Experimental Study of Ultrasonically Assisted Turning of AISI52100 Based On Taguchi Method

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Abstract: Ultrasonically assisted turning (UAT) is a hybrid machining technique employing high -frequency small-amplitude vibration superimposed on the tool movement during turning. The aim of this study is to investigate the effect of machining parameter on AISI52100, during UAT, and evaluate improvement of surface roughness. An experimental setup for UAT at Jamia Milia Islamia University was used to accomplish this investigation. A surface roughness tester was used to evaluate surface roughness. Cylindrical work piece of AISI52100 was turned under UAT. Experimentation has been done using Taguchi's L_9 orthogonal array. Each experiment was conducted under different combinations of speed, feed and amplitude. The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (*S/N*) ratio, analysis of means and analysis of variance (ANOVA). Further, the level of importance of the machining parameters on response surface roughness was determined by using ANOVA. The study shows that the Taguchi's method is suitable to solve the stated problem with minimum number of trails.

Keywords: Ultrasonically Assisted Turning, Surface Roughness, AISI 52100, Taguchi's Method and ANOVA.

I. INTRODUCTION

Ultrasonic vibration has been harnessed with considerable benefits for a variety of manufacturing processes, for example, ultrasonic cleaning, plastic welding, etc. In typical ultrasonic machining, high frequency electrical energy is converted into mechanical vibrations using a transducer or booster combination, which are transmitted through a horn or tool assembly. Ultrasonic 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 [1].

In ultrasonic assisted machining, vibration amplitude (normally sine wave) lead to an alternating gap during cutting and was identified as an important mechanism in vibration cutting. Increasing the vibration amplitude means an enlargement in the gap that allows more cutting fluid to extract the heat during the cutting process, thus enhancing the tool's life, improved work-piece finish, reduction in cutting forces and decreasing the chance of build-up-edge formation [4-5]. In turning process there are three independent principal directions in which ultrasonic vibration can be applied (Figure 1.1).Significant advantages were obtained when the usual continuous interaction between the cutting tip and the work-piece was replaced by intermittent cutting [6-7]. However, when the cutting tip is vibrated ultrasonically the following restrictions are imposed:

Tangential direction: $Vc=\pi ND < Vt=2\pi af\ b$ *(1.1)*

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

II. LITERATURE SURVEY

Introduction

Now a day's manufacturing industries are very much helpful in our daily life. Ultrasonic assisted turning is one of the best manufacturing processes, for example, ultrasonic cleaning, ultrasonic grinding, ultrasonic welding and ultrasonic turning, ultrasonic drilling etc. Ultrasonic assisted turning (UAT) is a new non-conventional technique, used to remove an unwanted material to produce a desired product. First attempt to employ the ultrasonic power is attempted by Russian [2, 11] as well as Japanese [3, 12] researchers.

Experimental study on ultrasonic assisted turning

Ainhoa Celaya and Aitzol Lamikiz [13] discuss the advantages and drawbacks of Ultrasonic Assisted Turning (UAT) have been investigated focusing on the effect of tool vibration on surface quality. They are done Several experiments have been performed on mild steels changing the cutting speed, feed and depth of cut, to study how the influence of the ultrasonic vibration on the surface roughness varies depending on the cutting conditions.

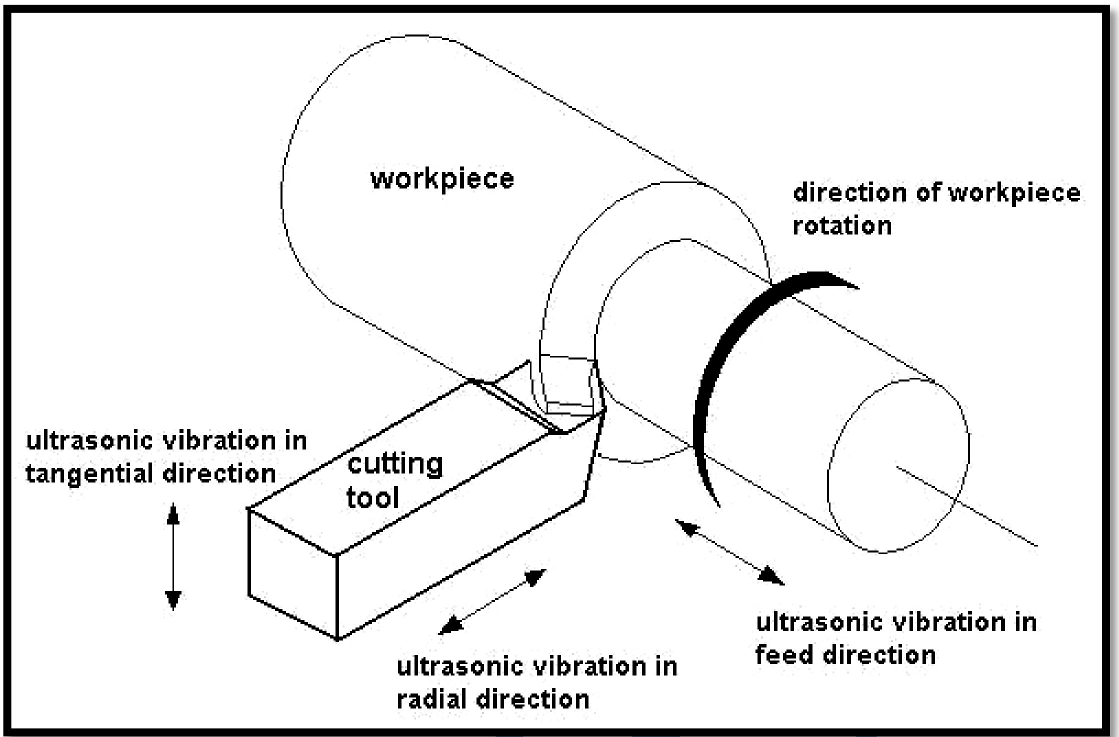


Figure1.1 Principal vibration directions during ultrasonically assisted turning

The cutting tests have been performed on an universal lathe. A commercial piezoelectric transducer Master sonic MSG-2000 (range of frequencies: 17.5–24 kHz) is used to generate the ultrasonic vibration. A booster attached to the transducer is used to amplify the vibration. The design of the booster has to allow the transmission and amplification of the vibration generated in the transducer while maintaining enough stiffness to be able to cut the material without a high deflection or dynamic problems. The vibration obtained has been measured with a laser vibrometer Polytec 0FV-505. After the experiment Ainhoa Celaya and Aitzol Lamikiz [13] experimental tests show an improvement in surface roughness up to 40% in the most favorable case when the vibration is applied in the direction of cutting speed and 6% when the vibration is applied in the feed direction. Also, it has been demonstrated trough an spectral analysis that the vibration in the cutting speed direction reduces the height of the crests produced by the tool and reduces the waviness of the generated geometry.

The roughness profiles of the surfaces machined both in conventional and with vibration cutting. It can be seen that the roughness profile of the UAT test is more uniform, and for example, it does not reach ±5 µm, as it does the conventional turning test.

Review of Ultrasonic Assisted Cutting

Ultrasonic assisted cutting technique is becoming very challenging in many recent engineering developments, especially in relation to surface finish and tool wear and material removal rate. The very basic component of ultrasonic assisted cutting system is piezoelectric transducer and ultrasonic vibratory tool. For different applications different designs have been developed, such as, ultrasonic assisted turning, welding, milling, drilling, grinding. Ultrasonic assisted machining technology has been studied by many cited references. All of these studies analyze in different ways, concept, design and dynamics of set-up, characteristics and finite element modeling and comparison of cutting forces during machining processes. In this present review only one dimensional ultrasonic assisted turning has been discussed and some ultrasonic assisted machining related to ultrasonic assisted turning is discussed.

Some Other Vibration Assisted Cutting

Liu et al. [14] have performed experimental study on distinctiveness of ultrasonic vibration-assisted cutting of tungsten carbide material using a CNC lathe with CBN tool inserts.. The SEM observations on the machined work-piece surfaces and chip formation indicated that the critical condition for ductile mode cutting of tungsten carbide was mainly the maximum undeformed chip thickness when the tool cutting edge radius was fixed, that is, the ductile mode cutting can be achieved when the maximum undeformed chip thickness was smaller than a critical value. Corresponding to the chip formation mode (ductile or brittle), three types of the machined work-piece surfaces were obtained: fracture free surface, semi-fractured surface and fractured surface. It was also found that the cutting speed has no significant effect on the ductile chip formation mode.Chen et al. [15] performed experimental study on turning W-Fe-Ni alloy by conventional turning and ultrasonically assisted turning. They found that in ultrasonic assisted turning, feed rate still has significant influence on surface roughness, next to important factors are vibration parameters, while the influence of depth of cut and cutting speed on surface roughness become less profound than others parameters. Comparing with CT, the surface roughness machined by UAT reduced by the range of 7.05%-30.06%. They observed that UAT can give smoother surface, but the residual stress is larger than that in CT. It confirms that the rake surface of the vibration cutter has an intense ironing effect on the work piece surface.

Hsu et al. [16] study on the machining characteristics of Inconel 718 by combining ultrasonic vibration with high-temperature-aided cutting. Experiment is done using Taguchi experimental design to clarify the influence of various machining parameters on the machining characteristics. They found that the percentage contributions of the cutting tool, feed rate, working temperature and depth of cut for surface roughness are 33.16, 25.00, 13.36 and 9.17, respectively and the percentage contributions of the cutting speed, feed rate, cutting tool and depth of cut for cutting force are 22.27, 16.88, 13.80 and 13.37, respectively and also found that Ultrasonic-aided cutting improved the surface roughness by 9.10–51.61%, as well as decreasing cutting force by 32.34–24.47%. As a result, ultrasonic-aided cutting can enhance the cutting quality of Inconel 718.

Summary

This chapter has presented a literature survey with a critical review on one dimensional ultrasonic assisted turning. Different ultrasonic assisted turning set up, previous experimental and finite element study on ultrasonic assisted turning has been discussed. The mechanism of one dimensional ultrasonic assisted turning is also discussed.

The previous works presented are adapted and improved to produce a novel idea in ultrasonic assisted turning system development. Experiments have been conducted and obtained data are analyzed statistically.

III. MATERIAL SELECTION & ITS PROPERTIES

Alloy steels contain different varieties of steels that exceed the composition limits of Mn, C, Mo, Si, Ni, Va, and B set for carbon steels. They are designated by AISI four-digit numbers. They respond more quickly to mechanical and heat treatments than carbon steels.AISI 52100 alloy steel is known as a high carbon, chromium containing low alloy steel. The following datasheet gives an overview of AISI 52100 alloy steel.

Chemical Composition

The following table 3.1 shows the chemical composition of AISI 52100 alloy steel

Table 3.1 Chemical Composition of AISI 52100 Alloy

Element	Content (%)
Iron, Fe	96.5 - 97.32
Chromium, Cr	1.30 - 1.60
Carbon, C	0.980 - 1.10
Manganese, Mn	0.250 - 0.450
Silicon, Si	0.150 - 0.300
Sulfur, S	≤ 0.0250
Phosphorous, P	≤ 0.0250

Steel

Physical Properties

The physical properties of AISI52100 alloy steel are listed in the following table 3.2

Properties	Metric	Imperial
Density	7.81 g/cm^3	0.282 lb/in^3
Melting point	1424°C	2595°F

Table 3.2 Physical Properties of AISI 52100 Alloy Steel

IV. EXPERIMENTAL SETUP & PROCEDURE

The experimental set-up as shown below in figure 4.1 :

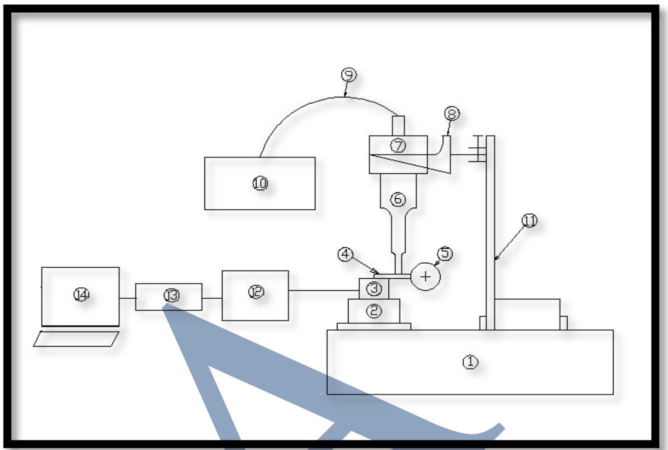


Figure 4.1 Schematic diagram of ultrasonic assisted turning system

Design of experiments

It is based on Taguchi's concept which have been in developed into an engineering method of quality improvement referred to as quality engineering in Japan and as robust design in the west, which is discipline engineering process that seeks to find best trade off a product design. Concepts technique used in robust design Taguchi's concept such as "quality", S/N Ratio, Orthogonal arrays Degree of freedom and analysis of variance " may be synthesis in engineering studies. The quality lose function is considered as an innovative means for determining the economic advantage of improving system safety or operational safety .orthogonal arrays are used to study many parameters simultaneously with a minimum of time and resources to produce an overall pictures for more detailed safety based design an operational decision making. The Signal to noise ratio is employed to measure quality. L9 mixed arrays table was chosen for the experiment. Three controlling factors having three levels (small, medium and large)were selected as controlling factors:

1. Speed
2. Feed
3. Amplitude

Table 4.1 Machining factors and their levels

Factors	Level-1	Level-2	Level-3
Speed	180	280	450
Feed	11	30	38
Amplitude	70	80	90

Orthogonal arrays

Taguchi's has developed a system of tabulated designs (arrays) that allow for the maximum number of main effects to be estimated in an unbiased (orthogonal) manner, with a minimum number of runs in the experiment. Orthogonal arrays [6] are used to systematically vary and test the different levels of each of the control factors. Commonly used as includes the L4, L9, L12, L18, and L27. The columns in the OA indicate the factor and its corresponding levels, and each row in the OA constitutes an experimental run which is performed at the given factor settings. Typically either 2 or 3 levels are chosen for each factor. Selecting the number of levels and quantities properly constitutes the bulk of the effort in planning robust design experiments.

Table-4.2 L9 TABLE

Exp no.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Signal to noise ratio and ANOVA approach

The S/N ratio developed by Dr. Taguchi [19] is a performance measure to choose control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. While there are many different possible S/N ratios, three of them are considered standard and are generally applicable in the situations below:

- Biggest-is-best quality characteristic (strength, yield),
- Smallest-is-best quality characteristic (contamination),
- Nominal-is-best quality characteristic (dimension).

In addition to the Signal to Noise Ratio (S/N ratio), the obtained results have been tested using statistical Analysis of Variance (ANOVA) with Pareto chart to indicate the impact of process parameters on surface roughness. The reason of combining Pareto chart with Analysis of Variance was to detect causes applying the principle that 80 percent of the problems usually stem from 20 percent of the causes. Pareto ANOVA technique of analysis has been used in this experimentation to analyze data for process optimization in past research also. Pareto ANOVA is a simplified ANOVA method, which uses Pareto principle. It is a quick and easy method to analyze result of parameters design. It does not require an ANOVA table and therefore, does not use F-test. The calculations of these tables are done by the use of standard orthogonal arrays. The preferred parameter settings are then determined through analysis of the "signal-to-noise" (SN) ratio where factor levels that maximize the appropriate SN ratio are optimal. There are three standard types of SN ratios depending on the desired performance response.

1. Smaller the better (for making the system response as small as possible):

$$\cdots SN_s = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

2. Nominal the best (for variability around a target):

$$\cdots\cdots\cdots\cdots SN_T = 10\log\left(\frac{\bar{y}^2}{S^2}\right) \quad (4.2)$$

3. Larger the better (for making the system response as large as possible):

$$\cdots\cdots\cdots\cdots SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (4.3)$$

These SN ratios are derived from the quadratic loss function and are expressed in a decibel scale. Once all of the SN ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data. In the graphical approach, the SN ratios are plotted for each factor against each of its levels. Finally, confirmation tests should be run at the "optimal" product settings to verify that the predicted performance is actually realized. 2. 5 Steps applied in Taguchi methods Taguchi proposed a standard procedure for applying his method for optimizing any process.

V. RESULTS AND DISCUSSION

In order to assess influence of various factors means and signal to noise ratio for each control factor are to be calculated. Levels of input parameters (i.e. speed, feed and amplitude) are selected as per orthogonal array selector and results of surface roughness test specimen for each trial are tabulated in table 5.1.

Analysis for Surface Roughness

Table 5.1 Taguchi Orthogonal Array Design for Surface Roughness L9

A	B	C	Ra	S/N Ratio
1	1	1	6.005	-15.5703
1	2	2	6.517	-16.2810
1	3	3	7.614	-17.6323
2	1	2	6.130	-15.7492
2	2	3	9.047	-19.1301
2	3	1	9.533	-19.5846
3	1	3	7.328	-17.2997
3	2	1	9.109	-19.1894
3	3	2	8.618	-18.7081

Level	A	B	C
1	-16.49	-16.21	-18.11
2	-18.15	-18.20	-16.91
3	-18.40	-18.64	-18.02
Delta	1.90	2.44	1.20
Rank	2	1	3

Table 5.2 Response table for signal to noise ratios (Smaller Is Better)

Main Effects Plot for SN Ratios

Initially the experimental results were used to obtain S/N Ratios for the performance characteristics to find a desirable result with the best performance and smallest variance.

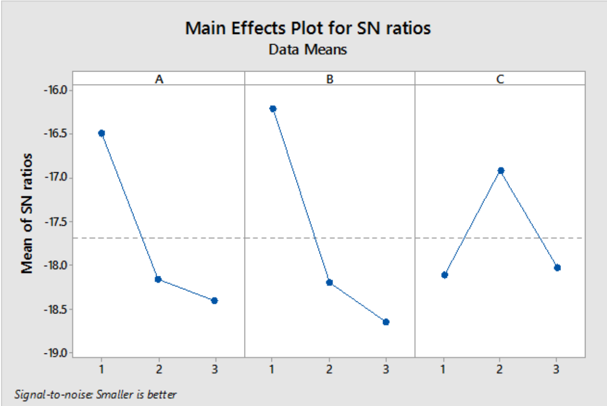
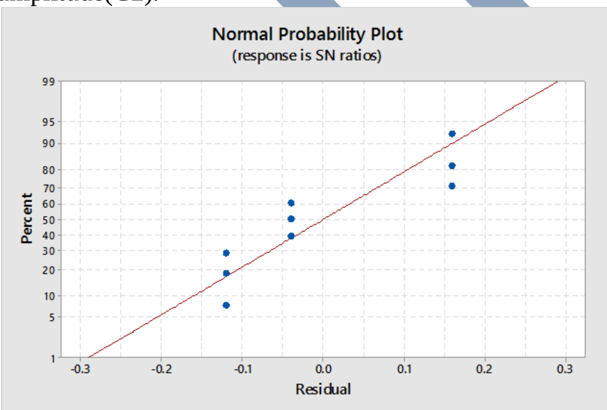


Fig 5.1 depicts the main effect plot for S/N ratio. It can be seen from Fig 5.1 that within the range of investigated input parameters, the optimal combination of the parameters surface roughness is A1B1 C2, i.e., at speed(A1) ,feed(B1) and amplitude(C2).



Normal plot of Residuals for SN Ratios- shows the normal probability plot of the residuals for surface roughness and it reveals that the residuals either fall on a straight line or are very close to the line implying that the errors are distributed normally.

Summary

The experimental study has carried out on turning AISI 52100 by ultrasonic assisted turning (UAT). 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. While the UAT can reduce the influence of deformation and built-up-edge formation because of high frequency reciprocating movement between the contacting surfaces of the tool and the work piece, so as to make the turning process more stable. UAT improved the surface roughness. It proves that UAT can obtain smoother surface. The analysis of variance (ANOVA) was conducted to study the significance of machining parameter on Surface Roughness based on their P-value and F-value. The ANOVA results are shown in Table 5.3. It can be seen from Table 5.3 that the speed and amplitude significantly affects the surface roughness as F calculated value is more than the tabulated F value. However, based on the percentage contribution of the machining parameters shown in Tale 5.3, it is found that % contribution of amplitude is maximum (58.667%) followed by speed (25.333%) and feed (16.00%).

5.1.3 Results of Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Distribution
A	2	6.4433	6.4433	3.22165	52.05	0.019	25.333
B	2	10.1005	10.1005	5.05027	81.60	0.012	16.00
C	2	2.6811	2.6811	1.34056	21.66	0.044	58.667
Residual Error	2	0.1238	0.1238	0.06189			
Total	8	19.3487					

Table 5.3 Results of Analysis of Variance:

Summary

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VI. 6. CONCLUSION

This work presents an experimental study in which UAT is performed on material AISI52100. Trial run was conducted to establish the range of selected parameters. Subsequently speed at three level, feed at three levels and amplitude at three levels are considered and 9 experiments as per the experimental plan of Taguchi's experimental design i.e. L9 OA are conducted. A response variable namely Surface Roughness measured. Signal to noise ratio for response variable is computed. Subsequently, analysis of variance is used to obtain the percentage contribution of the parameter.

The analysis of mean is performed to obtain optimum level of the machining parameters for multi performance characteristics.

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