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Research Article

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Modal Analysis of Horns Used in Rotary Ultrasonic Machining

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Abstract

The horn is an important element in transferring the ultrasonic vibrations received at its input end from the transducer to the end of the horn in ultrasonic machine. So, the design of the horn has a huge impact on the amplitude of ultrasonic vibrations being imparted to the end of the horn. The most important aspect of the horn design is the determination of the resonant frequency, the resonant length, and the magnification factor of the horn. Hence, different sonotrode shapes have been studied and analysis is performed to identify the desired shape of the concentrator. Modal analysis was performed to calculate the mode shapes, natural frequencies, as well as the resonant length of different shapes of the horns. Here the modal analysis is performed for the horn used in rotary ultrasonic machining. Therefore, the required analysis is performed using ANSYS 15.0 workbench interface and the dimensions of the sonotrode resonant frequency within the range of 15 - 30 kHz is selected.

Keywords

Modal analysis, Natural frequency, Resonant length, Rotary ultrasonic machine

Introduction

Horns are made of materials which have a good combination of acoustical and mechanical properties. Titanium has the best acoustical properties and high fatigue strength which helps it to withstand high cycle rate at high amplitude. Titanium (R54520) is often used to fabricate most of the horns, as this higher grade of titanium is stronger than the more common titanium (R50250) [1-2]. Apart from this one other main reason is that higher amplitude can be achieved with horn made out of titanium (R54520). Titanium horns can be carbide-coated for adding wear resistance when working with abrasives materials containing glass. Horn made of titanium is typically more expensive than other materials due to the higher cost of material and machining time. Heat treated aluminum alloys have excellent acoustical properties and are used to make horns not requiring high amplitude and strength [2-5]. Aluminum horns can be plated with chromium to prevent it from part marking. Horns made of alloy steel can be heat treated for a wear resistance surface, but the low acoustical efficiency of steel limits its use to horn for low amplitude application such as insertion. Most important feature of the horn design is the determination of resonant frequency and resonant length [6-8]. The length must usually be in integral multiples of sonotrode wavelength. The design of horn is a complicated process, and it involves the selection of correct material, production of required amplitude and tuning it to specific frequency. Incorrectly tuned horns can cause damage to the converter and power supply. The Finite Element method is used to design and optimize the horn for proper drilling. Horns are made of several shapes and amplitudes to meet the requirement of various industrial applications [8-11].

Different shapes of the horn

Stepped horns consist of two different sections, each having a uniform cross-sectional area. It has the highest amplification factor of all horns due to abrupt change in cross-sectional area at nodal plane. Stress is the maximum near the transition of two sections. These horns can be used for any gain high in the application for drilling. Amplification factors of up to 4:1 can be attained by using the stepped horns. The conical horns have an area that changes gradually with the axial length of the horn. Stress over the axial length of the stepped is more as compared to the conical horn. Stress concentration is more in steeped horn as compared to the conical horn. They have generally the lower gain factor. They are used in the application where requiring forces and the low amplitudes are required. The main function of the concentrator (horn) is to amplify the vibrations imparted to it from the transducer to the desired level. It also acts as the means of transferring the vibrations from the transducer to the tool in resonance with the generator. Manufacturing as well as designing of the rotary ultrasonic horn must be done carefully because inaccurately designed concentrator (horn) may cause reasonable damage to ultrasonic transducer and pulse generator.

Magnification principles of the horns

The main purpose of the horn design is to magnify the amplitude of vibrations. Usually, the amplitude produced by the piezoelectric transducer is in the range of 10 - 15 μm. The amplitude required for the machining of rotary ultrasonic machine is greater than the 50 - 110 μm. So, concentrator is used at that point, to amplify the amplitude of the vibrations to the desired level. The basic principle of the magnification of the concentrator is that the total vibrational energy through a particular cross-sectional area decreases and the energy density increases. For different magnification factors, we are employing the different shape of the tool holder, having the less cross-sectional area at the output (tool) end when it is compared to the input end. Stepped and conical are the common shapes of horn for the different types of applications.

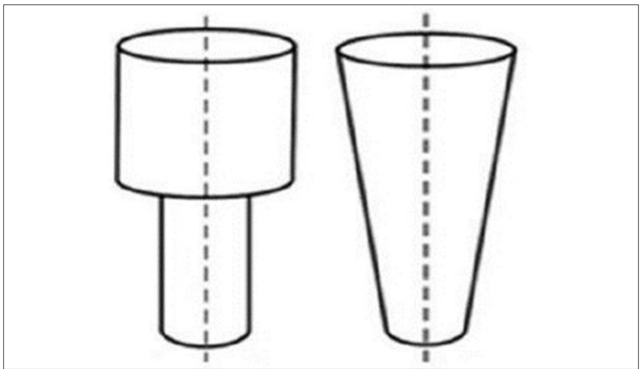

Figure 1: Stepped and conical horn.

Modal Analysis

Modal analysis is performed to obtain the natural frequency and the mode shape obtained by the different shapes of the concentrators, for the different materials. Analytical determination of the natural frequencies for the cylindrical shape is simple, whereas for the stepped and conical it is more complicated. To determine the natural frequencies for different materials, the finite element method is used. Modal analysis generally deals with the free vibration analysis of a structure or body. The purpose of this analysis is to find the resonant frequency and the mode shapes at which the horn will amplify load. In other words, it will generate the natural frequency of the horn for different modes of frequency or different mode shapes. Mode shape is the shape of the vibration corresponding to the vibration which the horn can absorb all the energy supplied by the excitation. For the ultrasonic vibrations concentrator should pose in the axial mode. Based on the different profile of the horn obtained during the mathematical modelling, horns have been designed using CATIA and analysis has been performed on the ANSYS workbench.

Results and Discussion

Modal analysis of horn for different shapes

Different profiles of horn designed here are the stepped and conical. The pulse generator having the resonant frequen-

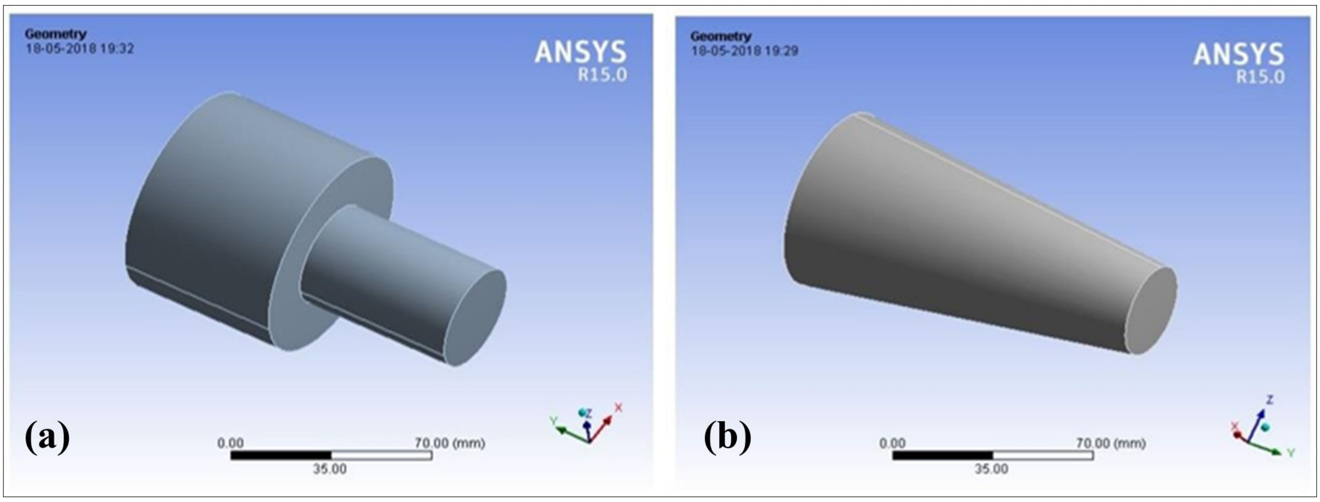

Figure 2: (a) Rotary solid model of stepped horn and **(b)** Rotary solid model of conical horn.

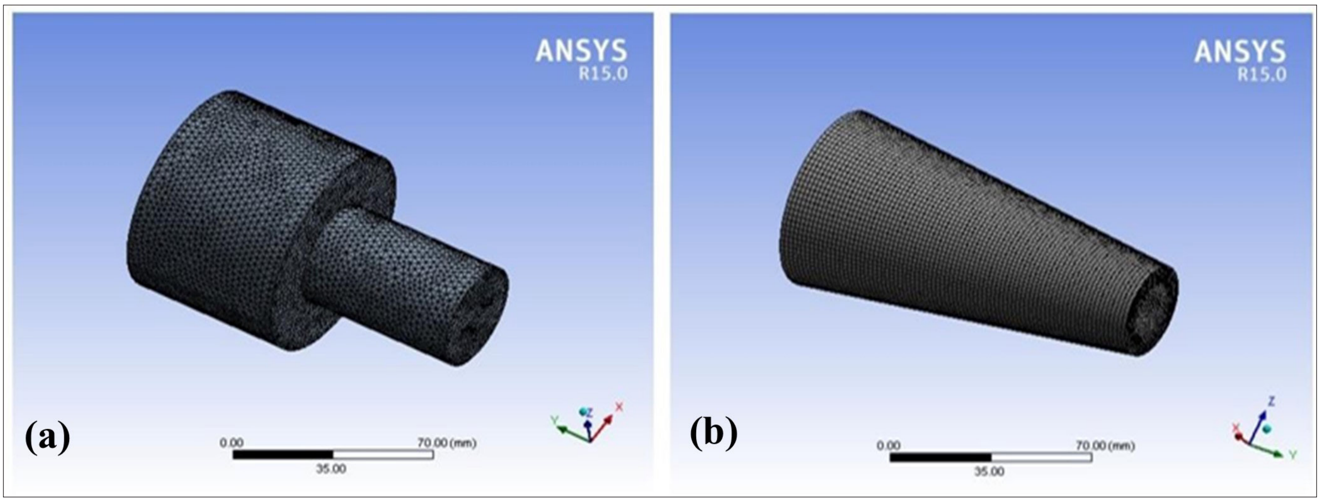

Figure 3: (a) Mesh part of stepped horn and **(b)** Mesh part of conical horn.

cy of 15 kHz, which was selected for our study. So, the horn to be connected to it should also possess the same frequency, in order to be in the resonance. Modal analysis is performed on the different profiles of the horn, to exactly trace out the horn operating at the same frequency as the horn. Material properties of plain carbon steel, stainless steel and titanium alloy have been assigned to observe the natural frequency of the different geometries of the horn. In the analysis it shows the frequency is maximum for the rotary stepped horn and minimum for the rotary conical horn. After the 1981 elements there is no change in the frequency and the result is optimized for the rotary stepped horn and rotary conical horn.

Modal analysis of ultrasonic horns with varying materials

Selection of the materials used in the fabrication of the rotary horn based on the result obtained by the modal analysis. So, the modal analysis is performed to calculate the natural frequency and the mode shape of the different materials. By performing the modal analysis of the different shape of the rotary horn, the stepped profile of horn is selected, as it is possessing the longitudinal mode of vibration at a frequency close to that of the frequency of the pulse generator. So, to select the material for the rotary stepped horn, again modal analysis is performed, to know the mode shape and natural frequency of the different materials. In figure 5 results from modal analysis is given for the materials plain carbon steel, stainless steel ant titanium alloy. Resonance frequency has occurred at the second node of the mode. At the second mode resonance frequency is minimum for the titanium alloy and at second mode maximum for the plain carbon steel. From figure 5 it can be observed that the variation of the deformation is maximum for the titanium alloy and minimum for the plain carbon steel. It has been also analyzed and it shows the variation of the frequency with respect to the number of elements. Plain carbon steel has the highest frequency and titanium alloy lowest. After 1981 elements the variation in the frequency is constant. In this the result of variation shows the 1981 elements are the optimum elements for the calculation of the resonant length of the given rotary horn material. In table 1 the resonance theoretical length is minimum for the stainless steel and maximum for the plain carbon steel. The theoretical length of the horn of stainless steel is 112 mm and theoretical length of the plain carbon steel is 114 mm. It has been obtained that the resonance length for the titanium is 113 mm.

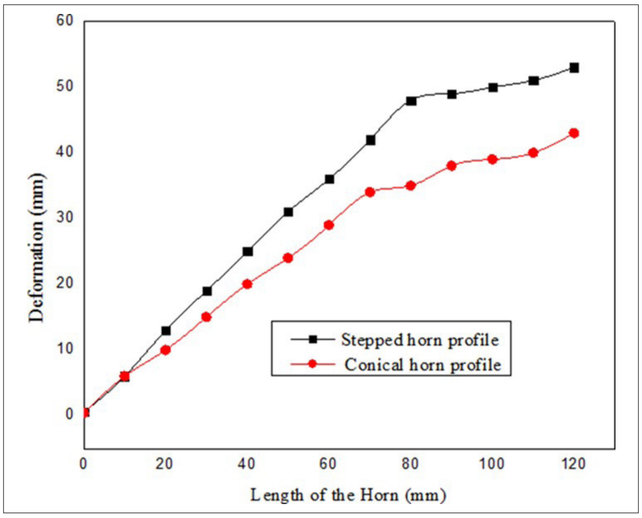

Figure 4: Deformation of different profile of horn.

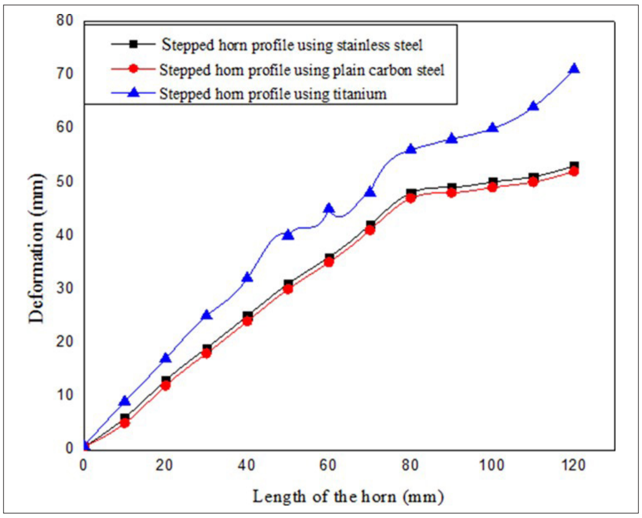

Figure 5: Deformation rate of different horn materials.

Table 1: Different mode shape frequencies.

Mode	Frequencies observed for stepped and conical shape of horns (Hz)	
	Stepped	Conical
1	20641	19889
2	22312	21204
3	24857	21204
4	28487	24755
5	28488	24755

Conclusions

The work has covered the design of a stepped and conical horn profiles for rotary ultrasonic machining by using the finite element method. The nodal displacement distribution has been concluded for the conical and stepped horn profile by using different horn materials. Also, some following points have been concluded.

- Different frequencies have been observed at different mode shapes and the desired frequencies have been obtained at the resonant longitudinal mode of the vibration.
- The desired longitudinal mode of the vibration is observed at 2nd mode for the stepped and conical horn profile.
- For industrial applications the appropriate material for rotary ultrasonic machining within the given range of the frequency can be found.
- Optimized resonance length has been calculated for the different material of the rotary stepped horn.
- Proper material, proper dimension and proper shape can be used for used for industrial rotary ultrasonic machine applications.

Future Research Scope

In present work study, an attempt has been made the design of stepped and conical horn. Some of the points which should be examined in future are summarized that, the present work has been carried out for stepped and conical horn. But further studies can be performed for other shapes of horn. In the present case different material have been taken for only stepped horn, further studies should be done by taking different horn profile for different materials.

Acknowledgements

None.

Conflict of Interest

None.

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