DESIGN AND FEM SIMULATION OF ULTRASONIC WELDING HORN

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ABSTRACT: The need for high quality joints between different materials has led to the emergence and development of new processes of joining (welding and brazing).Of these, the ultrasonic welding process is characterized in that the contact surfaces are vibrated with ultrasonic frequencies simultaneously by applying external pressure in order to increase friction. The connection is done at temperatures lower than melting, thus eliminating the heat affected zones. Using the relationships from literature and using integrated CAD-CAE applications, the paper presents the design and verification of a horn used on ultrasonic systems for welding cables for the automotive industry.
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1. INTRODUCTION

Due to miniaturization of components and increasing their reliability was found out in more and more applications the use of acoustic waves, both in processing methods as well as for assisting other technological processes. Ultrasonic welding can be done with or without filler material.

The joint results due to diffusion effects, cavitations, absorption, which occurs in the work area due to the introduction of ultrasonic energy in the form of longitudinal or transverse oscillations. The joint occurs at temperatures lower than the melting eliminating heat affected zones.

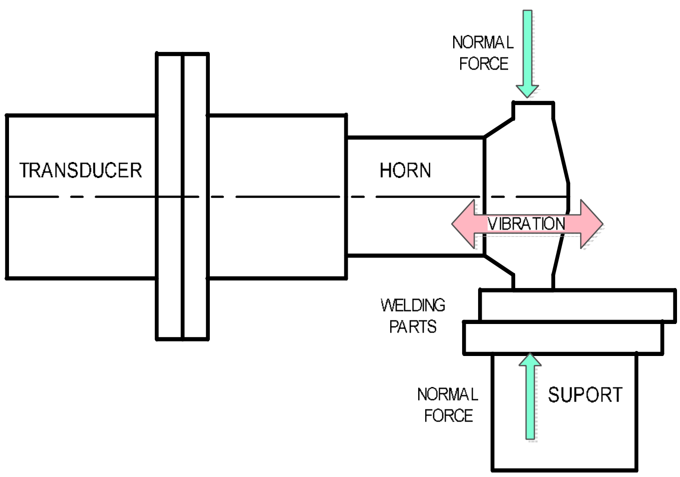

Figure 1. The system for ultrasonic welding.

The ultrasonic welding system is schematically shown in Figure 1. The installation consists of the following main components: ultrasonic generator, transducer, Booster and horn, rigid fixture for welding components and a system for producing the normal force.

The welding process is characterized by the fact that contact surfaces are vibrated with ultrasonic frequencies, when applying external pressure in order to increase friction.

Increasing temperature in the contact area is due to the heat generated during friction. This leads to the appearance on welded points between surface components (Figure. 2). [1]

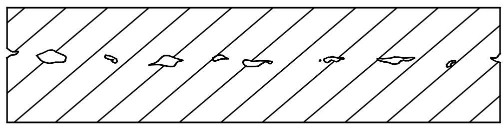

Figure 2. The contact surface after ultrasonic welding.

The effectiveness of energy transfer in the welding area depends largely on the horn, and fixing components during the welding process. For a good weld it is necessary to apply a clamping force, which must have a proper value to prevent slippage of components during the welding process.

Joint quality depends on the optimal welding parameters for certain materials. This is determined from experimental studies that involve consideration of influencing factors such as the amplitude and frequency of ultrasonic oscillation, welding time, the normal force in the contact area, the rate of plastic deformation [8].

There are studies and researches both in our country and in foreign countries which approach on different aspects the use of ultrasound in different field of activities

The study [9] aims calculation of resonance length, the voltage and oscillation amplitude for different horn profiles such as exponential, conical and stepped.

In [3] is presented a study about a design of a booster for the welding, ultrasonic device, and is [7] approached the design and simulation of a stepped horn used in ultrasonic machining.

In the papers [6] and [10] are presented studies about the high power horns used in ultrasonic welding fields. In order to set up the best vibration, the results of research are based on finite element analysis.

In industrial ultrasonic installations the horn is designed to work at frequencies between 15kHz and 300kHz, but welding installations use frequency ranged in 20-40 kHz, commonly 20 kHz [4].

Based on known relationships indicated in [5], and using integrated CAD-CAE applications in this paper are presented the design and FEM simulation of an ultrasonic horn used at welding copper cables for the automotive industry.

2. THEORETICAL ASPECTS

Horn is the element that assures the transfer and focuses the ultrasonic energy to the work area. Horn design starts from the propagation equation of longitudinal oscillations [5].

The equation of propagation of longitudinal waves in cylindrical horn is described by:

$$\frac{1}{c_L^2}\frac{\partial^2\xi}{\partial t^2}-\frac{1}{S}\frac{\partial S}{\partial x}\frac{\partial \xi}{\partial x}-\frac{\partial^2\xi}{\partial x^2}=0 \qquad (1)$$

ξ represents amplitude of displacement;

x is distance from free side of horn

ω – pulsation

c_L –velocity of sound in the medium of the horn [m/s];

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

f – frequency [Hz]

Based on relationship (1) for a longitudinally half wave resonant horn putting boundary conditions, the solution in term of displacement is:

$$\xi = \xi_0 \cos\left(\frac{\omega x}{c_L}\right)\cos(\omega \cdot t) \qquad (3)$$

The velocity is obtained by derivation the previous relation relating on time:

$$v = -\omega\xi_0 \cos\left(\frac{\omega x}{c_L}\right)\sin(\omega \cdot t) \qquad (4)$$

The acceleration of a point situated at distance x from the side of the application of vibrations is:

$$a = -\omega^2\xi_0 \cos\left(\frac{\omega x}{c_L}\right)\cos(\omega \cdot t) \qquad (5)$$

$\xi 0$ is the maximum displacement situated at x=0

To determine the stress (σ) we'll use the relationship:

$$\sigma(x) = -E\cdot\xi_0\frac{\omega}{c_L}\sin\left(\frac{\omega x}{c_L}\right)\cos(\omega\cdot t) \qquad (6)$$

The mechanical impedance represents the strength of a structure subjected to the movement under action of an applied force.

In a point of a structure, the mechanical impedance is given by the ratio between the acting force and speed:

$$Z(x) = \frac{F(x)}{v(x)} \qquad (7)$$

After doing the calculus:

$$Z(x) = S(x)\cdot\frac{1}{c_L}\cdot\frac{tg\left(\frac{\omega\cdot x}{c_L}\right)}{tg(\omega\cdot t)} \qquad (8)$$

Where S(x) is the cross-sectional area of the horn at distance x

3. NUMERICAL STUDY

The horn was designed for a 20 kHz working frequency. The analytical relationships were used to determine the displacement, velocity and acceleration, stress and mechanical impedance of horn.

In Figure 3 is shown the variation of amplitude depending on the distance from the end.

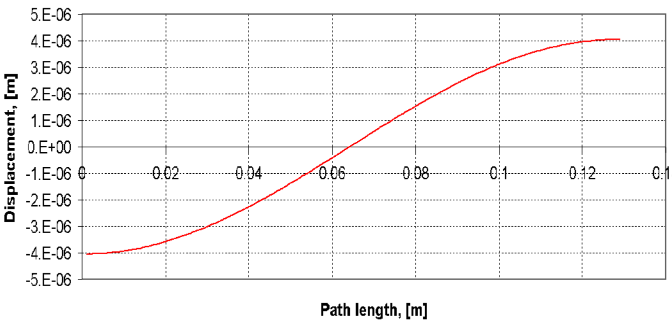

Figure 3. The amplitude of displacement depending on the path length

Figure 4 shows the variation of the speed according to the position of the end section, and in Figure 5 shows the stress dependency of the distance from the end of input.

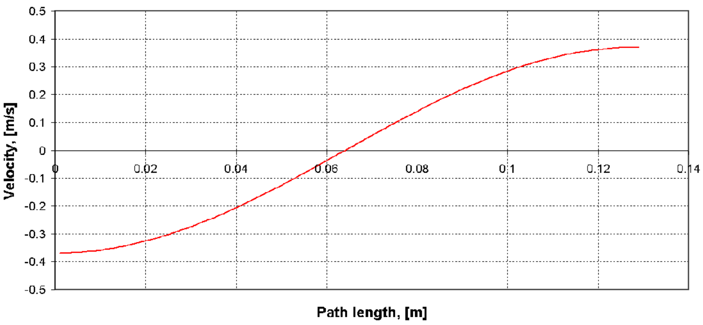

Figure 4. The velocity depending on the path length.

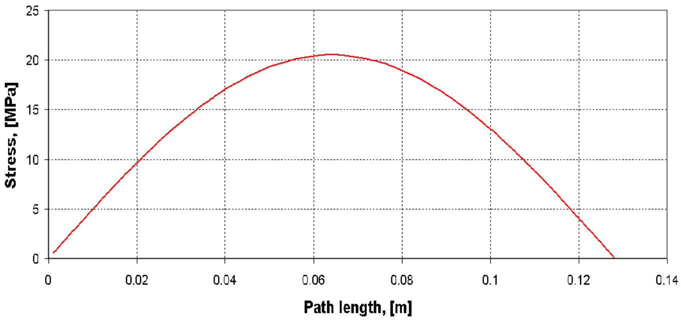

Figure 5. The stress depending on the path length

Variation of mechanical impedance is shown in Figure 6

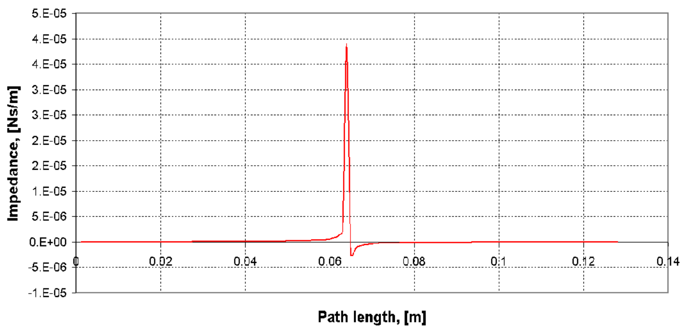

Figure 6. The mechanical impedance vs. path length.

4. DESIGN OF ULTRASONIC HORN

The main role of a horn is to transmit the vibration energy from the transducer to work area and to increase the amplitude of ultrasonic vibration.

To obtain maximum efficiency is needed that the horn be in resonance state with transducer.

Horn design requires to determine the resonant frequency and the wavelength [11].

For a horn with a simple geometrical form, the resonance frequency can be analytically determined.

Generally horns are made of materials with low acoustic losses and good resistance to fatigue.

The horn incorrectly made will affect the processing performance and can lead to destruction of vibration system and can cause considerable damage to the generator. To achieve the horn, was chosen a C45 steel material, which has good acoustic properties, is easily processed and has a low price

To reduce losses at the surface of contact between the transducer and horn, their assembly will be done by screwing.

The main characteristics of the used material for horn are presented in Table 1.

Table 1. The main characteristics of the used steel

Young's modulus E [GPa]	Density ρ [kg/m^3]	Poisson's ratio ν	c_L [m/s]
210	7830	0.31	5125

For horns in half-wave, length determination of the resonance length L is done with the relationship:

$$L = \frac{c_L}{2f} = \frac{\lambda}{2} \tag{9}$$

The node of oscillations is situated at a distance given by:

$$d = \frac{c}{4f} \tag{10}$$

Based on constructive-functional considerations and previous relationships were determined the dimensions of ultrasonic horn. The 3D model is shown in Figure 7, and several constructive data are shown in Figure 8.

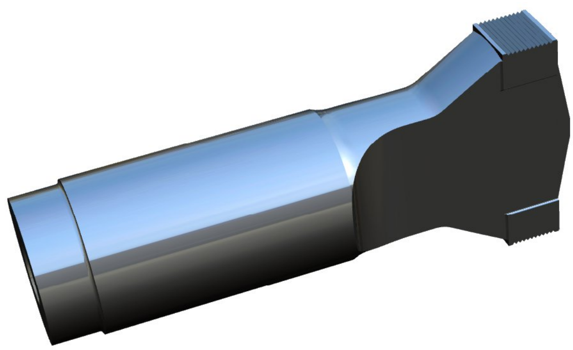

Figure 7. The 3D model of ultrasonic horn.

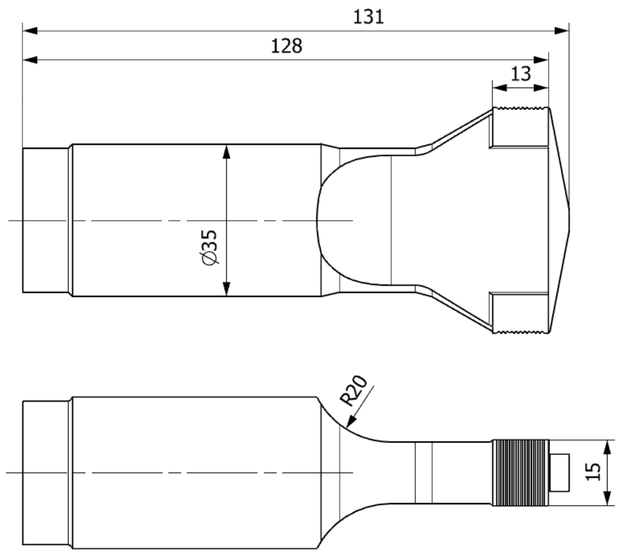

Figure 8. The main dimensions of the ultrasonic horn.

5. FEM ANALYSIS

In the field of ultrasonic waves, FEA is used to predict the vibration behavior of the horn and its ultrasonic assembly before being manufactured [6].

Modal analysis is usually the first step of analysis. Knowing their own vibration modes give information on limits of use of frequencies to work, with positive implications in terms of time and cost of designing, manufacturing and use of horns.

Although modal analysis results are obtained without damping, the vibration tendency can be specified with tolerances of about 500-600 Hz.

Also, some errors may occur as a result of material parameters introduced as input for the FEM analysis.

The elements on 3D mesh model of the concentrator are presented in Table 2.

Table 2. The FEM data

Mesh	Element Family	Elements	Nodes
Solid : PSOLID1 , Steel			
3d_mesh	Tetra10	10718	17478

The 3D mesh for designed horn is presented in figure

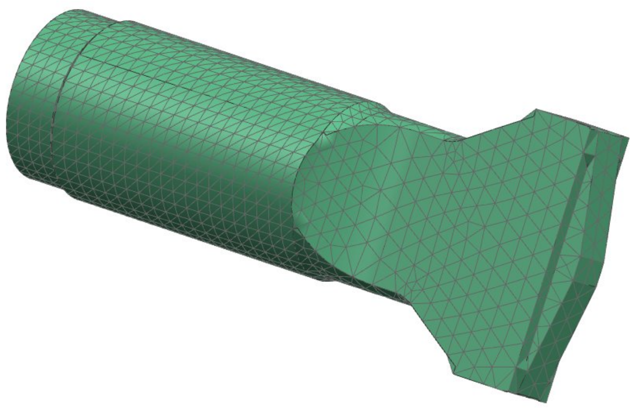

Figure 9. The discretization of horn.

For finite element analysis were used the data from Table 3.

Table 3. The simulation data

Solver:	NX NASTRAN
Analysis Type:	Structural
Solution Type:	SEMODES 103 - Response Simulation
Linearity:	Linear

After running the finite element analysis were obtained their own vibration modes shown in Figures 10-12. From their analysis, it follows that the vibration mode 2 (19909 Hz) corresponds in terms of its vibration direction - longitudinal - at a frequency very close to that which has been designed the horn.

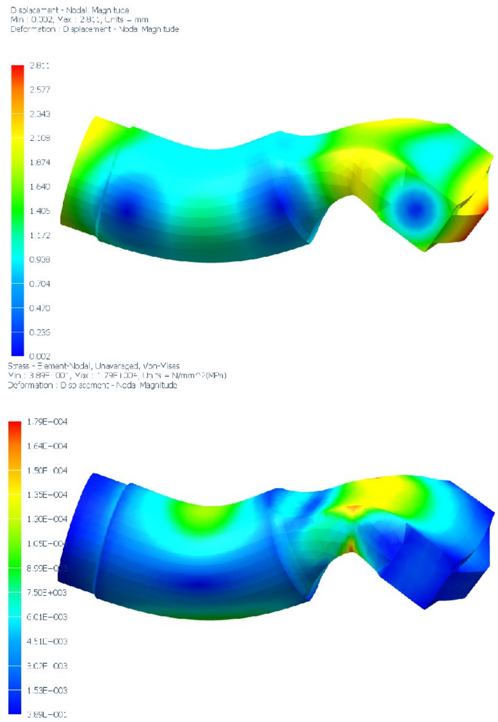

Figure 10. Displacement and stress (Von Mises) for Mode 1 (16130 Hz)

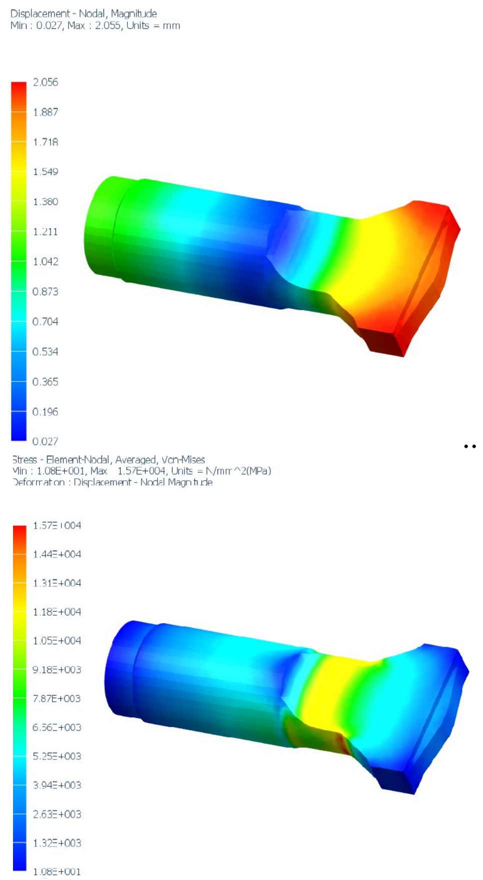

Figure 11. Displacement and stress (Von Mises) for Mode 2 (19909 Hz).

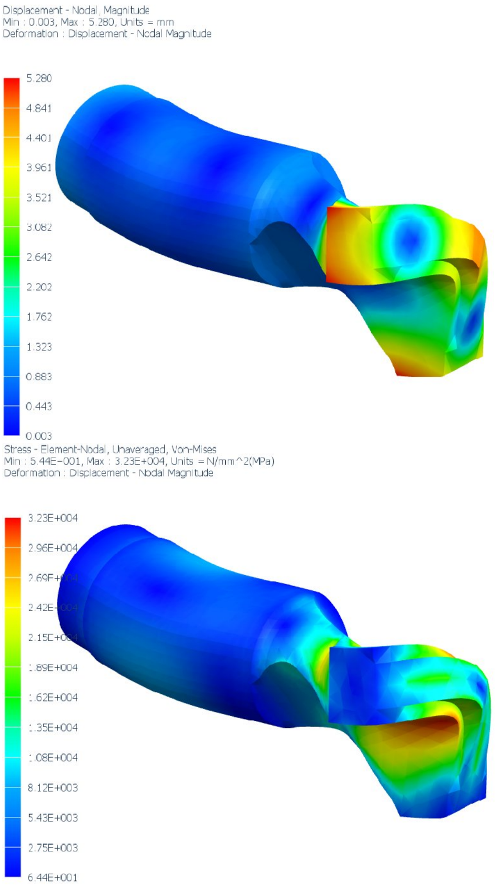

Figure 12. Displacement and stress (Von Mises) for Mode 3 (23690 Hz)

6. CONCLUSIONS

Using analytical relationships and integrated CAD-CAE applications, the paper presents the design of a horn used in ultrasonic installations for welding copper wire cable.

The effectiveness of energy transfer in the welding area depends on a number of parameters. Among the most important factors is the design of the horn.

For maximum efficiency it is necessary that the horn be in resonance states with transducer.The horn design requires determining resonant frequency and wavelength determination.

Numerical studies used the analytical relationships in a computer program for determining the amplitude, velocity, acceleration, stress and mechanical impedance of the horn.

FEM analysis is one of the most important stages of the design of the elements that make up the ultrasonic processing systems.

The main dynamic characteristics of the horn in the state of resonance were studied in function of the geometrical shape and dimensions.

Analyzing their own vibration modes, gives information on the use of frequencies to work with positive implications in terms of time and cost of designing horns.

The horn was designed for a frequency of 20kz, FEM analysis confirms that the horn is vibrated longitudinally close to 20 kHz, which ensures uniformity of vibration amplitude of the horn to work surface.

7. REFERENCES

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