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Design and Analysis of Acoustic Horn for Assistance in Die-Sinking EDM

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Abstract - Many industrial applications and production technologies are based on the application of ultrasound. In many cases, the phenomenon of ultrasound is also applied in the technological processing of the machining of materials. The main element of equipment that uses the effect of ultrasound for machining is the ultrasonic horn. It is also called a sonotrode. The performance of ultrasonic machining technologies depends on the properly designed sonotrode shape. The dependence of fundamental modal properties (natural frequencies, mode shapes) of various sonotrode shapes for various geometrical parameters is analyzed. Modal analysis of the models is determined by the numerical simulation using the finite element method (FEM) design procedure. In ultrasonic machining, the ultrasonic horn plays a vital part in the high-energy machining process. Electric discharge machining (EDM) is used to achieve high processing quality but the machining efficiency is low. The new (EDM+USM) is used for high machining efficiency. The acoustic analysis of the ultrasonically vibrating tool is done with the assistance of the finite element method (FEM) so that it can be used for EDM applications.

Key Words: Modal analysis, Ultrasonic horn, Numerical analysis, efficiency of machining, acoustic analysis.

1. INTRODUCTION

Resonance is a phenomenon in which a vibrating system or external forces drives another system to oscillate with greater amplitude at specific frequencies. Frequencies at which the response amplitude is a relative maximum are known as systems resonant frequencies or resonance frequencies [1]. Free vibrations of an elastic body are called natural vibrations and occur at a frequency called the natural frequency. Natural vibrations are different from forced vibrations which happen at a frequency of applied force. An ultrasonic horn also known as an acoustic horn, sonotrode, acoustic waveguide, or ultrasonic probe is a tapering metal bar commonly used for augmenting the oscillating displacement amplitude provided by an ultrasonic transducer operating at the low end of the ultrasonic frequency spectrum [2]. EDM is a non-conventional machining technique uniquely used for cutting metals that are not possible to cut with traditional methods EDM only works with electrically conductive materials. Delicate cavities and intricate contours which are difficult to produce with grinding or other machining can be done with Electric Discharge Machining (EDM) [3]. In the ultrasonic machining process, the material of the workpiece is removed by the repetitive impact actions of abrasive particles. This process removes material through high-frequency, low-amplitude vibrations of a tool against the material surface [4]. The most frequently used shapes of ultrasonic horns are cylindrical, tapered, exponential, and stepped. To achieve optimal performance in an ultrasonic machining system is necessary to take into account all relevant effects and parameters that affect the dynamics of the system. The ultrasonic transducer converts the electrical vibrations into mechanical vibrations which are relatively small and had to be amplified by using the horn. The primary function of the horn is to amplify the vibration of the tool to the level required for effective machining assistance, but it also serves as a means of transmitting the vibrational energy from the transducer [5]. ultrasonic horn aid to the turning process had given improved machined outputs Forces in machining reduced and improved surface quality was obtained [6]. Computer-aided design done on acoustic horn gave a new profile of horn material. This profile resulted in improved MRR and safety [7]. A stepped ultrasonic horn was used in EDM for improved MRR by the cavitation process. Analysis was done by varying diameters of horn, lengths of steps, and provision of groove around the centroid [8]. In-situ sampling thereafter analyzing is a major challenge that will be faced by NASA. Normal robots cannot perform this task. In order to face this NASA developed Ultra Sonic Driller and Corer (USDC) drilling technology. To maximize the amplitude of displacement the energy supplied by piezo-materials must be optimised. Various types of horn profiles and materials were tried and the results were published [9]. Design and analysis of the ultrasonic horn with double extrusion helped process both flanges simultaneously. Analytical and numerical calculations ed that the machine's frequency is very much matched with the natural frequency of the vibration of the horn [10]. Even though the machining was introduced way back 1940's, there is a large gap in understanding and controlling gap phenomena. Also stepped horns can be used only when the amplitude is less. Control of flushing the debris from the machining zone is still a challenge. It was proposed to take graphite as tool material, this is because of the good electrical and thermal conductivities of graphite. Also, there are limited works on studying graphite tool effect on EDM process.

2. Design procedure of acoustic horn

2.1 Length calculation*:* In the case of a stepped horn, length calculation is very important. This is important as the frequency of vibration depends on the length of the acoustic horn. A general formula for the calculation of length is

$$L = k_1\, c/(4f) + k_2 c/(4f)$$

Upon considering $k_1 = k_2 = 1$

$$L = c/(2f)$$

Where L is length of horn

c = velocity of wave in the medium,

and f is frequency of vibration

2.2 Finite element analysis: The ultrasonic horns of the two below-mentioned shapes and dimensions are subjected to modal and harmonic analysis using ANSYS software.

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ANSYS software. In the Sec. 2.2, Table1 shows the different dimensions of model 1 and Table 2 shows the dimensions of model 2.

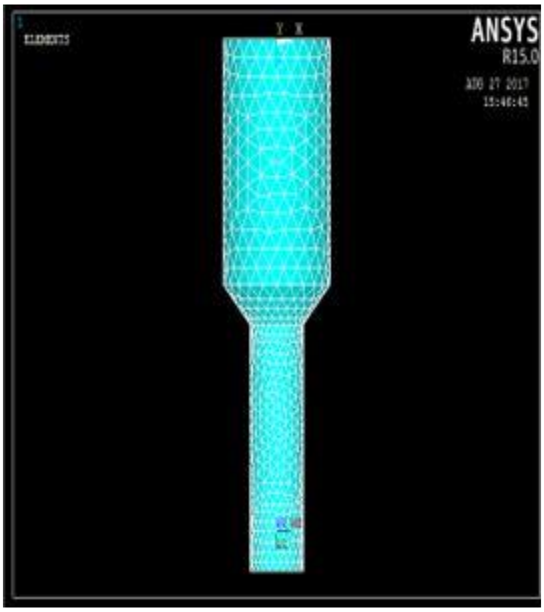

Fig-1: Model 1 developed in ANSYS Mechanical APDL

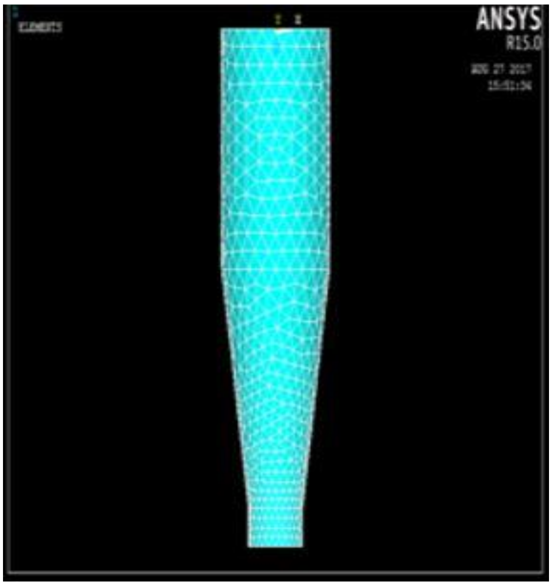

Fig-2: Model 2 developed in ANSYS Mechanical APDL

2.2.1 Material properties: The ultrasonic stepped horn (USH)and tool are stainless steel and graphite. The material properties required are density, poison's ratio, thermal strain, secant coefficient, and instantaneous coefficient values. These values are collected and placed in Table 3 to Table 8.

2.2.2 Meshing: In the analysis process, when too small elements are used the meshing will generate too many elements and nodes. This increases computational intensity, resulting in model that is either too time-consuming to be solved, or potential errors could occur. Reasonable mesh element size is a factor that must be considered in the present modelling

Table 1: Different dimensions of model 1

S.No.	Parameter	Value of dimension (m)
1	Total length of horn	0.123
2	Major diameter	0.02
3	minor diameter	0.01
4	length of conical section	0.0515
5	length of major cross section	0.0615
6	length of graphite tip	0.01

Table 2: Different dimensions of model 2

S.No.	Parameter	value of dimension (m)
1	Total length of horn	0.123
2	Major diameter	0.02
3	Minor diameter	0.01
4	Length of conical section	0.01
5	Length of major cross section	0.0615
6	Length of minor cross section	0.0515
7	Length of graphite tip	0.01

2.2.3 Modal analysis of acoustic horn: Modal analysis is to determine the vibration characteristics (natural frequencies and mode shapes) of a structure while it is being designed. The procedure for a modal analysis consists of four main steps:

1. Build the model.
2. Apply boundary conditions.
3. Expand the modes.
4. Review the result

The natural frequencies got from the modal analysis do not reach the required ultrasonic range i.e. 20-40 kHz. So, the design is modified to a stepped shape. In the new design, the conical section is removed and modal analysis is carried out to obtain the required frequency. In the case of a modified stepped design, the modal analysis is carried out and the modes are extracted.

Table 3: Thermal strain for stainless steel

Temp	THSX	Temp	THSX
300	0.0001	900	0.011
400	0.00167	1000	0.013
500	0.00338	1100	0.0513
600	0.00519	1200	0.0174
700	0.00709	1300	0.0195
800	0.009	1500	0

Table 4: Thermal strain for graphite

Temp	THSX	Temp	THSX
45	-0.0019125	273	-0.00675
100	-0.00342	573	0.00577
150	-0.003315	1023	0.00206
200	-0.0025	1273	0.00288
250	-0.00134	1173	0.0047136
300	0	2773	0.008952

Table 5: Secant coefficient for stainless steel

Temp	α_{sec}	Temp	α_{sec}
300	14.78	900	18.32
400	15.61	1000	18.71
500	16.33	1100	19.03
600	16.91	1200	19.27
700	17.42	1300	19.45
800	17.89	1400	19.61

Table 6: Secant coefficient of graphite

Temp	α_{sec}	Temp	α_{sec}
45	0.0000209	523	0.0000257
100	0.0000215	1023	0.00003
150	0.0000220	1273	0.0000334
200	0.000023	1773	0.0000338
273	0.0000233	2273	0.000043
300	0.0000235	2773	0.000048

The solution and natural frequencies of vibration are obtained. These natural frequencies are within the range of 20-40 kHz. Fig.3 shows the new design which is proposed to get resonance in ultrasonic range.

Table 7: Instantaneous co-efficient for stainless steel

Temp	$^{dy}/_{dx}$	Temp	$^{dy}/_{dx}$
300	14.90	900	20.69
400	16.27	1000	21.04
500	17.50	1100	21.25
600	18.58	1200	21.36
700	19.49	1300	21.40
800	20.20	1400	21.45

Table 8: Instantaneous co-efficient for graphite

Temp	$^{dy}/_{dx}$	Temp	$^{dy}/_{dx}$
45	0.000007	523	0.0000258
100	0.000017	1023	0.000028
150	0.000022	1273	0.000029
200	0.000025	1773	0.000031
273	0.000025	2273	0.000034
300	0	2773	0.000036

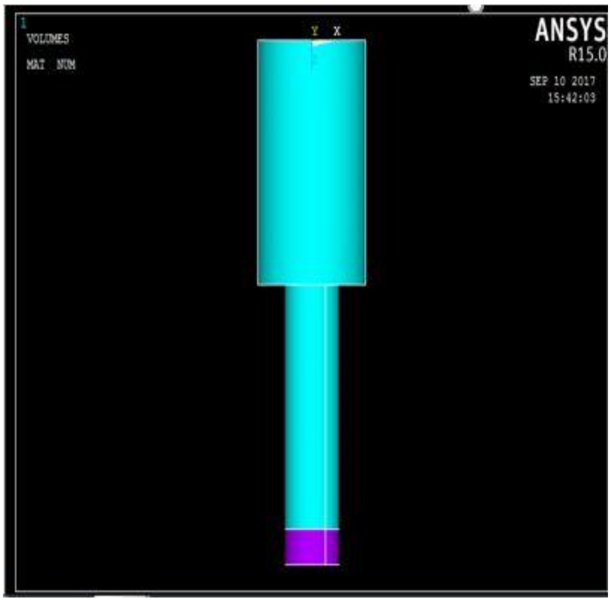

Fig-3: New proposed design

2.2.4 Harmonic analysis:

Harmonic analysis is carried out to find amplitudes of vibrations at various frequencies. Fig.4 shows the amplitude of the tip of the tool for varying frequencies. There is an ultrasonic level frequency of 22500 Hz at which there is amplified displacement of the tip which will serve the basic need of ultrasonic horn

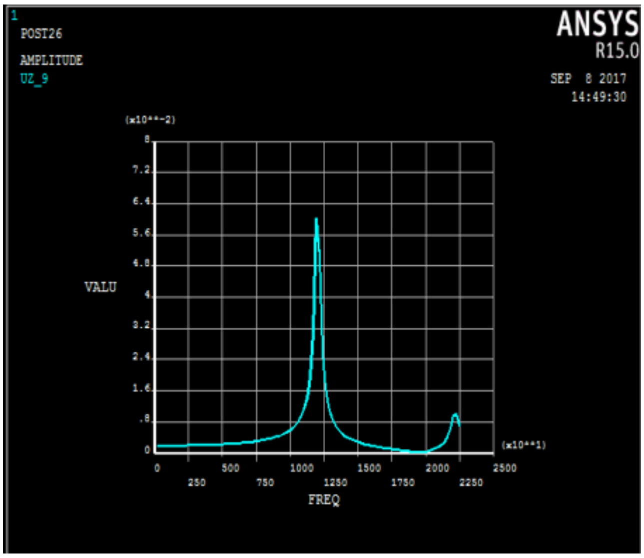

Fig-4: Nodal displacement at tip

3. Conclusions

1. The ultrasonic horn was designed to have a natural frequency of vibration in the ultrasonic range so that it can be used for EDM assistance.

2. The harmonic analysis of the acoustic horn was done and frequency responses of the structure were found.

3. Nodal displacements of the horn at various frequencies for the response frequency of the structure were simulated**.**

4. The acoustic horn was found to be safe and appropriate for assistance in EDM.

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BIOGRAPHIES

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