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COMPARISON AND ANALYSIS OF DIFFERENT TYPES OF HORN GEOMETRY FOR ULTRASONIC WELDING.

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Abstract:

Ultrasonic horns are tuned components designed to vibrate in a longitudinal mode at ultrasonic frequencies. Reliable performance of such horns is normally decided by the uniformity of vibration amplitude at the working surface and the stress developed during loading condition. The horn design engineer must pay particular attention to designing a tool that will produce the desired amplitude without fracturing.The present work discusses horn configurations which satisfy these criteria and investigates the design requirements of horns in ultrasonic system. Different horn profiles for ultrasonic welding of thermoplastics have been characterized in terms of displacement amplitude and von-Mises stresses using modal and harmonic analysis. To validate the simulated results, four different horns are fabricated from Copper ,tested and tuned to the operating frequency
Keywords : horn, ultrasonic

Indroduction:

The increasing use of polymers in various industries has necessitated the use of joining processes suitable for polymers. Among the different processes used today, Ultrasonic welding (USW) is the most preferred method for joining thermoplastics. As the process is fast, efficient and economical with weld times being less than a second; it is gaining popularity in recent times to join a variety of industrial thermoplastic components[1]. Ultrasonic welding is extensively being used in automobile, medical, pharmaceutical, consumer appliances and more recently in the pump industry to weld thermoplastic impellers.In USW, the parts to be joined are held together under pressure and are then subjected to ultrasonic vibrations usually 20 kHz, although frequencies in the range 15–60 kHz are used by the industry depending on the application at hand. The resulting alternating stresses generate heat in the plastic and if the components are properly designed, this heat can be localized at the joint where heat generation is by inter-molecular friction[4]. The ability to weld a component using ultrasonics is governed by the design of welding equipment: horn and fixture, the mechanical properties of the materials to be welded, the design of the components and welding parameters.The ultrasonic plastics welding machine consists of the power supply (generator), transducer, booster, horn, control and a fixture to hold the components. A piezoelectric transducer converts electrical energy to mechanical vibrations which are then passed through the booster. The booster transforms the vibration amplitude delivered by the transducer to the value required by the horn. The booster is connected between the transducer and horn to achieve variations in amplitude that cannot be achieved by the horn alone. A horn or a sonotrode further amplifies and transmit the ultrasonic vibrations from the booster to the components being welded. The horns act as impedance transformers, at one end they have to match the amplitude of the booster and at the other end the components to be welded[3].The horn is usually designed to have a higher amplitude/velocity at the tip so as to provide sufficient amplitude for welding. This amplification of amplitude (or gain) is achieved by reducing the cross section along the length of the horn. The common profiles of horns for amplifying the output of the transducer are stepped, conical and exponential. As very high amplitudes predominate in the welding of plastics, the stress on the horn is considerable. Hence the design engineer has to strike a balance between the high amplitude requirements and maintaining low stresses experienced by the horn. Owing to the dynamic nature of the horn design considerable research has been carried out to study its performance both analytically as well as by finite element analysis (FEA).

From the literature it is clear that the characterization of different horn profiles in terms of displacement amplitude and stress needs to be done as a prelude to optimizing the horn design. The efficiency of the horn is adjudged by the displacement amplitude available at the tip of the horn. It is also known that amplitude plays an important role in welding as it influences the heating mechanism responsible for melting and bonding. Considerable literature is available reporting the various methods and mechanisms available to measure the horn displacement. So far, horn displacement has not been correlated to any welding output viz. interface temperature, weld strength, etc. In the present study the computational modeling of four different horn profiles is carried out using ANSYS.

Designing of horn:

Horn is the key component for ultrasonic welding to produce sufficient amplitude at the joint area hence the design of horn is of critical importance. At one end it must be shaped to focus energy into the work piece while at the other end it must match the transducer closely. The horn must be resonant at the operating frequency, so as to maximize the displacement amplitude i.e., it is half a wavelength or full wavelength long[1]. Amplitude transformation or gain is achieved by reducing the cross section along the length of the horn. The energy of vibrations is non-uniformly distributed along the length of the horn with velocity/amplitude being greater at the tip of the horn than at the booster end. The commonly used horn profiles in the industry are Stepped and Exponential .Along with these horns the Cylindrical, Tapered horn profiles are considered for the present study[3]. The Cylindrical horn was included so as to have comparison with low amplitude horns. The performance of a horn is usually assessed by the amplification factor or 'gain' that can be achieved at the horn face/end. The gain 't' is defined by the ratio of output amplitude (A2) to input amplitude (A1) .The basic requirement for a gain is when the amplitude factor 't' > 1. Different horn shapes give different gain depending on the variation of their cross sections. For a cylindrical horn the gain in amplitude is '1' as it is of uniform cross section. Modal analysis is an important tool in the analysis, diagnosis, design and control of vibration. Most practical problems require using the finite element method to define a model.
Design of the horn involves a lengthy mathematical exercise.The first step in designing a horn is calculating the length of the horn. The length of the horn is decided by the material being used to fabricate the horn. Ideally, horns are made of materials that are strong and have good acoustical properties. Titanium has the best acoustical properties of all high strength alloys. Copper has excellent acoustical properties, but because of its lower strength and hardness, it is subjected to wear and fracture when used for highly stressed design[4].

Modal analysis

As modal displacements in the actual horn occur in the x, y and z directions it is better to consider a 3D horn model with a suitable element'. The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions and is well suited to model irregular meshes (such as produced from various CAD/CAM systems). An element mesh size of3 (manual) was selected to carry out the meshing. Below this element size there was no improvement in the results as the FE model has reached convergence.Two or more modes, close to the axial mode will result in modal coupling, which reduces the efficiency of the horn and is to be avoided. Two different modes obtained for Catenoidal profile are shown in. The longitudinal or axial mode is the required mode shape[1].

Selection of profile of horn*:*

For selection of horn profile a force of 50 N was applied at upper surface of horn and lower surface is assumed to be fixed .For selecting various profile of sonotrode input as well as output diameter are selected according to transducer and welded part diameter .Input diameter is 5mm and output diameter is 3 mm and length of sonotrode is 60 mm .Accordingly various shape such as cylindrical, tapered ,stepped and exponential profile are selected for study[1].

Analysis of Stress, Deformation and Modal are done on ANSYS Workbench.

Material properties

Material used: Copper (Cu 99.5% C 0.5%)

Mechanical properties:

Density	7800kg/m3
Youngs Modulas	148 GPa
Poisson Ratio	0.3
Maximum Tensile Strength	450 MPa
ım Compressive Strength	250a

1) **Cylindrical horn**:

Cylindrical horn does not have any equation for its profile, hence input diameter is 3 mm as part to be weld is of 3mm.

Specifications are: Input diameter: 3mm Output diameter: 3mm Length of horn: 60 mm

Figure 1 - Cylindrical Horn

Properties:

Volume	424.12mm^3
Mass	3.2393e-003 kg

Statistics of Mesh:

Nodes	17125
Elements	3600
Type of mesh	Fine

Stress Analysis:

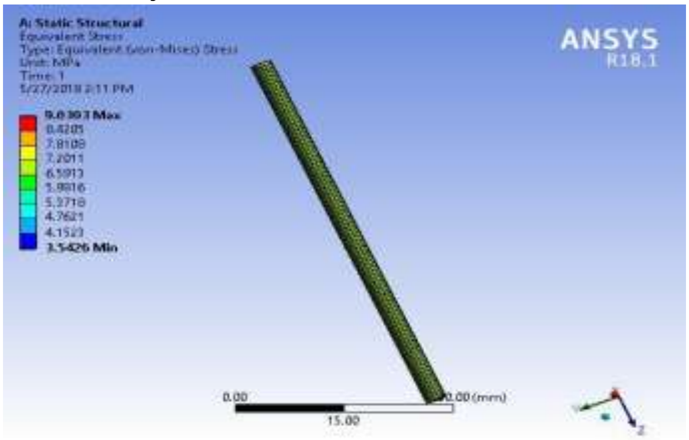
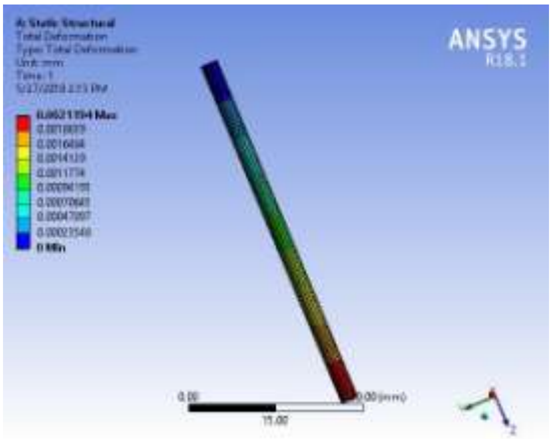


Figure 2 - Stress analysis of cylindrical horn

Equivalent Stress

aximum Stress	9.0303MPa
inimum Stress	3.5436MPa

Deformation Analysis:



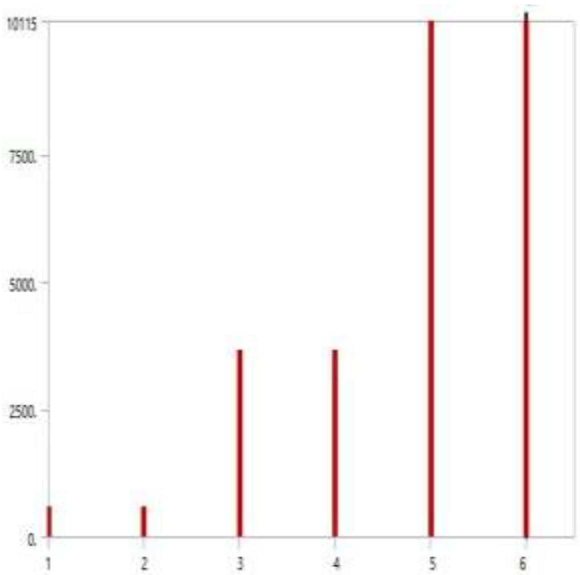
Deformation

Maximum Deformation	0.0021 mm
Minimum Deformation	0.00023 mm

Figure 3 - Deformation of Cylindrical Horn.

Modal Analysis:

Consideration: 6 Modes of Frequency is to be consider .6 natural frequency of horn are obtained.



Mode	Frequency(Hz)
1.	588.88
2.	588.92
3.	3659.7
4.	3660
5.	10115
6.	10115

Figure 4 - Frequency plot cylindrical horn.

2) **Stepped Horn**:

Stepped horn does not have equation for its profile. Its input diameter is 5mm and length is 30 mm and similarly its output diameter is 3mm and length is 30mm Therefore overall length of horn is 60 mm.

Specifications:

Input diameter: 5mm

Input length: 30mm

Output diameter: 3mm

Output length: 30mm

Properties:

Volume	801.65mm^3
Mass	6.2929e-003 kg

Figure 5 - Stepped horn.

Statistics of mesh:

Nodes	7690
Elements	4287
Type of mesh	Fine

Stress Analysis:

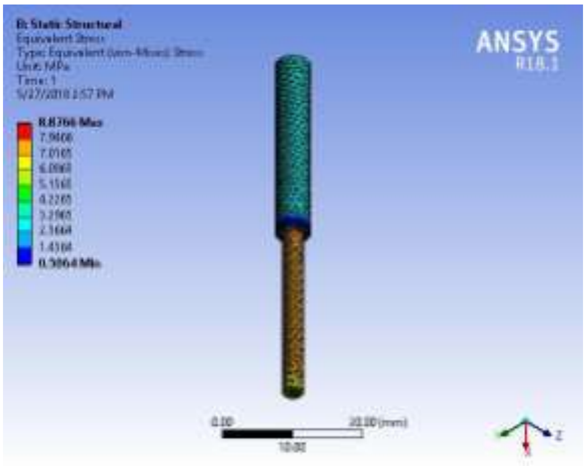
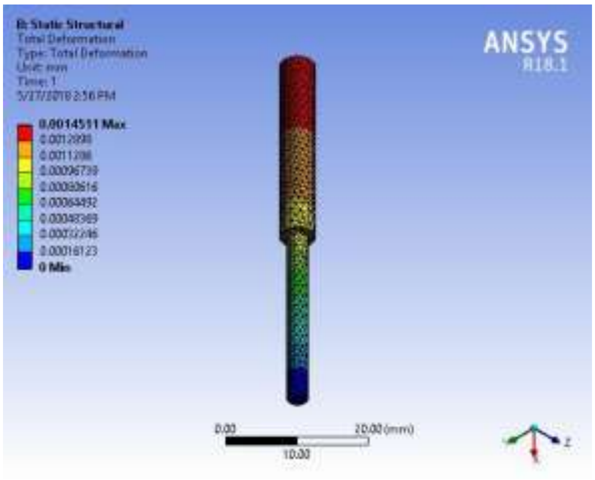


Figure 6 - Stress analysis of Stepped Horn.

Equivalent Stress

aximum Stress	8.8766MPa
inimum Stress	0.5064MPa

Deformation Analysis:



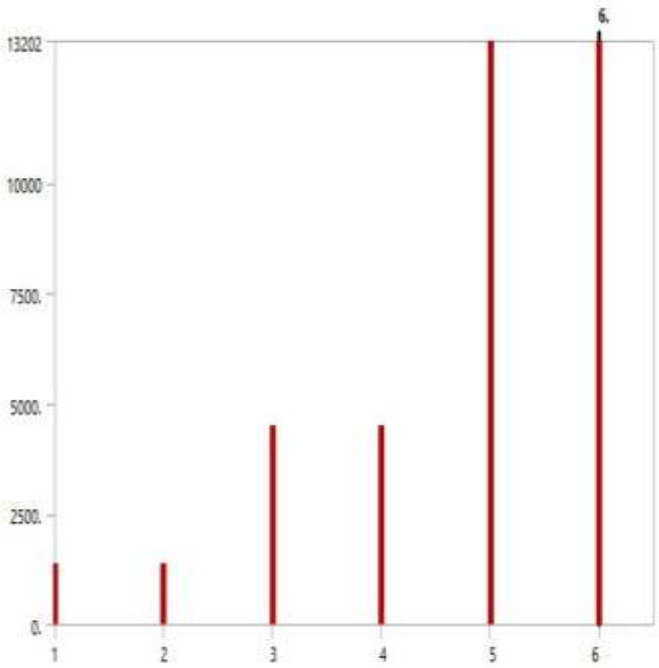
Deformation

Maximum Deformation	0.00145 mm
Minimum Deformation	0.00016 mm

Figure 7 - Deformation of Stepped Horn.

Modal Analysis:

Consideration: 6 Modes of Frequency is to be consider .6 natural frequency of horn are obtained.



Mode	Frequency(Hz)
1.	1360.3
2.	1360.4
3.	4507.1
4.	4507.6
5.	13200
6.	13206

Figure 8 - Frequency plot of Stepped horn.

3) **Taper Horn**:

Taper horn does not have any equation for its profile, hence input diameter is 3 mm as part to be weld is of 3mm.

Specifications are: Input

diameter: 3mm Output

diameter: 3mm Length of

horn: 60 mm

Figure 9 - Taper horn.

Properties

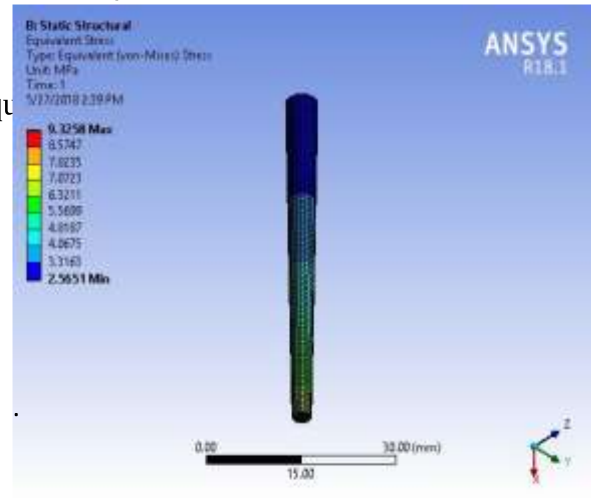
Volume	769.69mm^3
Mass	6.0421e003 kg

Statistics of mesh:

Nodes	28106
Elements	6100
Type of mesh	Fine

Stress Analysis:

Equ



aximum Stress	9.3258MPa
inimum Stress	2.5651MPa

Figure 10 - Stress analysis of taper horn

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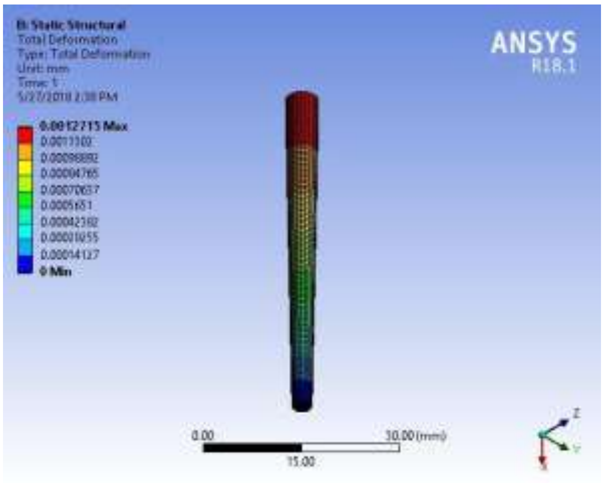
Deformation Analysis:



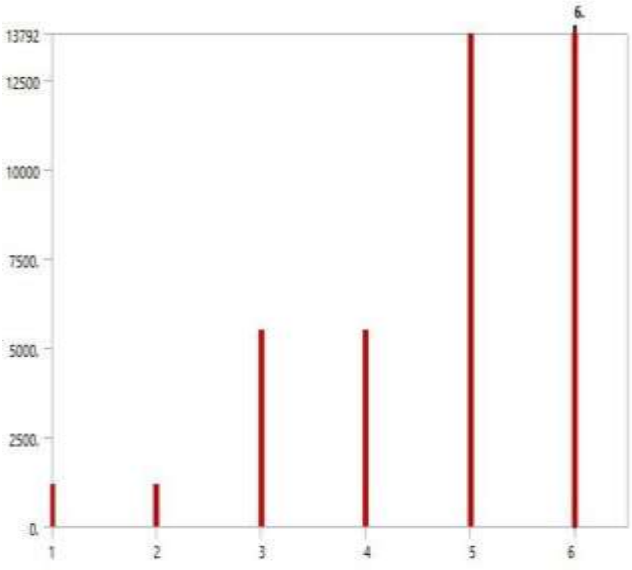
Deformation

Maximum Deformation	0.00145 mm
Minimum Deformation	0.00016 mm

Figure 11 - Deformation of Taper horn

Modal Analysis:

Consideration: 6 Modes of Frequency is to be consider .6 natural frequency of horn are obtained.



Mode	Frequency(Hz)
1.	1203.7
2.	1203.7
3.	5510.7
4.	5510.8
5.	13792
6.	13792

Figure 12 - Frequency plot of taper horn.

4) **Exponential horn**:

Equation of curve of exponential horn is y=e^x. We know input as well as output diameter ie. 5mm and 3mm and length of sonotrode is 60 mm .Hence curve of profile is generated with help of given equation.

Specifications:

Input diameter: 5mm

Output diameter: 3mm

Overall length: 60mm

Figure 13 - Exponential horn

Properties

Volume	761.39mm^3
Mass	5.9769e003 kg

Statistics of mesh:

Nodes	8748
Elements	1690
Type of mesh	Fine

Stress Analysis:

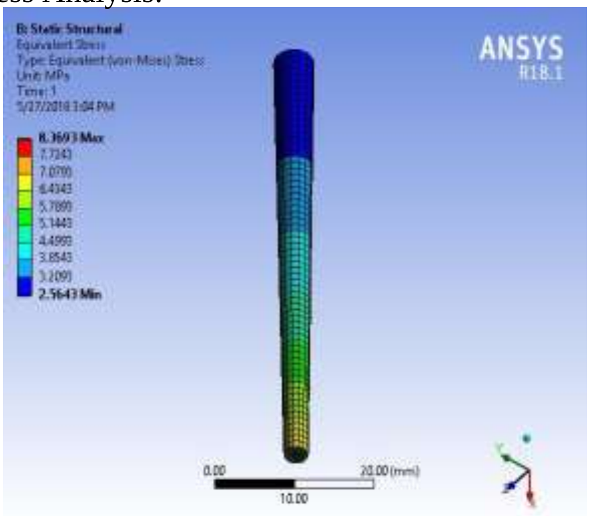
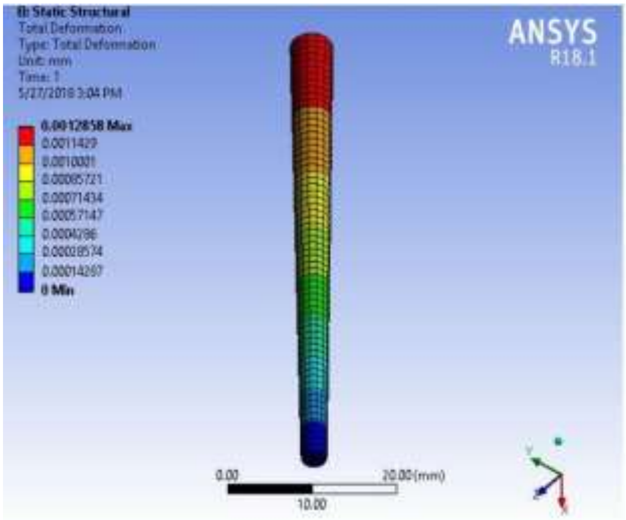


Figure 14 -Stress Analysis of Exponential horn

Exponential stress

aximum Stress	8.3693MPa
inimum Stress	2.5643MPa

Deformation Analysis:



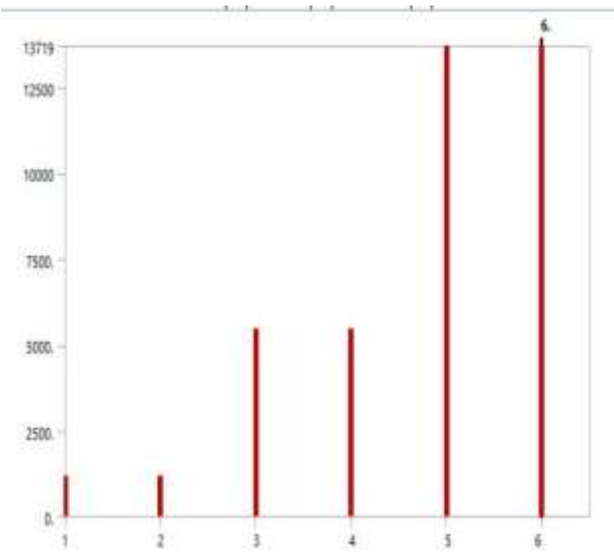
Deformation

Maximum Deformation	0.00128 mm
Minimum Deformation	0.00014 mm

Figure 15 - Deformation of Exponential horn

Modal Analysis:

Consideration: 6 Modes of Frequency is to be consider .6 natural frequency of horn are obtained.



Mode	Frequency(Hz)
1.	1198.8
2.	1198.8
3.	5476.6
4.	5476.7
5.	13719
6.	13719

Figure 16 -Frequency plot of Exponential horn

Result table:

1) Maximum Stress in all types of Horn:

Sr.no.	Horn type	Maximum Stress(MPa)
1.	Cylindrical Horn	9.0303
2.	Stepped Horn	8.8766
3.	Taper Horn	9.3258
4.	Exponential Horn	8.3693

2) Maximum deformation in all types of Horn:

Sr.no.	Horn type	Maximum Deformation(mm)
1.	Cylindrical Horn	0.0021
2.	Stepped Horn	0.00145
3.	Taper Horn	0.00146
4.	Exponential Horn	0.00128

3) Maximum natural frequency in all types of Horn:

Sr.no.	Horn type	Maximum frequency(Hz)
1.	Cylindrical Horn	10115
2.	Stepped Horn	13206
3.	Taper Horn	13792
4.	Exponential Horn	13719

Conclusion:

By taking into consideration all those factors optimum solution obtained is of exponential and stepped horn.. But as stepped horn is feasible to manufacture as well as gain ratio is high than exponential horn stepped horn is selected mostly in industrial applications.Only one disadvantage of stepped horn is stress concentration at midpoint due to sudden change in diameter .Hence they should be provided with certain fillet so as to minimize its stress concentration.

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