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Finite element analysis of ultrasonic vibratory tool and experimental study in ultrasonic vibration-assisted Turning (uvt)

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ABSTRACT: *In recent year's applications of hard materials in different industries, like aerospace, defense and petrochemicals sectors etc. have been increased remarkably. The machining of these hard materials is very difficult in conventional turning process. Ultrasonic assisted turning is a suitable and advanced process for machining hard and brittle material because of its periodic cutting mechanism. In the present work, an ultrasonic vibratory tool (UVT) is designed and analyzed using ANSYS® environment for calculation of its natural frequency and working amplitude of vibration. An ultrasonic assisted turning system is designed in consideration of cutting tool as a cantilever beam. Experimental study has been carried out to find the difference between ultrasonic-assisted turning and conventional turning at different cutting conditions taking Stainless steel (a general purpose engineering material) as the work piece material. It is found that ultrasonic assisted turning reduces the surface roughness and cutting forces in comparison with conventional turning. It is well known that cutting forces and surface finish/roughness are two major parameters which affect the productivity of the turning process.*
Keywords*: CT, Model analysis, Triangular rule***,** *UAT, UVT.*

I. INTRODUCTION

Metal cutting by using ultrasonic frequencies vibrations is more suitable technique, comparison with traditional cutting method [1]. The present research is particularly focused on ultrasonic vibration-assisted turning. Ultrasonic-vibration assisted turning is a cutting technique in which a certain frequency (in ultrasonic range) of vibration is applied to the cutting tool or the work-piece (besides the original relative motion between these two) to achieve better cutting performance [2]. A number of experimental setup has been proposed to make the process simpler, but the tendency is to apply the process to a wide range of materials and to study the effect of machining parameters. Many researchers have reported significant improvements in noise reduction, tool wear reduction, surface finish, etc [3,4]. Applying ultrasonic vibration on the horn in Tangential direction while during the machining is shown in Fig.1.

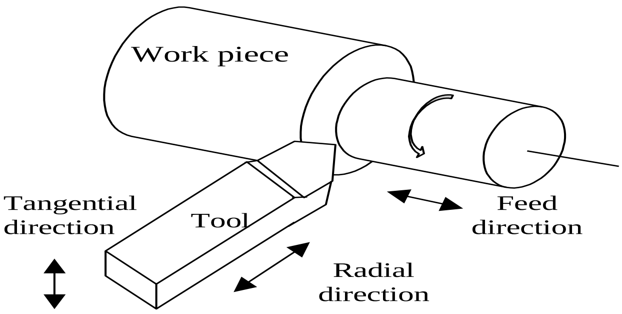


Figure1. Principal vibration directions during ultrasonically assisted turning [5].

When the ultrasonic vibrations applied in Tangentional direction the following restrictions are imposed:
Tangential direction: $V_c=\pi ND < V_t=2\pi af$

Where V_c is the cutting speed during turning operation, N is the rotational speed of work-piece, V_t is the tip velocity, *f* is the frequency of vibration and *a* is the amplitude of vibration [6].

II. FINITE ELEMENT MODELING OF ULTRASONIC VIBRATORY TOOL

2.1. Modeling pre-processor

Finite element analysis is performed by using the commercial package ANSYS® which is one of the most powerful and flexible tools for available for dynamic analysis of structures. The finite element method is very useful in finding the resonance frequency and analyzing the vibration displacement distribution of acoustic horn with any dimension. In this finite element analysis, the major factors used for modeling a general structural pressure simulation included element type, real constant, material properties, geometry, meshing, boundary conditions, etc.

2.2. Material properties

The titanium is used as the horn material for the analysis with properties, elastic modulus E= 110 GPa, Poisson's ratio, γ=0.33, mass density ρ= 4700 Kg/m^3. Tool steel is used as the single point cutting tool for the analysis with properties, elastic modulus E=210 GPa, Poisson's ratio γ=0.30, mass density ρ=8150kg/m^3.

2.3. Boundary condition

After finalizing settings for the ANSYS® pre-processor, boundary conditions are provided to the solution-finding processor. The output of piezoelectric transducer is applied as input of tool. 0.01mm displacement uniformly distributed loads is applied at the big end of the ultrasonic vibrating tool.

2.4.1 Modal analysis

Modal analysis allows the design to avoid resonant vibrations or to vibrate at a specified frequency. It helps in calculating solution controls for other dynamic analyses, because a structure's vibration characteristics determine how it responds to any type of dynamic load; always perform a modal analysis first before trying any other dynamic analysis. Modal analysis is a linear analysis, any nonlinearities such as plasticity and contact elements, are ignored, even if they are defined. Several mode extraction available in the modal analysis but in present case BLOCK LANCZOS extraction method is selected shown in Fig 2.

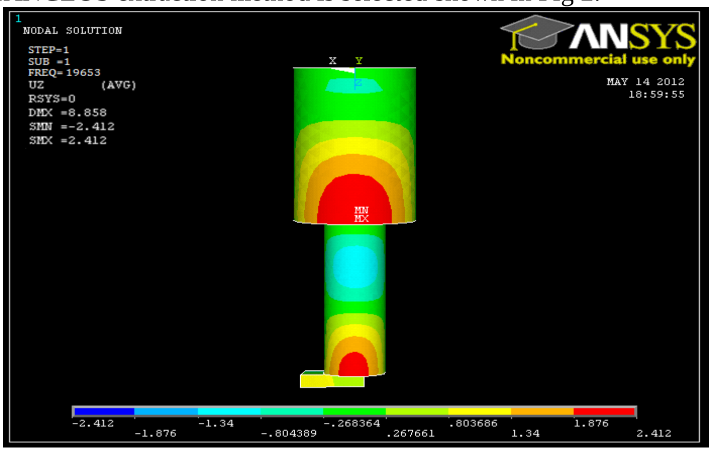


Figure2. Modal analyses of UVT

In modal analysis the frequency is generating 19653Hz and out-put amplitude is 4 times greater than input amplitude.

2.5.2. Harmonic analyses

The technique to determine the steady state response of a structure to sinusoidal (harmonic) loads of known frequency where the input harmonic loads are forces, pressures, imposed displacements, and imposed voltage of known frequency. The output parameter is harmonic displacement at each DOF, current flow for piezoelectric elements, stresses and strains.3. Methods of solving the harmonic equation of motion, but in present case Full method is selected, it is uses in full structure and unsymmetrical matrices (ultrasonic stepped horn) shown in Figure 3.

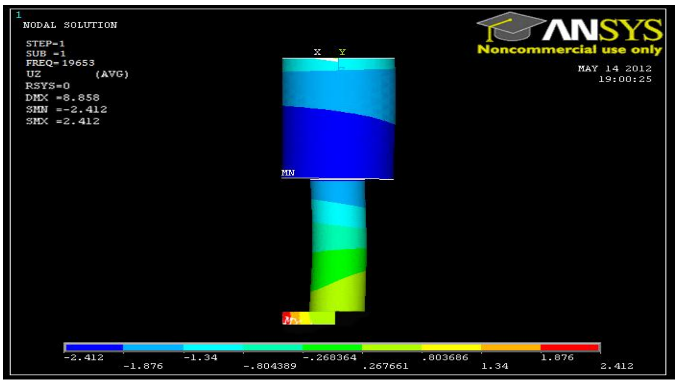


Figure3. Harmonic analysis of UVT

An additional point to be considered when designing UAT setup is that the horn should have at least one natural frequency within the allowable ultrasonic frequency, in this case 19653 Hz (19,500–20,500 Hz). It can be concluded that the geometrical dimension and material properties of UVT used in analysis of horn can deliver the required frequency. This frequency is match with other part of the ultrasonic system and the resonance frequency of the horn under the generator frequency and the UVT is amplified 4 times of source amplitude to working amplitude.

Table 1. Dynamic Analysis of UVT

<table>
<tr><th colspan="2">Analysis type</th><th colspan="2">step</th><th colspan="2">Sub step</th><th>Natural frequency</th><th>Figure no.</th></tr>
<tr><td colspan="2">Modal analysis</td><td colspan="2">1</td><td colspan="2">1</td><td>19653</td><td>3.9</td></tr>
<tr><td colspan="2">Harmonic analysis</td><td colspan="2">1</td><td colspan="2">1</td><td>19653</td><td>3.10</td></tr>
<tr><td colspan="3">Horn material</td><td colspan="5">Titanium</td></tr>
<tr><td>D1</td><td>D2</td><td>Fillet dimension (h/r)</td><td>Resonance length</td><td>Driving amplitude</td><td>Nodal point xn</td><td>Amplitude at working end (theoretical)</td><td>Amplitude at working end (ANSYS®)</td></tr>
<tr><td>40mm</td><td>20mm</td><td>2</td><td>120mm</td><td>0.01mm</td><td>60.275mm</td><td>0.04mm</td><td>0.02412mm</td></tr>
</table>

III. EXPERIMENTAL PROCEDURE

The work-piece (SS-304) is clamped by the three jaw chuck of "HMT model NH 26" lathe. The commercial piezoelectric transducer (unloaded 20±0.5 kHz frequency) provides vibration to the ultrasonic vibratory tool (UVT). The tip of UVT is placed vertically on the cutting tool. The cutting tool is treated as a cantilever beam, which is fixed on Kistler model 9272 dynamometer. The UVT placed perpendicularly to the work-piece in the horizontal plane allows the cutting tool to make the ultrasonic vibration movement in the cutting velocity direction. The amplitude of vibration is 16µm at cutting tool tip as calculated, which the working amplitude for all experiments.

The ultrasonic transducer is clamped at its nodal point by a light weight bracket and the bracket is fixed by sliding mechanism with special designed L-shape holder. This L-shaped holder maintained the height of the ultrasonic transducer, which is fixed on cross slide of the lathe. The UVT is connected to generator by H.F. Cable with 4 pin coaxially (M) to (F). The generator is generating high frequency around 20±0.5kHz with 2.0kW (max) power from the input mains voltage 230V AC, 50Hz frequency.

3.1. Cutting condition

Table 2. Cutting condition used in experiment

Work-piece material	S(m/min)	D(mm)	f(mm/rev)	d(mm)
Stainless steel(SS304)	57	45	0.04	0.1
	74	45	0.05	0.15
	96	45	0.06	0.2
	125	45	0.07	0.25

3.2. Work piece preparation and processing

The work-piece is cylindrical and faces are machined prior to the experiments. A finishing cut with a very small depth of cut is performed using the same cutting tool to be used in the experiments, in order to eliminate any leftover eccentricity. In the experimental run, first cut is made conventional and as soon as the tool travelled by 10mm (depends upon the time) the vibration is switched on thus allowing the second cut to proceed under same cutting condition but with ultrasonic vibration.

Figure4. Work piece preparation in UAT using lathe (HMT Model NH 26).

After finishing one experiment as shown in Figure 4, it is marked for identification. So, every experiment is divided into two parts, the first part is convention turning (CT) and second one is ultrasonic assisted turning (UAT). Each experiment was done at different cutting condition and the same procedure is applied in different experiments shown in Figure5.

Figure5. Work piece after the experiment.

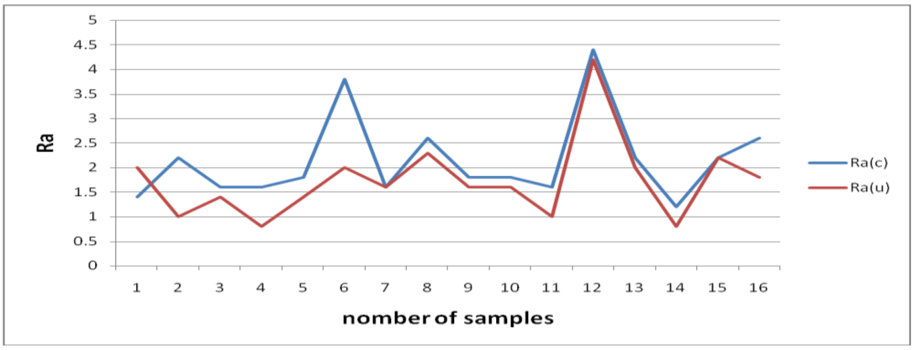
'TALISURF' equipment is used to Measure the surface roughness on the Stainless steel Workpiece in Ultrasonic Assisted Turning (UAT) as well as conventional turning(CT). By using Kistler model 9272 dynamometer and control unit measuring the cutting forces on both CT and UAT.

IV. RESULTS AND DISCUSSION

Based on the experimental data UAT improved the surface roughness by 15.0–40.0%. It proves that UAT can obtain smoother surface in comparison with conventional turning. It proves that UAT can obtain smoother surface. Because of the unstable turning process in CT, the surface can easily produce some defects such as burrs, tearing and so on, so the quality of surface becomes poor.

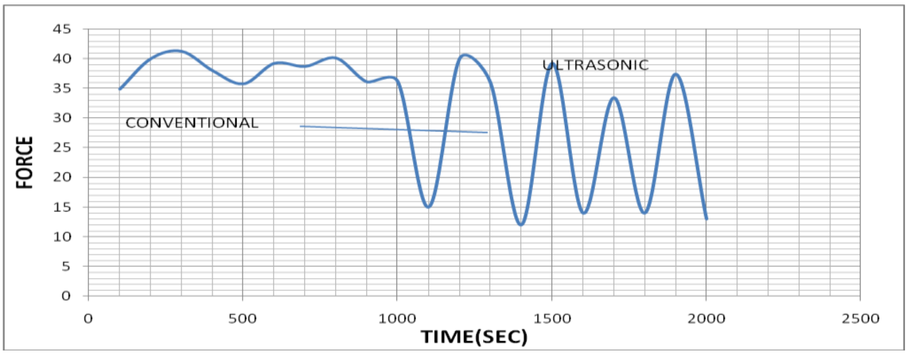
Ra (c)-surface roughness in conventional turning

Ra (u)-surface roughness in ultrasonic assisted turning



Graph 1 Surface roughness in UAT and CT

The test results show that the cutting force for the UAT method decreases by 25.0–35.0 % in comparison with CT shown in bellow graph.



Graph 2 Forces in UAT and CT

V. CONCLUSION

In this present work the experimental study has been carried out to find the difference between UAT and CT. Discuss the experimental set-up and procedure. The results have been compared with Ultrasonic assisted turning (UAT) and conventional turning (CT) process. The UAT method has been found to be a suitable technique to achieve high-quality surfaces finish and lower cutting force requirement not only for hard material but also for general purpose engineering material, like stainless steel etc.

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