Research Article

Optimal Selection Process Parameters of Ultrasonic Machining of Tool Stepped Horn Modelling Using FEM Analysis

Jitender Bhaker[1], Shushil Kumar[2], Sanjeev Kumar[3]

Abstract

The objective of this study is to investigate the von- mises stresses and total mechanical stress induced in ultrasonic machining tool. Generally, the sonotrodes are made up of metals which have very low acoustic losses and high fatigue strength. The design of stepped horn in terms of resonant frequency and determination of the correct sonotrodes resonant wavelength has been done with their area and diameter ratio. In Harmonic analysis, we find the degree of freedom of solution (displacement vector sum) in stepped Horn. An ultrasonic vibratory tool has been designed and analyzed using Harmonic analysis for calculation of its equivalent (von-Mises) stresses under its natural frequency and working amplitude of vibration. The Harmonic analysis of tool will enable us to find (using ANSYS Mechanical APDL) the nodal displacement with total mechanical strain and deformations values in z direction if get less value deformations then value of deformations also less on the workpiece also. So surface finishing will be more and less tool wear rate.

Keywords: Frequency, Harmonic analysis, Nodal displacement, Von-mises stress, ANSYS

Introduction

Ultrasonic machining method is the most effective method used for hard or easily breakable materials like silicon, glass and ceramics. It is a mechanical NTM process in which the vibrating tool removes workpiece material by cutting action of abrasive slurry. The abrasive slurry used lubricates and cools the tolerance of tool and workpiece. Many factors are considered such as work material characteristics (hardness, depth of machining), Tool characteristics (Tool Material, Tool Shape, Amplitude, and frequency), Slurry material characteristics (Abrasive grit size, Slurry Concentration).[1]

Tool models were developed using FEM to predict mechanical stresses and strains. Using ANSYS CFX abrasive slurry flow behavior was analyzed.[2] Calculations for natural frequency of horn were researched. Experiments showed that using ultrasonic vibration assisted turning, not only reduces cutting forces but also surface roughness comparing with the conventional turning. Results showed ultrasonic vibration assisted turning is very suitable for machining hard material like the stainless steel materials.[3]

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How to cite this article: Bhaker J, Kumar S, Kumar S. Optimal Selection Process Parameters of Ultrasonic Machining of Tool Stepped Horn Modelling Using FEM Analysis. *J Adv Res Prod Ind Eng 2017;* 4(1&2): 30-35.

ISSN: 2456-429X

Taguchi with TOPSIS method is used to optimize both cutting force and surface roughness to find the best possible machining parameters under the used experimental working condition in UAT. Further, difference between UAT and CT was also imposed. UAT is suitable for high quality surfaces finish and lower cutting force requirement.[4]

Operating parameter of Ti grade 5 (Ti6Al4V) using the adding of electro-discharge with ultrasonic machining were type of dielectric, grit size, and concentration of abrasive particle in dielectric fluid and discharge current. Material removal rate of the mixture EDM and USM process was greater than the conventional electro-discharge machining. The outcome was that MRR increased due to distilled water than kerosene whereas surface roughness was found to be better in kerosene than in distilled water.[5]

MRR depends upon the orientation.[6] Increase in tool length, mass and resonance amplitude increases but decrease in resonance frequency. Longer tool may render it to withstand a much bigger binding stress are likely to cause damage.[7]

Research Methodology

FEM method was used for the dynamic analysis of tool and horn. This is useful in finding the resonance frequency and analyzing the vibration displacement distribution of horn with required dimensions. Harmonic analysis of tool and horn were done to find the steady state response of horn to harmonic load of known frequency. To do this we need the material properties (E, υ, ρ, etc.) and boundary conditions (load, frequency, displacement) element type, mesh size, etc.

Table1. Materials parameters selection

Materials	Young modulus (E)	Poisson ratio (υ)	Density (ρ)
Horn material- Ti grade grade5	110 GPa	0.33	4700 kg/m3
Tool material- high carbon high chromium, stainless steel (sample 1)	210 GPa	0.3	7700Kg/m3
Tool material-Stainless steel 304 (sample 2)	200 GPa	0.29	8050 Kg/m3

Modeling of Stepped Horn

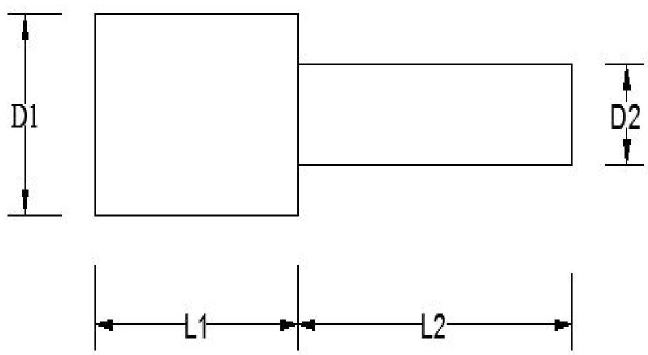


Figure 1.Shape of Stepped Horn

Table 2.Horn length calculation

Sound velocity of material (C)	Wavelength (λ)	Wave Number (K_u)	Horn length (L_1)	Horn length (L_2)	Magnification factor (M)
C = √E/ρ m/sec	λ =C/F $_{cal}$	Ku=2π/ λ	L_1= 1.5/Ku m	L_2 = 1.6/ Ku m	$M=(d_1/ d_2)^2$
= 4837.79 m/sec	λ=0.24189m	=25.975	L_1=0.5774 m	L_2=0.6159 m	M = 4

Diameter is d1=40mm and d2=20mm taken for horn.[3] C- Sound velocity of material, ρ- Density of material, E- Young modulus of material, λ- Wavelength of the Horn, Fr- Frequency of the horn. L= L1 + L2 = K1C/ 4Fcal + K2 C/4Fcal where K1, K2 is correlation factor which depends upon the cross-section area of horn. So we have total theoretical length of horn i.e. 119.33mm. The tool dimensions are taken from the reference.[2]

Boundary condition for Horn and Tool

To determine the study state response of horn under sinusoidal load harmonic analysis did with in boundary condition. In boundary condition, we select the solid element with 20 node 186, mesh size 3 mm. In boundary condition are the upper end is fixed (0, 0) in all degree of freedom, at lower end displacement is applied of 0.1mm, the harmonic frequency is 19650 KHz. For tool, SS304 and D2 steel material are two materials taken for harmonic analysis. In boundary condition, we select the solid element with 20 node 186, mesh size 3 mm, frequency 20000 Hz, and load is 4.6 Kg. The load is applied at lower end of tool (on 161 nodes) and upper end is fixed with 0.0 displacements.

Results and Discussions

In Harmonic analysis, we found the degree of freedom of solution (displacement vector sum) at 19650 Hz harmonic frequency and 0.01mm displacement at the end of Horn. Maximum deflection and maximum result value on plot is 0.292E-5. Thus, we have the value of maximum deflection and maximum strain in Stepped Horn.

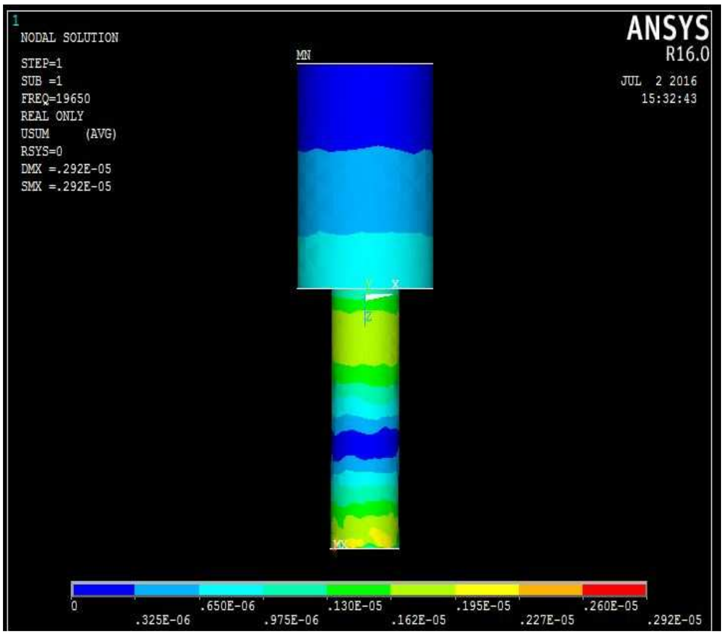


Figure 2.Harmonic analysis of Ti Horn

Result validation of Ultrasonic Horn

Table3. Result of ultrasonic horn

Result	Horn material	DMX	SMX	Frequency (in Hz)	Displacement at end (in mm)
Final result	Titanium Grade 5	0.292E-5	0.292 E-5	19650	0.01
Ref. result[4]	Titanium Grade 5	0.392 E-5	0.392 E-5	19650	0.01

In Stepped Horn modeling and Harmonic analysis result less deformation about 0.1 mm was obtained. The difference between the reference horn length (120mm) and test horn length (119.33mm) is 0.77mm so in sample modeling length decreases. If horn length is increased, the mass and resonance amplitude too increases, but there is decrease in the resonance frequency. Then, the long horn may produce bending stresses, which may cause failure. By increasing the length of horn the deformation also increases. As less material is used, the cost of manufacturing also decreases due to the reduction in the horn length.

Result Calculation of Tool

Total Mechanical strain is calculated in D2 tool and SS304 At different frequency in Z direction so have the maximum deformation, minimum strain and maximum strain.

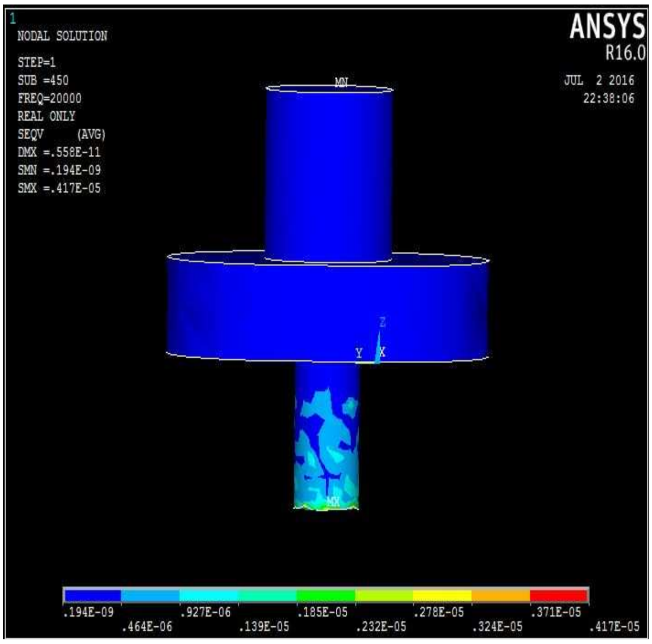


Figure 3.Von- mises stress in D2 tool

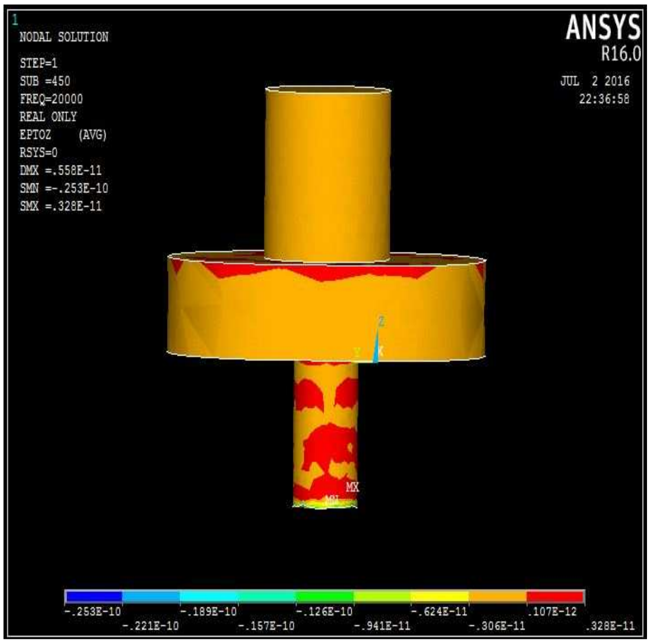


Figure 4.Total Mechanical Strain in D2 tool (in Z axis)

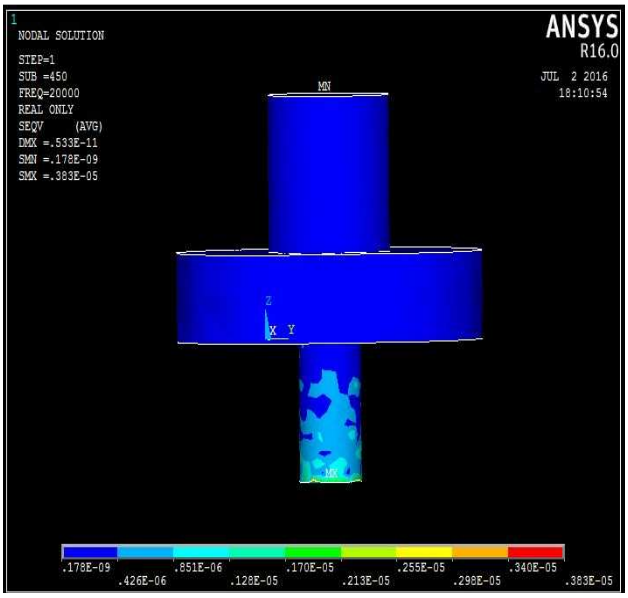


Figure 5.Von- mises stress in SS304 tool

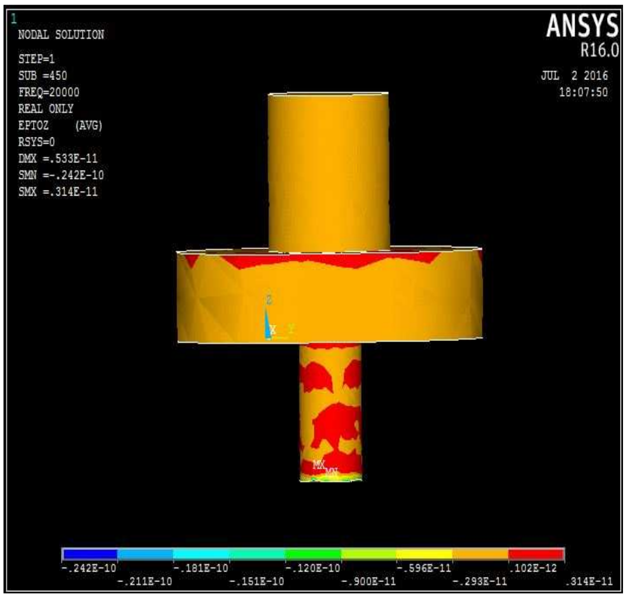
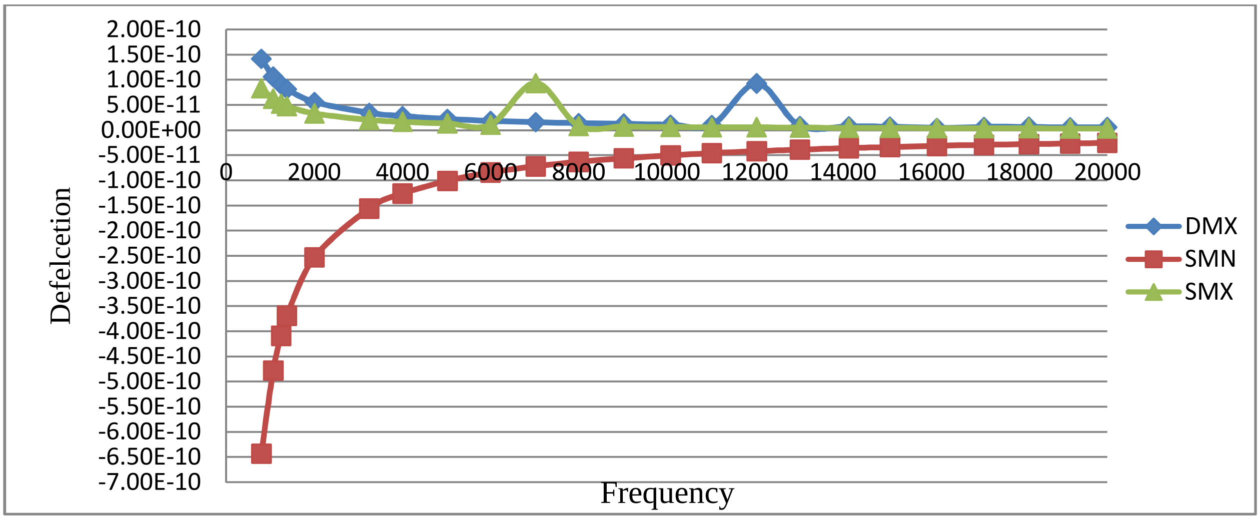


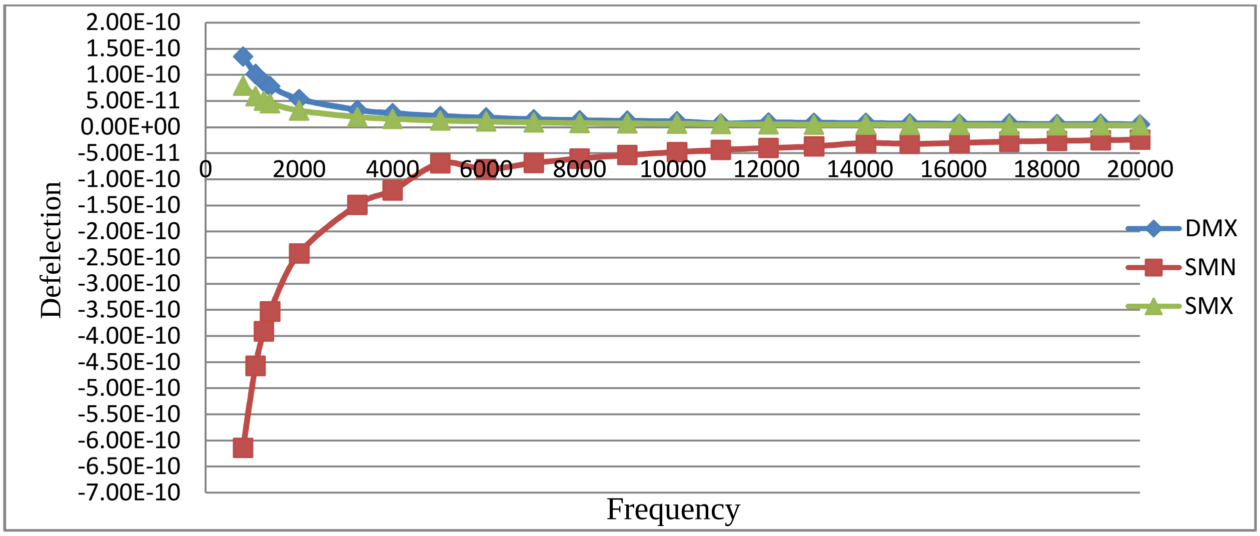
Figure 6.Total Mechanical Strain in SS304 tool (Z axis)

SS304 and D2 steel material are two materials taken for harmonic analysis. Parameter selection for the solid element is 20 node 186, mesh size 3 mm, frequency 20000 Hz, and load is 4.6 Kg. The load is applied at lower end of tool (on 161 nodes) and upper end is fixed with 0.0 displacements. From the result we got the mechanical Strain in SS304 tool (Z axis) and Von- mises stress in sample 1 similarly we got result for sample 2 also. Then we compare the sample result with reference result. After the harmonic analysis we found that SS304 gives less value of maximum deformation, maximum strain and minimum strain.

Then we find the deflection at different frequency in the range of 2000 Hz to 20000 Hz for both samples. Further we made the table from these values. From this table, we have plotted the graph for both materials at different frequency in Z direction so the maximum deflection, minimum and maximum strain value. The graphs are plotted below for both samples.



Graph-01 for D2 steel tool material



Graph- 02 for SS304 tool material

We found that the value of maximum deflection, minimum strain and maximum strain in z direction is less at which the tool is designed from value of table and graph.

Result validation of Ultrasonic Tool

Table 4.Total mechanical strain in z direction (EPTOZ)

Results	Tool material	Harmonic force (in kg)	Frequency (in Hz)	DMX	SMN	SMX
Sample 1 Results	D2 steel	4.6	20000	0.558E-11	-0.253E-10	0.328E-11
Sample 2 Results	SS304	4.6	20000	0.533E-11	-0.242E-10	0.314E-11
Ref. Results[2]	Al T651	4.6	20000	0.150E-10	-0.399E-10	0.486E-11

Table 5.Von mises stress produce in z direction (SEQV)

Results	Tool material	Harmonic force (in kg)	Frequency (in Hz)	DMX	SMN	SMX
Sample 1 Results	D2 steel	4.6	20000	0.558E-11	-0.194E-9	0.417E-5
Sample 2 Results	SS304	4.6	20000	0.533E-11	-0.178E-9	0.383E-5
Ref. Results[2]	AlT651	4.6	20000	0.150E-10	-0.298E-14	0.315E-8

Less deformation is seen in SS304 for Total mechanical strain in z direction (EPTOZ).

1. Additional research is necessary to reduce the tool wear rate, effect of harmonic force and frequency.
2. Further analysis is needed for the result of different horn material with respect to their deformation and frequency.
3. Advance study is required for finding the optimal tool material to increase its life time.
4. Further exploration to be required for using ultrasonic machining to work under command of programming languages or coding like C language.

Conclusion

In this investigation, FEM analysis was distributed in three major parts. Firstly, the modeling of Stepped Horn, after that, we found the Harmonic analysis of it and analyzed the dynamic behavior of Horn. Secondly, Harmonic analysis of high carbon high chromium steel, (D2 steel tool) and found the total mechanical strain, Von-Mises stress produce in tool at 20000 Hz frequency and 4.6 kg harmonic force. Thirdly, Harmonic analysis of SS304 and found the total mechanical strain, Von-Mises stress produce in tool at 20000 Hz frequency and 4.6 kg harmonic force. Then, compared the results with respect to the reference results.

1. In Stepped Horn modeling and Harmonic analysis result we got less deformation by 0.1mm. The difference between the reference horn length (120mm) and our horn length (119.33 mm) is 0.77 mm so in our modeling length become decrease. If horn length is increased so the mass increase and resonance amplitude but decrease in the resonance frequency. The long horn may be producing the bending stress in the horn which may cause the horn to damage or break, so the fracture chances of horn will increase. If there is increase in the length of horn then deformation also increases.
2. SS304 gave result better at same boundary condition than reference material so less tool wear rate and life of tool is increased.
3. Thus, SS304 having less total mechanical strain than high carbon high chromium steel and Al T651.
4. The result for both SS304 and high carbon high chromium steel with respect to frequency in increasing order.
5. There was less deformation in the tool, in both SS304 and high carbon high chromium steel, than the reference material. So deformation in the workpiece will also be less, good surface finish and accuracy can be achieved by this method.

Acknowledgement

We would like to thank Mr. Gaurav Mahajan, Assistant Professor at J.N.G.E.C., Sunder Nagar for helping us with the basics of the analysis procedure. My friends and classmates were very motivating and pushing me to get a quality output. Mr. Nitin Chauhan, Associate Professor, LPU, Punjab was very helping in hand to make us understand the software. A very thankful to CADD Center, Jalandhar, Punjab for lending a hand with the software ANSYS 16.0 licenses.

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