, paper sample, research paper, friction hardening, simulation modeling, dunamic processes.

I. Introduction

Urgent task of modern mechanical engineering is providing appropriate surface condition which determines the performance properties of machine parts. This led to forming of a new branch in mechanical engineering – the surface engineering. The development of surface engineering involves the development of new processes that modify the surface layer, drastically change its structure and properties. For modification of metals' surface, methods of surface processing with application of the concentrated flow of thermal energy are used. During the friction processing, an intense source of thermal power appears due to high-speed friction of the tool on the assembly part in the area of contact. There is also intense shear deformation of the surface layer of the metal. To increase the shear deformation a tool with transverse grooves cut in its working surface [1] is used. In the superficial layers of metal, reinforced nanocrystalline surface layers are formed. Intensive dynamic processes occur during friction hardening.

II. Analysis of Recent Research and Publications

Simulation modeling is a versatile method for studying dynamic systems, the behavior of which depends on random variables. Such factors when considering the dynamics of surface hardening during friction treatment may include disturbances that occur in the treatment zone. In the basis of simulation modeling lays statistical experiment, the implementation of which is impossible without the use of computer technology. Integration of one of the fastest matrix mathematical systems (MATLAB with Simulink package) opens up new possibilities of using different mathematical methods for solving problems of dynamic situational simulation of complex engineering systems, processes and devices. Package Simulink for simulation of dynamic systems is one of the best tools of modeling of dynamic systems [2].

The Simulink Package allows reducing the terms of design, improving the quality of technical systems development models and modeling processes that occur in these systems. The package Simulink fundamentally changed the nature of the requirements placed on mathematical software: to manage the whole course of the calculation process graphical modules used to create block diagrams of the systems are developed.

The process of frictional hardening of the working surfaces of machine parts is similar to the grinding process in kinematics. At the same time, in the formation of nanocrystalline hardened layer during friction hardening, the workflow is different from the process of grinding in force, temperature interactions that occur in the contact zone of the tool with the assembly part. In frictional enhancing there is virtually no surface layer cutting process, there occurs the process of high-speed friction in the contact zone of tool with the assembly part, there is intense shear deformation of the surface layer. Currently, the studies of dynamic processes during frictional hardening, including the interrupted hardening, are absent.

III. Body Part

Friction on the principle of strengthening its performance is similar to grinding. Therefore, for its implementation surface grinding machines, or OD grinding machines, or specially designed equipment can be used. Friction strengthening of flat surfaces was performed by upgraded surface grinding machine SPC-20a. To strengthen the necessary friction, linear velocity at the periphery of the tool shall be V_{tool} = 60-80 m/s, so the main machine component has been upgraded. Instead of abrasive wheel metal tool disc made of carbon structural steel 45 in normalized condition was set.

The metal disc was installed directly on the machine spindle cone to reduce its beating and therefore vibrations that are transmitted to the spindle hub. To increase the shear deformation in the surface layers of the assembly parts in the contact zone tool-detail during frictional strengthening, a tool with transverse grooves cut in the working part was used. The width of the groove was chosen from the condition of guaranteed full disengagement of the tool and assembly part.

The oscillating system of the machine is two-mass and shown in Fig. 1. For ease of analysis of the oscillatory processes, we will change the two-mass oscillating scheme to one-mass [2], in which the shown mass of the machine table will oscillate on spring-elastic elements with a present deflection rate relatively to the immovable center of the rotation tool (Fig. 2).

The interference between the assembly part and the tool (vertically) will be modeled by contact stiffness and damping power of local elastic-plastic deformation of the assembly part surface.

We write the differential equation that describes the forced oscillations of the table and the assembly part with respect to a fixed center of rotation of the tool in the vertical direction:

$$\begin{aligned}&\frac{d^2 y_{table}}{dt^2} m^*_{table} + c_{contact}\left(y_{table} - y_{tool.}\right) + \\ &+ k_{contact}\left(\frac{dy_{table}}{dt} - \frac{dy_{tool}}{dt}\right) + c^*_{table-v}\, y_{table} + \\ &+ k^*_{table-v}\frac{dy_{table}}{dt} = 0\end{aligned} \qquad (1)$$

where: m^*_{table} – reduced weight of the table (kg);

$$\frac{1}{m^*_{table}} = \frac{1}{m_{table}} + \frac{1}{m^*_{spindle}} \qquad (2)$$

$m^*_{spindle}$ – brought to machine tool spindle weight (kg);

$$m^*_{spindle} = m_{tool} + \frac{1}{3} m_{spindle} \qquad (3)$$

m_{tool} – weight of the tool (kg); $m_{spindle}$ – weight of the machine spindle shaft (kg); $c_{contact}$ – contact stiffness between the tool and assembly part (N/m); $k_{contact}$ – damping coefficient between tool and assembly part (internal damping) (Ns/m); y_{tool} – vertical movement (coordinate) of the tool (m); $c^*_{table-v}$ – reduced vertical stiffness of the machine (N/m), $k^*_{table-v}$ – harmonized machine damping (Ns/m);

$$\begin{aligned}&\frac{1}{c^*_{table-v}} = \frac{1}{c_{table-v}} + \frac{1}{c_{spindle-v}}, \\ &\frac{1}{k^*_{table-v}} = \frac{1}{k_{table-v}} + \frac{1}{k_{spindle-v}}.\end{aligned} \qquad (4)$$

$c_{table-v}$ – vertical stiffness of the machine; $c_{spindle-v}$ – vertical stiffness of the machine tool spindle; $k_{table-v}$ – vertical damping factor of the machine table; $k_{spindle-v}$ – vertical spindle machine damping coefficient.

Fluctuations in the horizontal plane of the machine table (Fig. 4) will be caused only by force of friction between the tool and the assembly part, since the transfer of momentum in the horizontal direction is necessary that the interference angle would be less than the angle of friction [3], which in this case is impossible.

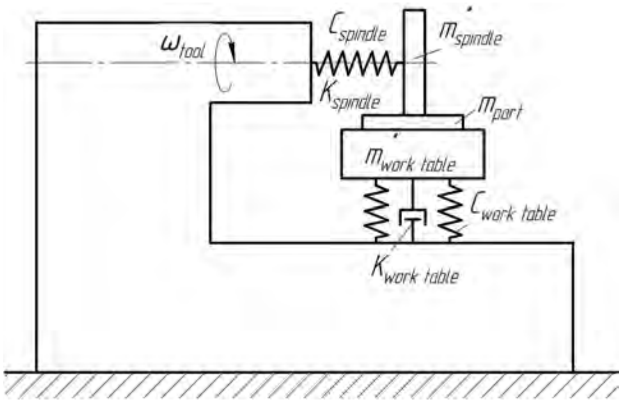

Fig. 1. Oscillating scheme of the machine

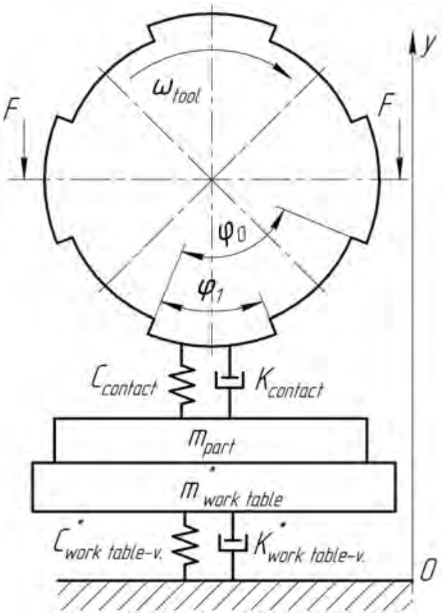

Fig. 2. Reduced to one-mass oscillating system with vertical fluctuations of the machine

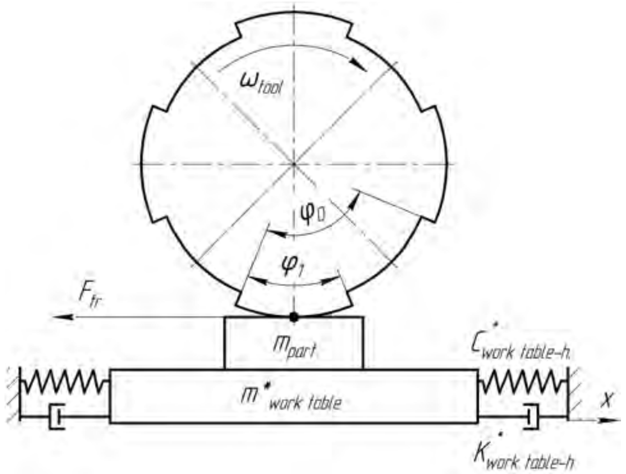

Fig. 3. Reduced to one-mass oscillating system with horizontal fluctuations of the machine

We construct a differential equation for the horizontal plane (axis) of the machine:

$$\begin{aligned}&\frac{d^2 x_{table}}{dt^2} m^*_{table} - F_{fr} + \\ &+ c^*_{table-h}\, x_{table} + k^*_{table-h}\frac{dx_{table}}{dt} = 0\end{aligned} \qquad (5)$$

where: $c^*_{table-h}$ – reduced horizontal stiffness of the machine tabl; $k^*_{table-h}$ – harmonized horizontal machine damping;

$$\begin{aligned}&\frac{1}{c^*_{table-h}} = \frac{1}{c_{table-h}} + \frac{1}{c_{spinde-h}}, \\ &\frac{1}{k^*_{table-h}} = \frac{1}{k_{table-h}} + \frac{1}{k_{spindle-h}};\end{aligned} \qquad (6)$$

$c_{table-h}$ – horizontal stiffness of the machine table; $c_{spindle-h}$ – horizontal stiffness of the machine spindle; $k_{table-h}$ – horizontal machine damping coefficient; $k_{spindle-h}$ – horizontal machine spindle damping coefficient; $c^{*}_{table-h}$ – the friction between the tool and the surface of the assembly part (N); *f* - coefficient of friction between the materials of tool and the assembly part.

The friction between the assembly part and the tool will be determined by the equation:

$$F_{fr} = c_{contact}\left(y_{table} - y_{tool}\right) f \qquad (7)$$

where: $c_{contact}\left(y_{table} - y_{tool}\right)$ – the value of the normal reaction between the tool and the assembly part.

$$\begin{gathered}\left(y_{tool} - y_{table}\right) > 0 \text{ then} \\ c_{contact} = 0;\ k_{contact} = 0\end{gathered} \qquad (8)$$

This condition implies the absence of contact stiffness in the absence of contact between the tool with the assembly part at the time of passage of the groove on the working surface of the tool over the zone of contact $c_{contact}\left(y_{table} - y_{tool}\right)$.

Numerical solutions of differential equations by the Runge-Kutta methods (1) (5) with the condition (8) for the actual experimentally determined parameters of the described above machine SPC-20a shown in Fig. 6–7. Tools of cut transverse grooves the number of which is equal to $n = 2$ for which the angle of the working segment is $\varphi_0 = \pi$, and the ratio of the working surface to the groove is $\varphi_1 = 0.5\varphi_0$. Tool radius $R = 0.1$ (m), it rotates with the angular velocity $\omega = 500$ (rad/s) and is pressed against the assembly part with force equal to 1,000 *N*.

To generate a signal which describes the rotation of the tool, we will use a tool from the library of Simulink – “Repeating Sequence”. The diagram describing the rotation of the tool, i.e. a full rotation (2π) at a given angular velocity of ω, is shown in Figure 3.

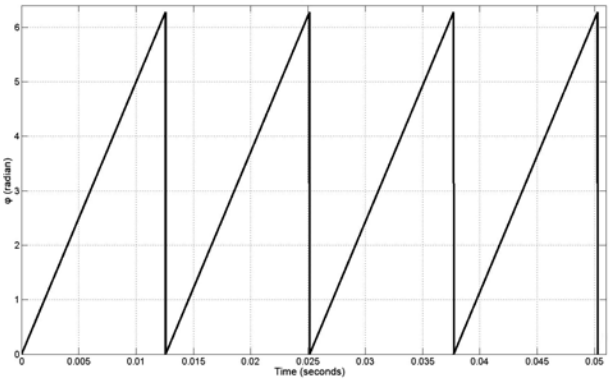

Fig. 4. Generation of a signal, which reflects the rotation of the tool

The mathematical model of interfering friction strengthening of flat parts is shown in Fig. 5. To display the block diagram of the model in general were applied power subsystems (Subsystem), which include: the rotation of the disk passing through the contact area and the smooth part of the groove, the solution of differential equations and the transfer of data via WorkSpace to Matlab. In the subsystem “Table oscillation in vertical direction” the equation of motion of the system in the vertical direction is represented by appropriate elements (Fig. 6), and in the subsystem “Table oscillation in horizontal direction” respectively in the horizontal direction (Fig. 7). To simulate contact of each smooth part and groove a cycle is used, i.e. “For Iterator Subsystem”. This subsystem includes the checking of the position of the smooth and the groove as in the point of contact with the assembly part and check the conditions of contact with the mutual movement of the parts and the tool vertically. The constant “n”, sets the number of cycles of the operator “For Iterator Subsystem”. Since each test of the conditions of the contact provides relevant individual values with respect to time, then combining them into a single signal that goes to the output of this subsystem uses the block “Sum”.

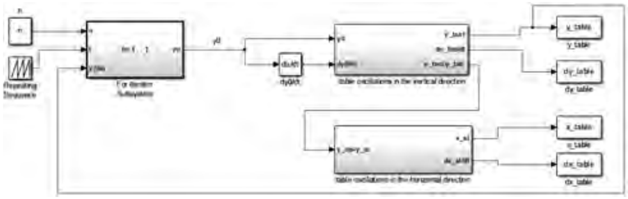

Fig. 5. Mathematical modeling of interfered friction strengthening of flat parts

With the help of the block “To WorkSpace”, after the calculation of differential equations system, the results are written to the workspace of MATLAB. Using additional m-file we build needed graphs using the data workspace. In Fig. 6-7 graphs of movement of the machine table in the vertical and horizontal directions are shown.

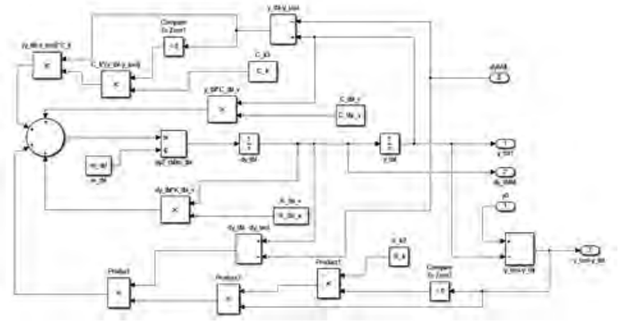

Fig. 6. Subsystem “Table oscillation in vertical direction”

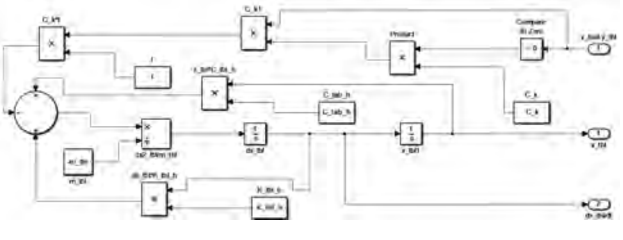

Fig. 7. Subsystem “Table oscillation in horizontal direction”

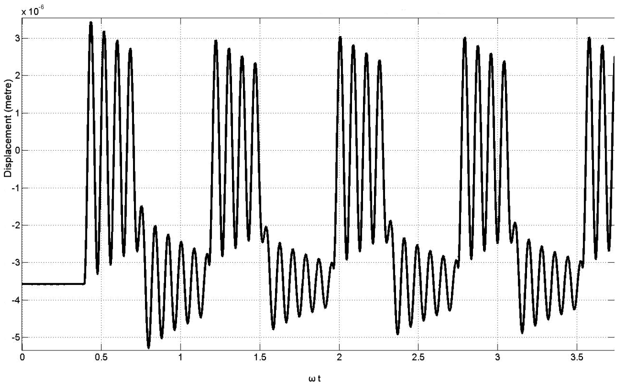

Fig. 8. The part displacement in vertical direction during frictional hardening

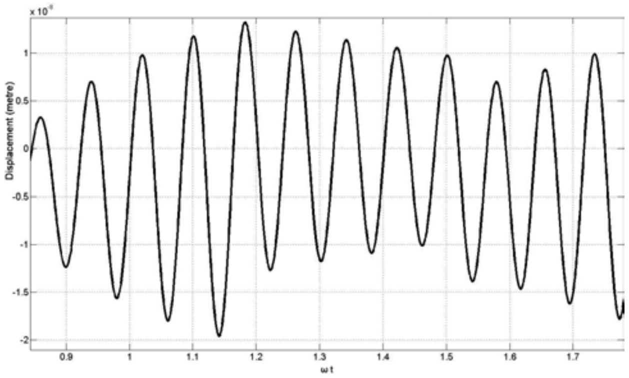

Fig. 9. The part displacement in horizontal direction during frictional hardening

Conclusion

The developed simulation model of the dynamic parameters of frictional strengthening allows exploring the processes that take place during frictional strengthening of machine assembly parts. Also it is possible to determine the influence of frictional strengthening process, the working part, the rigidity of the technological system's parameters on the behavior of dynamic characteristics of the machine.

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