THE PARAMETRIC DESIGN OF THE ULTRASONIC EXPONENTIAL HORNS

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Abstract: In industry the ultrasonic waves are used both in dimensional processing operations and in auxiliary processes like: washing, deburring, ultrasonic material testing. By the use of ultrasonic waves they can be processed almost all types of materials, but ultrasonic erosion is applicable primarily to those materials with high fragility, not too great hardness and also which do not have plastic deformation before breaking, such as ceramics, glass, quartz, ferrite, etc. Starting by the known relationships, it is presented a modern method useful to design exponential ultrasonic horns. This method assumes a calculation program, which supplies the coordinates in different cross-sections of the horn and allows its graphical representation. The performed program can save the matrix with coordinates in xls format, which can be calculated in Solid Edge application in order to obtain the 3D model.

Keywords: horn design, ultrasonic erosion

1. INTRODUCTION

The rapid development of the machine building industry lead to expand the use of acoustic waves, which are used as a direct method of processing or to assist other technological processes.

Ultrasonic Machining has these very different applications, due to specially properties which the ultrasonic waves have: short wavelength, great accelerations - particle accelerations can reach up to values 10^5 larger than the gravitational acceleration, possibility to direct the ultrasonic fascicle to places difficulty accessible; possibility of concentrate and focus the acoustic energy in a limited space.

In industry the ultrasonic waves are used both in a dimensional processing operations and in auxiliary processes like the washing, deburring, ultrasonic material testing.

With ultrasonic waves they can be process a large kind of materials, but ultrasonic erosion is applicable primarily to those materials with high fragility, not too great hardness and also does not have plastic deformation before breaking, such as ceramics, glass, quartz, ferrite, etc.

Also, the ultrasonic waves can be used in good condition at the processing of materials that have an average machinability, such as: carbide, hardened steels, titanium alloys, etc.

The metallic materials which have a large plastic deformation before breaking, such as: soft steel, copper, aluminium, etc. can not be processed at all or may be processed, but in very difficult conditions with ultrasound. This is because of the suspension of abrasive grains used in the material is easily dick in the workpiece material without causing dislocations.

Ultrasonic processing is based on a few main effects of ultrasonic field, such as:

- the "acoustic softening" effect, which consists in reducing the static tensions that are necessary to static deformation of the metal with increasing acoustic energy density.
- the "acoustic hardening" effect which is manifested by increased external static pressure required in plastic deformation, in the same time with some structural changes.
- the acoustic hardening effect which appears as a result of modifications of structure dislocations.
- the thermal effect is manifested by great heating of metallic material, the increasing temperature being corresponding with increasing intensity ultrasonic waves and the activation time.

For the time being the ultrasonic processing is done in two ways:

- ultrasonic processing with abrasive suspension, in which case in the space between the workpiece and tool is brought an abrasive suspension, the abrasive particles must be harder than the workpiece.
- ultrasonic processing using abrasive tool with diamond powder.

The tool vibrations with ultrasonic frequencies between 16-35 kHz, amplitudes up to 120 μm and pressures between 20-30 daN/cm^2, exercise an abrasive action on the workpiece, leading to destroy parts of material in the work area.

2. INSTALLATION OF ULTRASOUND PROCESSING

Ultrasound machines look like drilling machines and they can be fixed or mobile, and can cover a wide range of operations such as: drilling, profiling, grinding etc.

The ultrasound processing machines are made from the following particular subassemblies:

- ultrasonic frequency generator;
- ultrasonic block;
- supply system for abrasive suspension or the cooling fluid, depending on the used tool;
- the displacement system of the working head.

The ultrasonic frequency generator serves to transform the industrial frequency of electric current (50 Hz) to ultrasonic frequency (16-35 kHz).

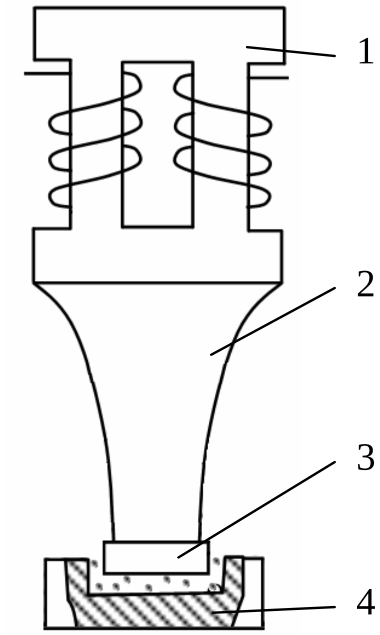


Figure 1

The ultrasonic block is used to transform electric energy received from the frequency ultrasonic generator in mechanical energy.

The main components are: ultrasonic transducer unit (1) (ultrasonic vibrator) and vibration horn (2) which transmit and concentrate the mechanical energy of transducers through the tool (3) on the workpiece (4) (Figure 1).

The transducer construction is based on the property of ferromagnetic materials to change its dimensions under the action of magnetic fields. Increasing vibration transducer can be achieved by introducing marginal piezoelectric components with different densities.

In order to be used in the processing, at the mechanical vibration generator with ultrasonic frequency, is added ultrasonic horn which is designed to transmit these vibrations at the processing tool and to increase the amplitude of mechanical oscillations.

Generally the horns perform the following functions:

- transfer ultrasonic energy from the vibration generator to working area;
- concentrate and focus the ultrasonic energy to the working area;
- increase tool amplitude vibrations;
- increase processing efficiency;

From the construction point of view it is necessary that the length of horn to be equal with an integer number of half of wave lengths of vibration generator.

The functional characteristic of ultrasonic horn is given by the amplification factor, which shows how often the size of amplitude vibration in working area is higher than the amplitude vibration of the generator. The highest values of amplification factor are obtained for ultrasonic horns with exponential form which, due to this property, are used especially in the drilling operations.

3. THE ULTRASONIC HORN DIMENSIONING

For designing the horn, first it is needed to specify the material and the value of the ultrasonic vibrations. The output diameter *d* of the horn depends on the diameter to be processed. The fixture diameter *D* of the horn is determined taking into account the type of operation (roughing or finishing). Considering the shape of transversal cross section of the horn is circularly, and the law of variation along the generating curve is exponential one, the diameter of a point *x* against of the fixture diameter will be:

$$D_x = D \cdot e^{-\beta x} \qquad (1)$$

β – exponent of reduction of cross section

It can be determined by following:

$$\beta = \frac{1}{l}\ln N \ \ [\text{m}^{-1}] \qquad (2)$$

where:

$$N = \frac{D}{d} \qquad (3)$$

l – resonance length

Resonance length of the horn is established by:

$$l = \frac{1}{k}\sqrt{\pi^2 + \ln^2 N} \qquad (4)$$

$$k = \frac{\omega}{c_L} \ [\text{m}^{-1}] \qquad (5)$$

ω – pulse

$$\omega = 2 \cdot \pi \cdot f \qquad (6)$$

f – ultrasonic vibration frequency;

c_L - ultrasonic longitudinal speed through horn material [m/s];

4. PARAMETRIC DESIGN OF HORN SHAPE. CASE STUDIES

As it is known, the efficiency and accuracy of ultrasound processing depend on the accuracy of the horn shape. In these conditions in order to achieve a high accuracy, to determine the precise diameter in different cross sections of the horn, it was made a computer program developed with the MATLAB application. After introducing the input data the program calculated the horn length and diameter in different cross sections and also saved this data in a matrix. The program also permits a graphical representation of the calculated horn. In order to obtain a properly precision, running the program was done for small steps (0.1mm). The graphical representation for several exponential horns calculated using the program is shown in Figures 2… 4.

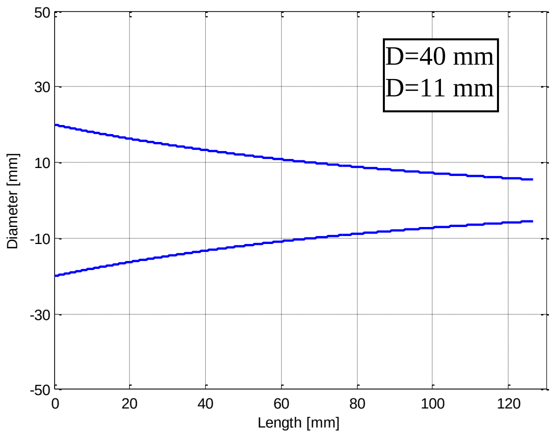


Figure 2

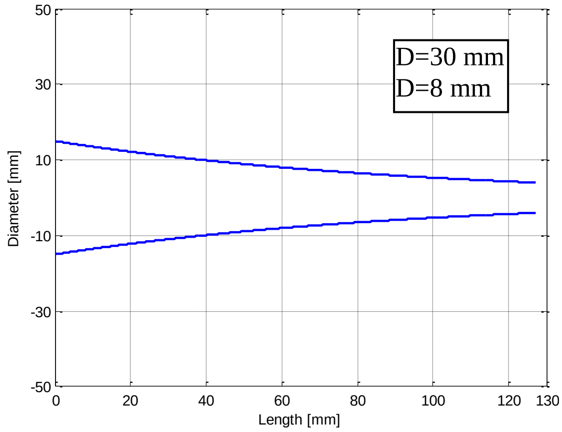


Figure 3

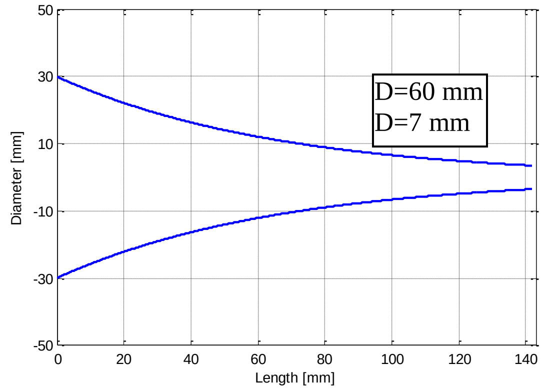


Figure 4

In tables 1 to 3 are presented some data regarding the diameter changes along the exponential horn length.

Table 1. A few calculated data for ultrasonic horn with D=40 mm, d=11 mm

Coordinate x [mm]	Variable diameter D_x [mm]
0	40.00000
10	36.12761
20	32.63011
30	29.47120
40	26.61810
50	24.04121
60	21.71379
70	19.61169
80	17.71308
90	15.99829
100	14.44950
110	13.05065
120	11.78722
126.7	11.01001

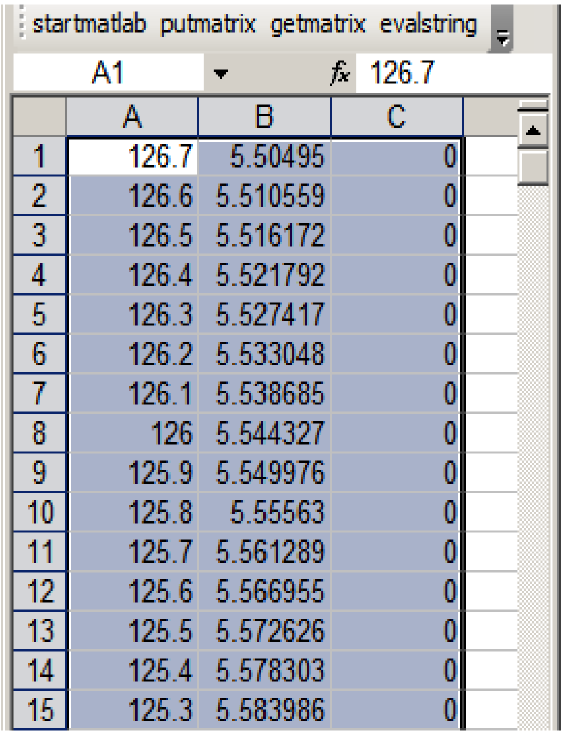
Table 2. A few calculated data for ultrasonic horn with D=30 mm, d=8 mm

Coordinate x [mm]	Variable diameter D_x [mm]
0	30.00000
10	27.03980
20	24.37169
30	21.96685
40	19.79931
50	17.84564
60	16.08475
70	14.49761
80	13.06709
90	11.77771
100	10.61556
110	9.56809
120	8.62397
127.2	8.00244

Table 3. A few calculated data for ultrasonic horn with D=60 mm, d=7 mm

Coordinate x [mm]	Variable diameter D_x [mm]
0	60.00000
10	51.57950
20	44.34074
30	38.11789
40	32.76836
50	28.16959
60	24.21622
70	20.81768
80	17.89609
90	15.38452
100	13.22543
110	11.36935
120	9.77375
130	8.40209
140	7.22292
142	7.00774

It further presents a method of making the 3D model of exponential concentrator calculated using Solid Edge software, the obtained 3D model could be in a CAM application to make CNC program to process the horn profile. The x, y coordinates obtained from program developed in MATLAB are saved in a matrixthat is exported in Excel application (figure 5).


startmatlab putmatrix getmatrix evalstring
A1 126.7

	A	B	C
1	126.7	5.50495	0
2	126.6	5.510559	0
3	126.5	5.516172	0
4	126.4	5.521792	0
5	126.3	5.527417	0
6	126.2	5.533048	0
7	126.1	5.538685	0
8	126	5.544327	0
9	125.9	5.549976	0
10	125.8	5.55563	0
11	125.7	5.561289	0
12	125.6	5.566955	0
13	125.5	5.572626	0
14	125.4	5.578303	0
15	125.3	5.583986	0

Figure 5

Obtaining the 3D model is realized by importing the coordinates x, y of the horn from the Excel application into Solid Edge modeling application.After importing these coordinates is obtained the following curve (figure 6)

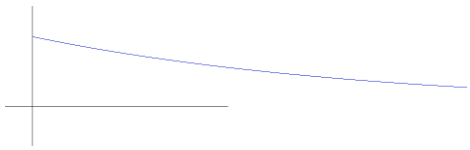


Figure 6

Using specified design commands of the mentioned application it is obtained a sketch that represent a half of longitudinal cross section of the designed horn (figure 7).

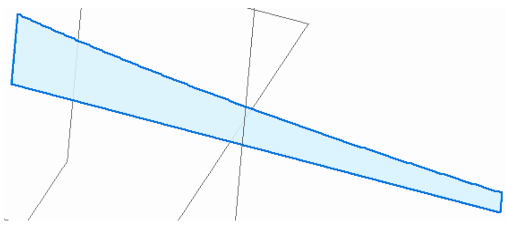


Figure 8

The sketch is used to obtain the solid model of the horn. In figures 9…11are represented the 3d models of the designed horns calculated by the use of the realized program.

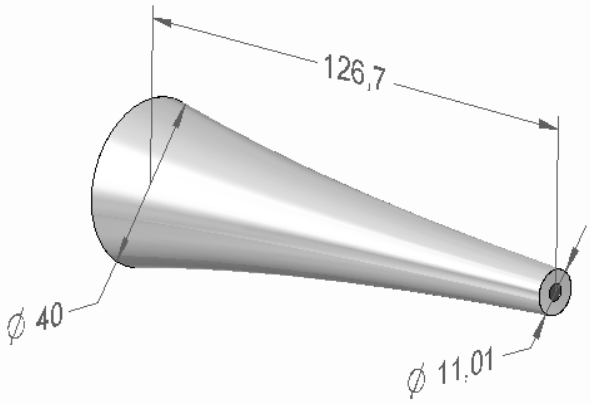


Figure 9

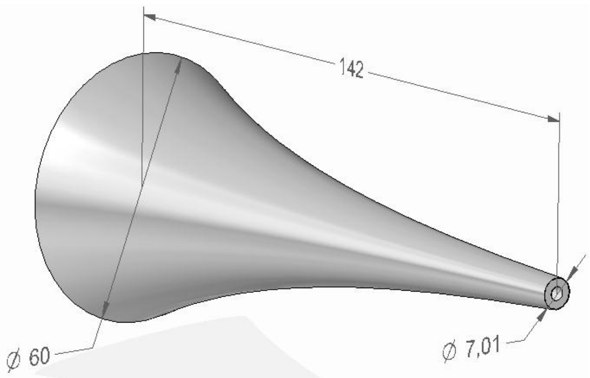


Figure 10

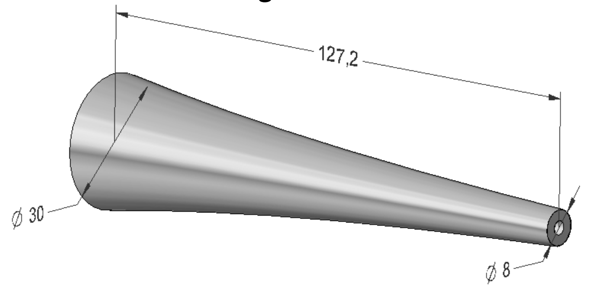


Figure 11

Establishing the theoretical form of the horn, is followed by its manufacturing process. The precise exponential form of the horn can be done either by using very precise patterns, or using CNC machines by CAD/CAM technology.

5. CONCLUSIONS

- Starting by the known relationships from the references, a modern method to design exponential ultrasonic horns is presented.
- The designed method consists on realization of a calculation program, which supplies the coordinates in different cross-sections of the horn and allows its graphical representation.
- The performed program allows to save the matrix with (x,Dx) coordinates in xls format, which can be calculated in Solid Edge application in order to obtain the 3D model.
- The solid realized model will be later used to make the CNC program using a CAM application.
- An important advantage of the presented method consists in easily parametric design of horns by integration of realized program made in Matlab into Solid Edge through Excel application.

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