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Ultrasound Treatment of Curved Contours and Complex Surfaces

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Abstract—The ultrasound treatment of curved contours and complex surfaces is considered. Appropriate design approaches are discussed. As examples, automated ultrasound treatment processes are presented.

Keywords: ultrasound, vibrational system, cleaning, surface plastic deformation, ultrasound systems

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The industrial uses of ultrasound range from metallurgy to manufacturing [1].

By ultrasound treatment based on high-frequency surface plastic deformation, cavitation, erosion, and abrasion, the most important surface properties of manufacturing products may be controlled, including surface cleanness and lack of contaminants. That, in turn, results in optimal performance [2].

Despite progress in ultrasound technology, modernization and automation remain a high priority [3, 4]. In addition, new processes must be developed, and high-efficient ultrasound equipment must be created. A priority is the machining of curved contours and complex surfaces.

Contoured systems may be used for the machining of curved contours and complex surfaces. Such systems may be developed without automation of the process. Topics of interest include maintenance of specified machining conditions; automatic selection of the technology and equipment for a specific product; and system operation according to a specified program or in interactive model (include control by means of an external PC).

THEORETICAL PRINCIPLES

The surface hardness and roughness obtained in ultrasound treatment, as well as the surface purity, depend directly on the precision of the tool's position with respect to the workpiece [5].

In ultrasound liquid treatment, such as cleaning, the distance from the ultrasound source to the workpiece surface has a considerable influence on the quality and efficiency of the process [6, 7]. Research on aluminum foil yields an experimental dependence of the cavitational erosion on the distance from the ultrasound source (Fig. 1).

In surface plastic deformation by ultrasound, the surface hardness and roughness obtained depend on the retaining force applied to the tool.

The experimental dependence of the roughness R_z on the retaining force F_{re} in the range 25–200 N (Fig. 2) shows that the roughness decreases monotonically with increase in the force up to F_{re} = 125 N. With further increase in the force, there is little change in the roughness.

On the basis of the results, the best conditions for the ultrasound treatment of curved contours and com-

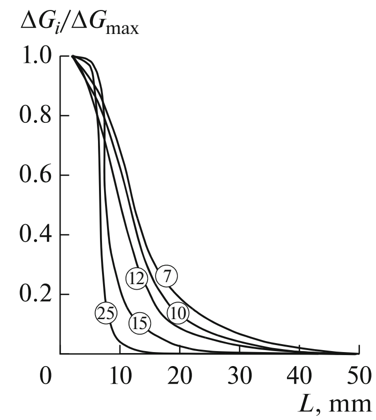

Fig. 1. Influence of the distance L from the ultrasound source on the cavitational erosion $\Delta G_i/\Delta G_{max}$ when the amplitude is 7, 10, 12, 15, and 25 μm.

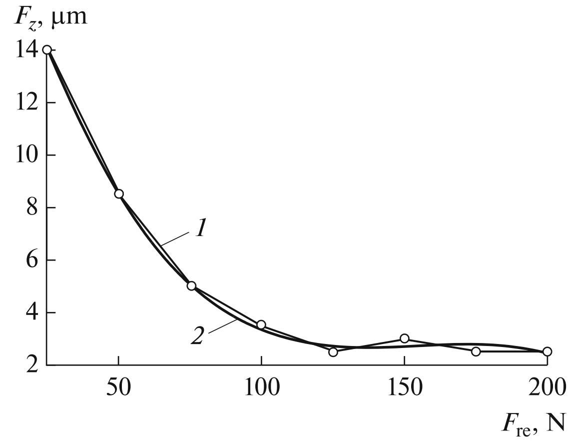

Fig. 2. Experimental dependence of R_z on F_{re} (*1*) and its polynomial approximation (*2*).

plex surfaces may be identified. In the most effective systems, the distance of the ultrasound source from the source remains constant.

AUTOMATED EQUIPMENT FOR ULTRASOUND TREATMENT

Since most manufacturing products are complex in shape, contour machining is technologically and economically expedient [8]. Three separate drives are used for motion of the tool with respect to the three coordinates. The drives used are as follows [9].

Ball–screw gears are used to convert the rotary motion of the motor's output shaft into reciprocating motion of the tool, since they are more efficient that screw–but gears and are less subject to wear. In addition, the accumulated error of the ball–screw gear increases slowly with increase in screw length. That is especially important for the machining of large parts.

AD-200 step motors are used. They permit precision positioning of the output shaft and accurate control of the rotor speed; in addition, they are relatively inexpensive. A symmetric control system may be used for the step motors. This is the simplest approach.

An SMSD-4.2 controller permits bipolar control of the step motors. Its four control outputs permit its use in controlling not only the three step motors of the tool drive but also additional equipment (for example, control of the pump supplying the detergent at the required rate in ultrasonic cleaning).

The digital code in the control program is converted to voltage pulses at the step motor by means of the Mach3 commutation driver.

The ultrasound unit for coordinate cleaning (Fig. 3) includes a light aluminum housing *2*, to which are attached the longitudinal *4*, transverse *5*, and vertical *6* drives of the ultrasound system.

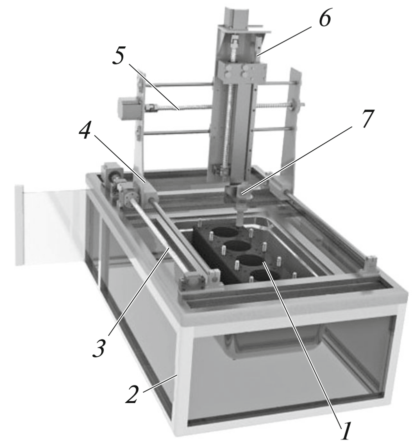

Fig. 3. System for ultrasound coordinate cleaning: (*1*) object to be cleaned; (*2*, *3*) lower and upper modules; (*4*, *5*, *6*) longitudinal, transverse, and vertical drives of the ultrasound source; (*7*) ultrasound source.

A piezoceramic vibrational system is used to simplify the design of the contour-machining unit, reduce its weight, and also reduce the power consumption and the cost.

The vibrational system moves with respect to the three coordinate planes in accordance with a predetermined control program. The control program for ultrasonic contour machining is based on a three-dimensional model of the object derived by means of three-dimensional design software (such as Kompas-3D or SolidWorks) or 3D scanners. The model of the part is imported into the automated preproduction system. We choose GeMMa-3D software, which has an elegant Russian-language interface.

Since CAM systems lack ultrasound treatment modules, we now analyze the possibility of using the closest analog built into the GeMMa-3D software. Milling most resembles ultrasound coordinate machining in terms of the reproducible shaping trajectories and the range of machining parameters. In milling, the tool moves systematically over the surface of the part (bypassing recesses). The only significant difference between the two processes is that there is no need for tool rotation in ultrasound treatment.

Analysis of the capabilities of GeMMa-3D software permits the selection of milling as the closest counterpart to ultrasound coordinate machining. After selecting the strategy for layer removal and the type of workpiece, the GeMMa-3D software generates internal files containing data regarding the type of tool, its position, and the machining parameters. These are converted to Mach3 postprocessor. Using the Mach3 postprocessor and the controller, the digital code in the control program is converted to voltage pulses at the step motor, so that the motor turns in the required direction, at the required speed [10].

MONITORING AND CONTROL OF ULTRASOUND TREATMENT

Virtual devices are used for monitoring and control of the process. The measuring component of the virtual device includes electrodynamic sensors, thermal sensors, dynamometers, and hydrophones. By that means, information regarding the change in amplitude, frequency, retaining force, and temperature is sent to a multichannel analog–digital converter, connected by means of a USB port to a personal computer. The PC software permits tracking of the measured variable, runs the machining protocol, and creates control signals for the working components [11].

For all ultrasound processes, the quality and productivity depend on the selection and maintenance of the amplitude and frequency of tool vibration. Electrodynamic sensors measure the amplitude and frequency in idling and operation of the vibrational system.

Under the action of the ultrasound vibrations, a voltage of around 1 V is induced in the sensor coil. That permits connection of the vibrational sensor to the PC by means of an analog–digital converter. That role may be played by a multifunctional spectral analyzer, which is used to measure signal parameters with different accelerometers and microphones, to correlate the signal structure, to generate electrical signals with standardized parameters, and to measure the noise level and vibration level in (1/3)-octave bands. That permits its use as a vibration and noise meter.

The multifunctional spectral analyzer is also used to control the ultrasound generator by means of a PC, through an RS-485 AF485M communications unit.

This approach to control and monitoring of the ultrasound system permits automatic or manual operation. Automatic operation relies on a database of operating conditions and equipment. Manual control permits selection of the treatment parameters and their adjustment in the course of the process.

CONCLUSIONS

(1) The proposed algorithm for the development of coordinate machining equipment may be used to create ultrasound technology for cleaning, surface plastic deformation, smoothing, cutting, and so on.

(2) The proposed measures intensify the machining of complex parts and reduce the time required by a factor of 3–5. The advantage of the technology is that it is universal: that is, parts of different size and configuration may be machined.

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