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SOME CONSIDERATIONS CONCERNING THE ULTRASONIC MICRODRILLING

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Abstract: *Ultrasonic machining is one of the non-traditional machining processes that allows for obtaining small diameter holes having linear or curvilinear axis and variable cross section, both in conductive or insulating materials, without thermally affecting the workpiece material. Ultrasonic micromachining can be regarded as a system with distinctive correlations among the input and the output variables. This work presents two solutions for assembling the tool to the horn, either by means of a threaded joining or by using a soldered joint. If the tool has a large length in comparison to the diameter, then buckling can occur and a brief analysis of this issue is included in the paper.*

Key words: *microdrilling, ultrasonic process, tool, horn, buckling strain.*

1. INTRODUCTION

Ultrasonic machining is a non-traditional process in which the material removal is caused by mechanical vibration that is induced in the work zone at a frequency larger than 20 kHz [6].

In the last decade of the 20th century, one of the technological issues that were studied by the experts in the field of machine manufacturing technologies was the so-called *micromachining*.

Typically, the term *micromachining* is used when at least one of the dimensions of the machined surface is smaller than 1 mm, which means that the dimensions can be expressed in micrometers.

A particular case of micromachining is *microdrilling*, in which the diameter of the machined holes is lesser than 1 mm.

It is important to mention that microdrilling easily allows obtaining holes with different cross sections and holes with curvilinear axes.

For the case of workpieces made of hard-to-machine metals, some non-traditional machining processes can be used to obtain micro-holes. For insulating materials, however, only a few of them can be used, namely the electron beam, the laser beam and the ultrasonic machining process.

The first two processes are characterized by the use of the thermal effect, and the resulting high temperature causes the melting and the vaporization of the workpiece material in the neighbourhood of the laser or electron beam spot.

This means that the workpiece material is affected on a certain extent by the high temperature developed in the work zone, as a consequence of the above-mentioned thermal effect.

Ultrasonic micromachining is valuable because the temperature increase that occurs in the work zone is not large enough to modify the metallographic structure of the workpiece material.

The first in deep Romanian research work in the field of ultrasonic machining was made by Tudor Inclănzan, in 1976 [2].

In addition, plastic deformation in an ultrasonic field was studied in 1976 by Gheorghe Amza, and Mihăiță Peptănaru developed some microdrilling tools in 1999 [5].

In 2002, Joseph McGeough [4] presented some general aspects of the ultrasonic micromachining process, and showed that the smallest diameter hole that could be achieved by microdrilling is around 0.2 mm.

However, some technological difficulties must be surpassed before one can use ultrasonic micromachining.

The first difficulty refers to finding out the tool's maximum allowable length, so that buckling will not occur.

Another difficulty concerns to the kind of device shall one use to mount the tool in the horn, taking into account that the tool diameter is lesser than 1 mm. In addition, it is necessary to find a solution to ensure that the appropriate pressure is exerted by the tool over the workpiece during the machining process.

At present, some of the main trends of research in ultrasonic machining relate to the process monitoring, to the use of new materials for tools and horns [5], to the optimization of the machining parameters [1], to the generation of rotating motion of either the tool or the workpiece [4, 7], and to the process modelling with neural networks [1].

2. A SYSTEMIC APPROACH TO THE MICRODRILLING PROCESS

One can look upon the microdrilling process as a system (Fig. 1).

As independent variables, we have the kind of tool clamping device, the diameter and the free length of the tool, the characteristics of the tool vibratory motion (type of pulse, amplitude and frequency), the characteristics of the abrasive slurry (chemical composition, size and hardness of the abrasive granules, coefficient of viscosity of the slurry), and properties of the workpiece material.

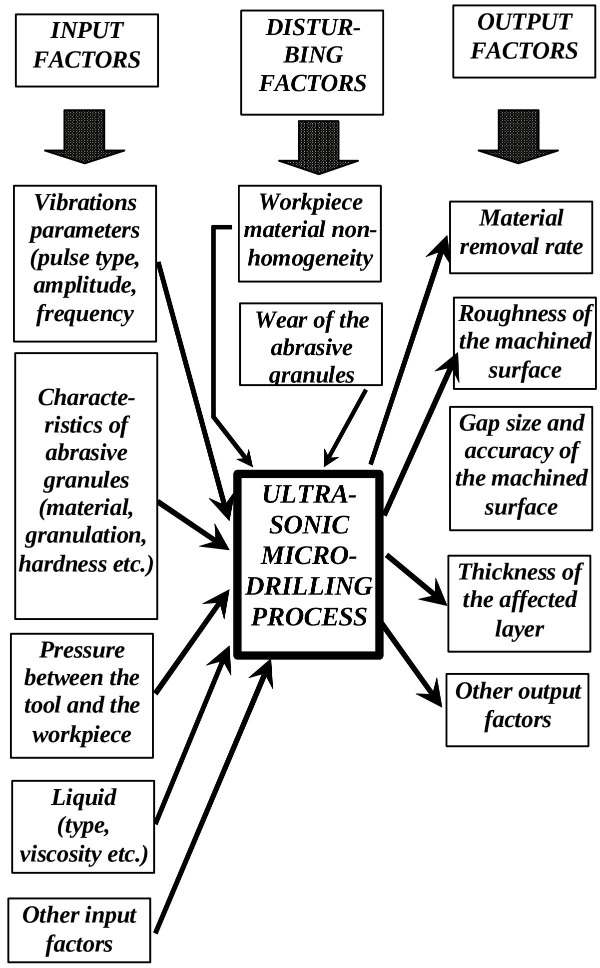

Fig. 1. The microdrilling process as system.

The dependent variables (considered as output factors) are the material removal rate, the penetration speed, the roughness and the accuracy of the machined surface, and the machining cost.

The main disturbing factors are the non-homogeneity of the workpiece material and the wear of the abrasive granules.

3. PREMISES FOR THE EXPERIMENTAL RESEARCH

This research work is being carried out at the Non-Traditional Technologies Laboratory, Department of Machine Manufacturing Technology, the "Gh. Asachi" Technical University of Iaşi, using an ultrasonic machine with three power level steps.

The ultrasonic horn of this machine can be manually positioned relative to the workpiece, and the force that is required by the machining process is manually achieved as well. As for the source of ultrasonic vibration, it is a piezoceramic transducer.

The horn is assembled by means of a threaded joint, and has a cylindrical zone that enters a hole in the piezoceramic transducer supporting device.

A circular worktable is used to clamp the workpiece. The Table is placed at the required height by means of a nut and a threaded section of a sliding bar/sleeve pair, and a helical spring generates the pressure that is required between the tool and the workpiece, as shown in Fig. 2.

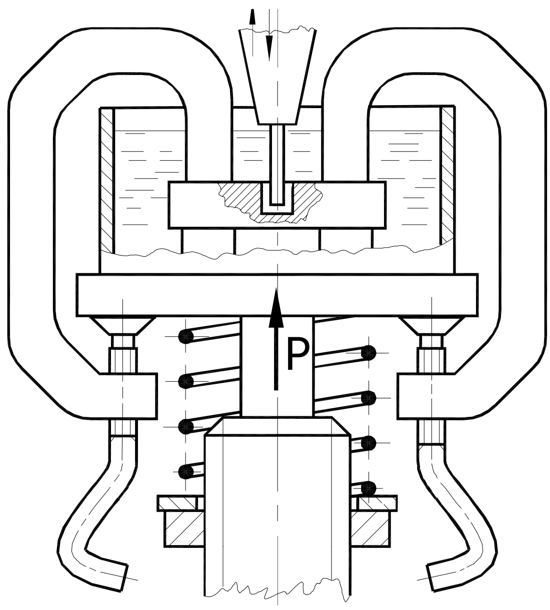

Fig. 2. The solution selected for the workpiece clamping on the work table.

Fig. 3 displays the elastic deformation curve of this spring, as obtained through a calibration procedure.

As for the workpiece clamping, the adopted solution avoids the perforation of the recipient in which the ultrasonic microdrilling process takes place, as it is also shown in Fig. 2.

As one can see, the workpiece is fixed to the worktable by means of two common G-clamps.

The next step was to find out an appropriate way to mount the small diameter tools.

First, a special chuck was designed and built (Fig. 4).

As one can see, an axial, cylindrical hole was machined at the free end of the horn, so that an elastic sleeve can be inserted.

In addition, a common screw thread has been machined at the external cylindrical surface of same free end.

A special nut screws on the threaded end of the horn, so that the internal conical surface of the nut presses the mating conical zone of the elastic sleeve. As result of the nut action, the tool is clamped by the elastic elements that form the sleeve.

Ideally, the natural frequency of the subsystem transducer/horn/tool should be close to the excitation

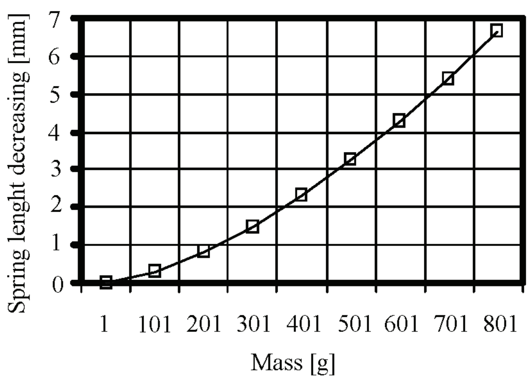

Fig. 3. The elastic deformation curve of the spring that ensures the required pressure between the tool and the workpiece.

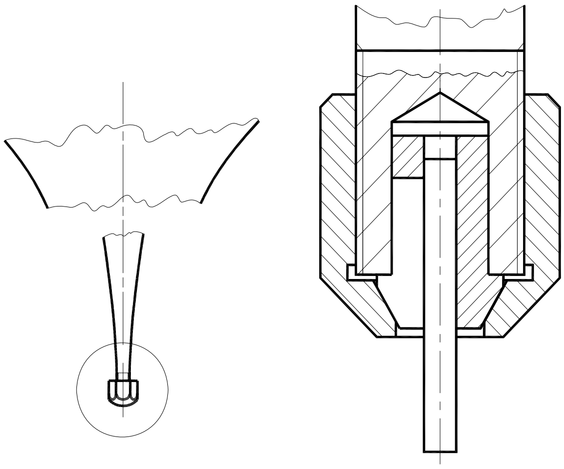

Fig. 4. Tool mounting by means of a chuck.

frequency. In such a close-to-resonance circumstance, the vibration amplitude is large and the machining process efficiency is improved.

It was noticed, however, that the amplitude of the tool vibration diminished after the above-mentioned horn was set up.

This fact was probably due the additional mass of the chuck and to an increased damping caused by the large area of the chuck in interaction with the slurry.

In fact, the mathematical relationship between the inertial component, $F_i = m\frac{d^2 y}{dt^2}$ (where m is the mass of the body supposed to be concentrated in a point), the component $F_f = D\frac{dy}{dt}$ induced by viscous damping (where D is the damping coefficient), the elastic component $F_{el} = ky$ (where k is the stiffness coefficient) and the excitation force F_{ex}, is given by

$$F_i + F_f + F_{el} = F_{ex} \tag{1}$$

or:

$$m\frac{d^2 y}{dt^2} + D\frac{dy}{dt} + ky = F_0 \sin \omega_1 t, \tag{2}$$

where F_0 is the amplitude of the periodical excitation force, ω_1 the pulsation, and t the time. The solution of equation (2) leads to the amplitude of the vibration motion, y_0, which is given by:

$$y_0 = \frac{F_0}{\sqrt{(D\omega_1)^2 + (k - m\omega_1{}^2)^2}}. \tag{3}$$

Equation (3) shows that for an excitation force with a given amplitude and a definite pulsation, the system's motion amplitude decreases when both the viscous damping and the mass increase.

Therefore, a new horn was designed and built in order to obtain a better dynamic response, this time using an aluminium alloy instead of steel. The new horn has hole at the bottom face to fit the small diameter tool, which that is fastened to the horn by soldering, as shown in Fig. 5.

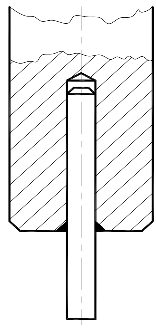

Fig. 5. Tool assembled to the horn by soldering.

The new solution proved to have a superior behaviour from the point of view of the ultrasonic vibration amplitude.

4. TOOL BUCKLING PREVENTION

Elastic buckling can occur during the machining process due to the high slenderness ratio of the tool.

Therefore, Euler's formula was used to determine the buckling critical force

$$F_b = \frac{\pi^2 E I_{\min}}{l_b^2}, \tag{4}$$

where E is the modulus of elasticity of the tool material, I is the cross section moment of inertia, and l_b is the length of buckling.

Considering the tool as a rod that is fixed at an end and free at the other end, we have

$$l_b = 2l, \tag{5}$$

where l is the true length of the free zone of the tool.

On the other hand, the force that is applied to the end of the tool is given by

$$F = pA, \tag{6}$$

where p is the pressure exerted by the tool on the workpiece, and A is the magnitude of the contact area between the tool and the workpiece. For ultrasonic machining, one usually has $p = 0.5\ldots5.0$ daN/cm^2.

In the case of a tool having a circular cross section, the cross section moment of inertia is given by:

$$I_{\min} = \frac{\pi d^4}{64}. \tag{7}$$

Substituting equations (5), (6) and (7) in equation (4), one can write:

$$p \cdot \frac{\pi d^2}{4} = \frac{\pi^2 E \cdot \frac{\pi d^4}{64}}{(2l)^2}. \tag{8}$$

Thus, the length of the tool should not exceed:

$$l = \sqrt{\frac{\pi^2 E d^2}{64 p}}. \tag{9}$$

According to equation (9), for example, the buckling length of a steel tool with $d = 0.65$ mm will be $l_b = 23.4$ mm for the working pressure $p = 2.5$ daN/cm^2.

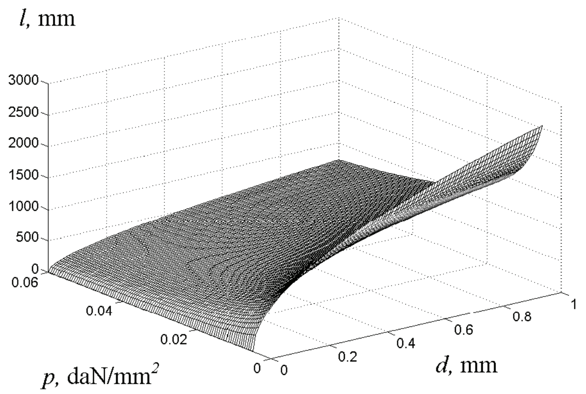

Fig. 6. Theoretical influence exerted by the tool diameter and by the work pressure on the tool free length.

The theoretical influence exerted by the diameter *d* and by the pressure *p* on the buckling length of a steel tool is depicted in Fig. 6.

5. CONCLUSION

The ultrasonic microdrilling is a machining process that allows for obtaining small diameter holes. The process can be considered as a system, with definite relationships between the input and output variables.

Two ways of mounting the tool in the horn were tested: a relatively complex chuck and a simple soldered mounting. The soldered solution was found to be superior.

The main concern about the tool is elastic buckling, and a brief analysis of this issue is included in the paper.

The preliminary research work that is described in this paper was done as preparation for a future study about producing small diameter holes (having the diameter smaller then 1 mm) in thick plates made of different materials.

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