International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 7 Issue 11, November - 2023, Pages: 32-37

Four spot weld horn design for ultrasonic plastic welding

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Abstract: *The acoustic horn is an essential component of high energy ultrasonic machining, and the effectiveness and quality of the machining process depend heavily on its design. This paper uses ANSYS finite element software to analyze and design acoustic horns for ultrasonic machining. The findings show that theoretically designed horns have amplitudes that are higher than those of horns sold in stores, and that their natural frequencies are closer to the vibration frequencies of ultrasonic generators.*

Keywords: Horn, Ultrasonic plastic Welding, Modal Analysis, Harmonic Analysis

1. Introduction

Ultrasonic metal welding is a solid-state joining process used to weld thin metal sheets, foils, and wire. The principle of this welding operation follows from the creation of an oscillating shear force (ultrasonic vibrations) under moderate pressure (normal force) at the interface between the mating surfaces [1].

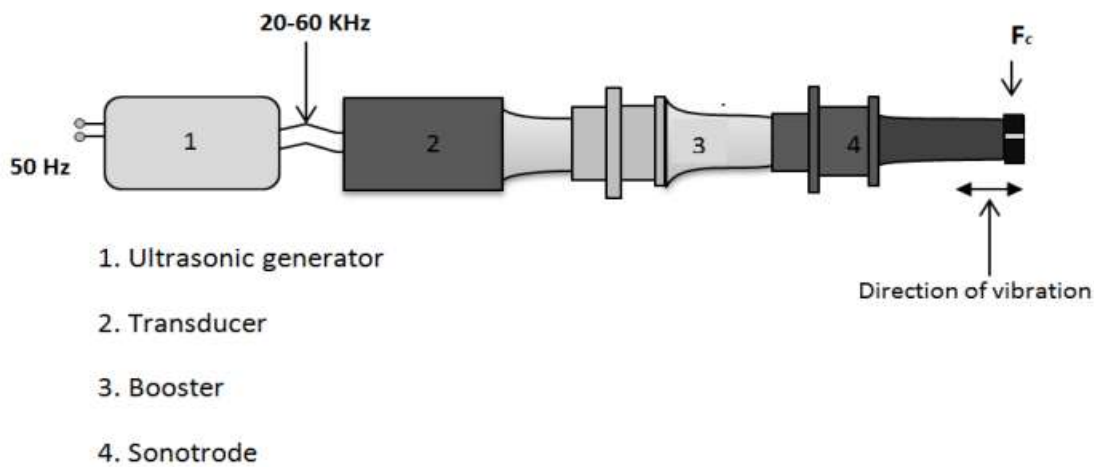


Figure 1. Principle of ultrasonic welding

The weld contact area is parallel to the applied vibrations. According to Fig. 1, an electrical energy supply of 50 Hz is given to the ultrasonic generator, which amplifies it to a frequency of 20–60 KHz. The same electrical energy is also given to the piezoelectric transducer, which transforms the electrical energy into mechanical vibrations, which are then amplified by a booster and sent up to the sonotrode. When vibrations enter the contact area, they cause oscillations that enhance diffusion over the weld interface and yield a weld that resembles diffusion welding. The combination of static load and ultrasonic vibration causes dynamic shear strains at the welding spot. The rubbing area will heat due to interfacial slip and plastic deformation, but the temperature generated will never reach the parent material's melting point. The neighboring contact surfaces connect as a result of the strong shearing and plastic deformation. The power needed to create the connection and the quality of the weld are controlled by these shear forces. Weld strength can be controlled by varying the forces acting at the weld interface. [2]. Elangovan et al. [2] created a model to represent the stress distribution in the welded joints and temperature distribution throughout the welding process. The interface temperature and stress distribution during welding, as well as their effects on the work piece, sonotrode, and anvil, may all be predicted using the Finite Element method. It also covered the impact of the coefficient of friction, material thickness, and clamping pressures on heat generation at the weld contact. concluded that because more heat is produced in the work piece where the ultrasonic energy is focused, there is a higher temperature there than there is in the sonotrode. Siddiq and Ghassemieh [3] They have stated that volume softening (plasticity) and surface friction combine to create ultrasonic welding. Thus, an effort has been made to mimic the effects of both of these on the metal while welding. The maximum temperature reached during ultrasonic welding is well below melting temperatures of the joining materials, and it was discovered that friction stresses at the weld interface decrease as a result of thermal and acoustic softening, which is consistent with the experimental results.

2. Modes of vibration

An electrical current that pulses through a piezoelectric element produces a small-amplitude vibrational wave that is insufficient for many ultrasonic applications**[4]**. Transducers use the mode shape of the structural geometry to amplify this amplitude in order to get around this limitation. Pre-stressed sandwich transducers work by altering the structure's resonance length to cause the transducer to vibrate at resonance**[5]**. This is accomplished by using the front and back masses. Other design parameters of the transducer parts are decided after the mode of vibration selection is taken into consideration based on the required application. Ultrasonic transducers typically use a single mode of vibration, which can be torsional (T), flexural (F), or longitudinal (L),**[6]**.as shown in Figure 2.

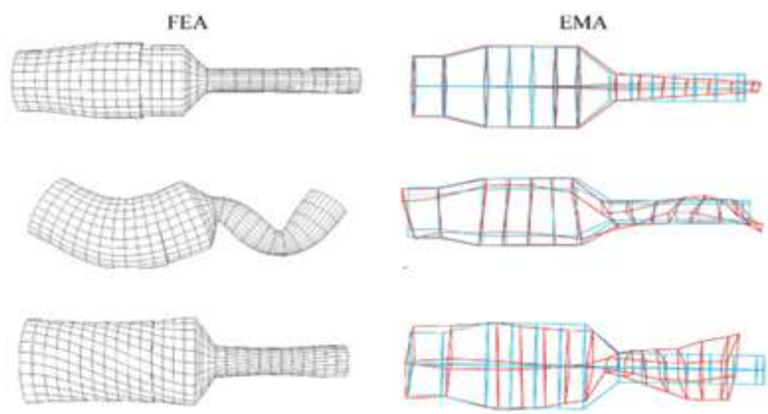


Figure 2:. Mode shapes, from a finite element model of a rod

3. Design of block horn

The titanium composite metal used in the construction of the horn allowed for improved strength and acoustic properties. The horn was designed as a half-wave resonator. Table 1 shows the material characteristics. Figure 3 show horn shape.

Table 1: Material properties of the horn

Property	Value
Young’s modulus	110 [Gpa]
Poission’s ratio	0.33
Density	4.7 [g/cm3]
yield strength	240 (Mpa)

$$\lambda = \frac{C}{f} = \frac{1}{f} * \sqrt{\frac{E}{\rho}} = 2h \quad (1)$$

c = $\sqrt{\frac{E}{\rho}}$ = 5077.2 m/s

Wavelength of mechanical vibrations, $\lambda = \frac{C}{f} = 2h$

2h = 5077.2/20000= 0.253 m
Height of block horn, h =0.127m=127mm

Where,
$\boldsymbol{\lambda}$ - Wavelength of mechanical vibrations ($\boldsymbol{\mu}$**m**)
$\boldsymbol{c}$ - Velocity of sound (**m/sec**)
f- Frequency of vibration (**Hz**)
E - Young's modulus of horn material (GPa)
$\boldsymbol{\rho}$ - Density of horn material ($\mathbf{kg/m^3}$)
L- Height of horn (mm)

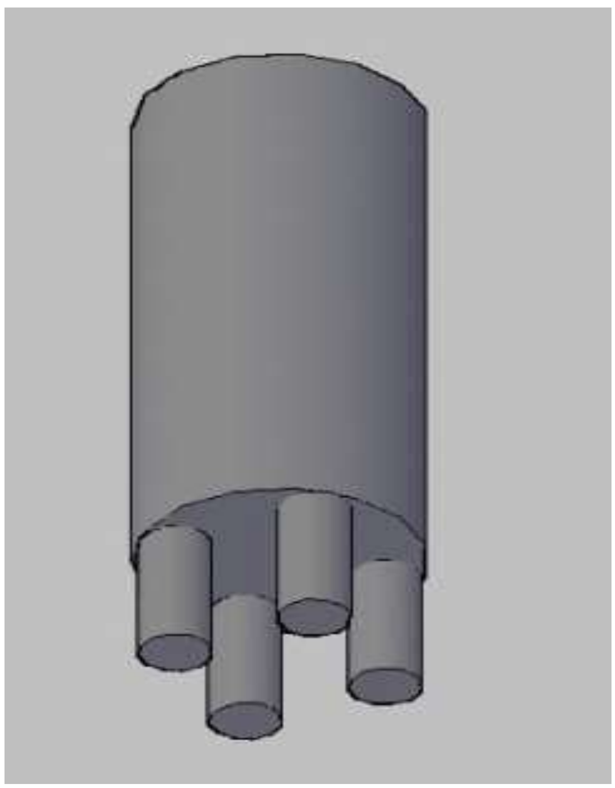
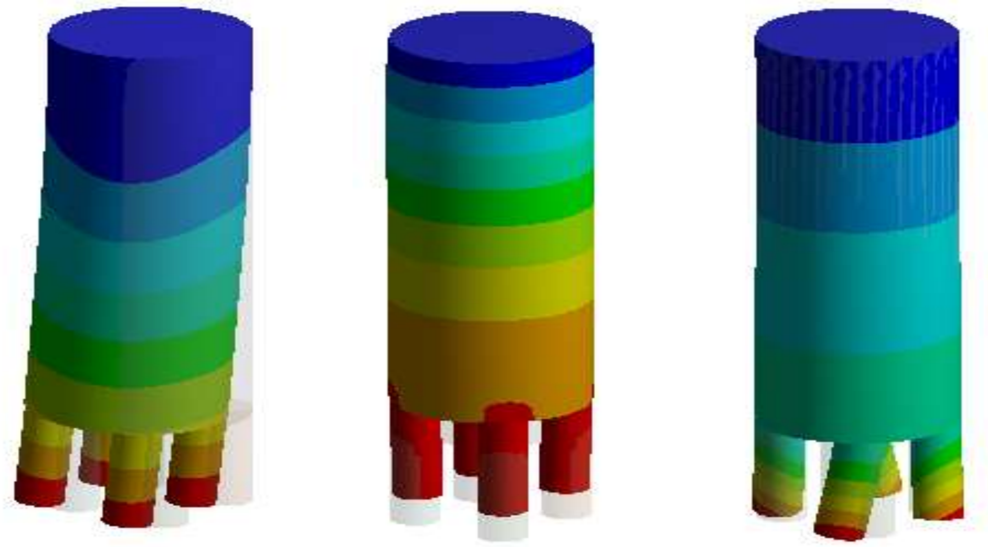


Figure 3: horn shape

4. Modal Analysis

The horn was intended to be a half-wave resonator**[4]**, and its exceptional acoustic properties and strength were achieved by using titanium composite metal. Table 2 displays the mode shape of it. The ultrasonic metal welder in this design was operating at a constant frequency of 20,000 Hz. The horn length that would result in resonance at 20,000 Hz and provide the maximum amplitude at the horn tip was determined using the equation of vibration. The model analysis was carried out and the natural vibration value was determined for each of the longitudinal, transverse and torsional phases, and their value was 19901, 17883 and 16545 Hz respectively, as shown in figure 4.



(a) (b) (c)

Figure 4: Natural frequency (a) flexural mode (b) longitudinal mode

(c) Torsional mode

Table 2: mode shape

Mode	Frequency [kHz]
1.	11.3
2.	13.65
3.	15.34
4.	13.53
5.	16.98.
6.	17.88
7.	16.87
8.	16.54
9.	18.76
10.	16.94
11.	17.87
12.	19.9

5. Harmonic analysis

The horn output displacement or amplitude at known operating frequency of 20 kHz is determined through harmonic analysis with input vibration of 33 µm, identifying the possibility of resonance occurrence in this frequency range. A step is included in the design at the central cross-section to increase the vibration amplitude. At this point, the amplitude is amplified by a factor known as the magnification factor, which is dependent on the weld area (lower surface of the horn) and the input area (upper surface of the horn) of the horn's cross section. In Figure 5, the results of the harmonic analysis are displayed.

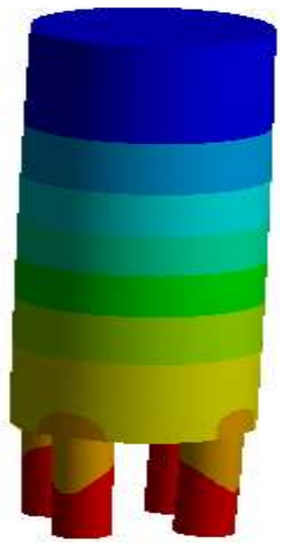


Figure 5: Harmonic response of horn

Conclusions

In the present work, horn for a known operating frequency of 20 kHz. Titanium composite metal is used for the design of horn because of its reliable acoustic properties. The designs are analyzed for the performance and safety in ANSYS. To characterize the vibration parameters of the tool at its tuned frequency, 3D FE simulation has been performed. This analysis looks at a selection of the geometry and material needed for the tool. In order to design and build ultrasonic tooling, the impact of the tool/material boundary conditions on the ultrasonic tool's operating performance is examined. Using modal analysis and optimal vibration performance information, an optimal configuration of the ultrasonic tool is determined using finite element analysis. To get the best efficiency out of the system, specific tuning is done using the calculated resonant frequency. Next, using this knowledge to optimize the benefits of ultrasonic.

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