Study of Effect of Machining Parameters on Surface Finish and Noise Patterns for Machining EN 19 Steel with PVD TiN Coated Mixed Ceramic Inserts in CNC Turning Operation

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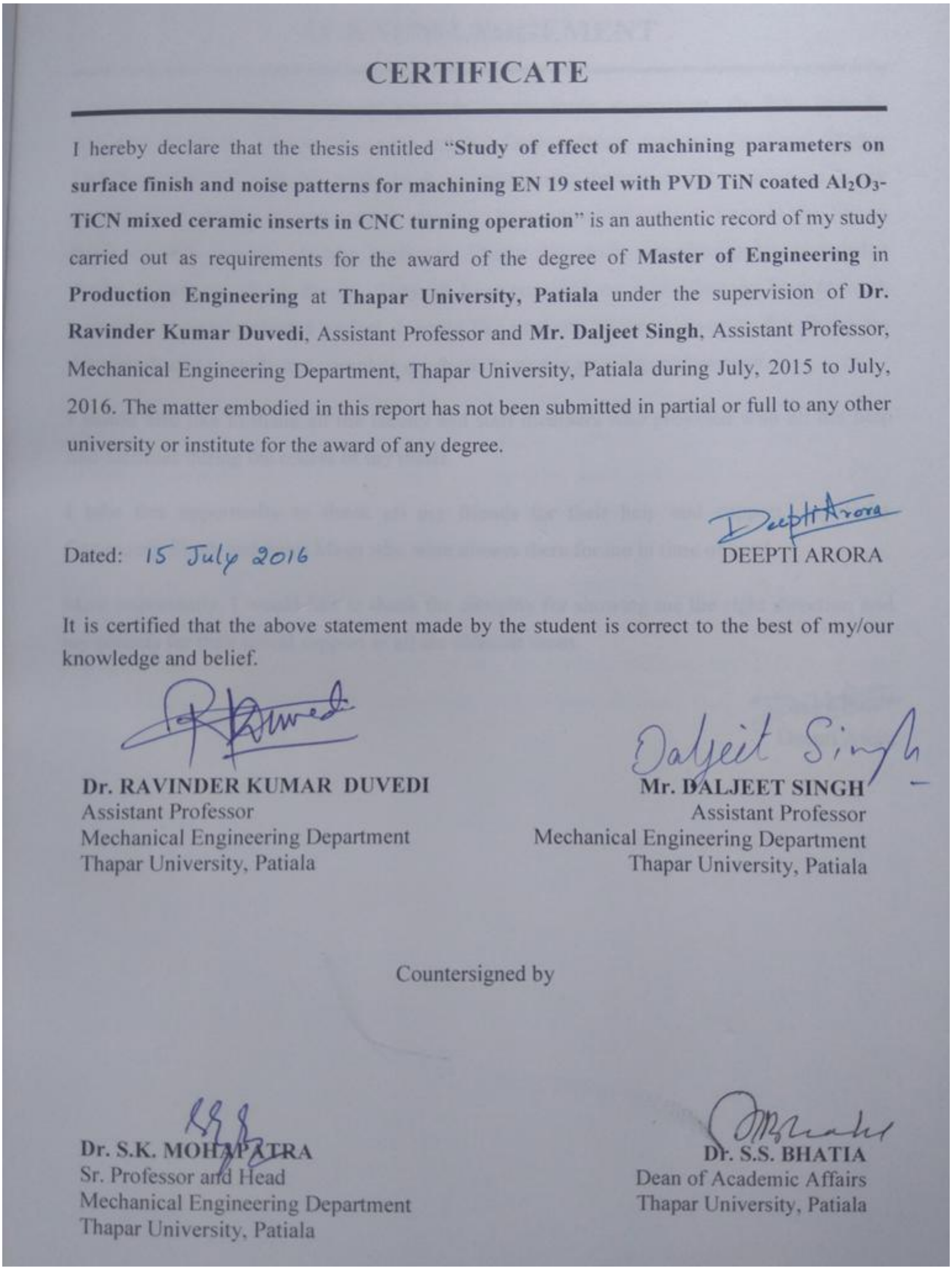

CERTIFICATE

I hereby declare that the thesis entitled "**Study of effect of machining parameters on surface finish and noise patterns for machining EN 19 steel with PVD TiN coated Al_2O_3-TiCN mixed ceramic inserts in CNC turning operation**" is an authentic record of my study carried out as requirements for the award of the degree of **Master of Engineering** in **Production Engineering** at **Thapar University, Patiala** under the supervision of **Dr. Ravinder Kumar Duvedi**, Assistant Professor and **Mr. Daljeet Singh**, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala during July, 2015 to July, 2016. The matter embodied in this report has not been submitted in partial or full to any other university or institute for the award of any degree.

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It is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.

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ABSTRACT

The surface finish of a product is one of the most important factors in determining the quality of the surface of the product. For long, research on optimisation of machining parameters and other inputs, to find ways to achieve the best surface finish has been done for a variety of materials.

In this study, hard turning of EN 19 alloy steel is done using PVD TiN coated mixed ceramic (Al_2O_3+TiCN) inserts on a CNC turning centre under wet lubrication conditions to investigate the effect of machining parameters on surface roughness. The turning operations are performed for different combination of cutting parameters viz. cutting velocity, feed and depth of cut. The combinations of these three parameters for experimental runs are obtained using full factorial design of experiments and thereafter, ANOVA is applied to find the effect of those parameters on surface roughness. Additionally, noise generated during the cutting operation is also studied keeping in mind the health hazards of high noise levels on the workers. Frequency spectrum analysis is also done to find out the frequency range in which highest sound levels are obtained. An attempt has been made to find a possible correlation between the two responses, surface roughness and noise. Optimum parameters have been determined for the best surface finish under said machining conditions and also for lowest noise generated if that may be the requirement, without compromising much with the surface finish.

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NOMENCLATURE

SYMBOLS	DESCRIPTION
P	Sound pressure
Hz	Hertz
f_{upper}	Frequency of upper limit
f_{lower}	Frequency of lower limit
f_{centre}	Centre frequency
Pa	Pascal
SPL	Sound Pressure Level
SL	Sound Level
SLM	Sound Level Meter
dB	Decibel
dBA	A-Weighted Decibel
L_{eq}	Equivalent Continuous Sound Level (dB)
AE	Acoustic emission
PVD	Physical vapour deposition
CBN	Cubic boron nitride
L_A	Equivalent sound level in A-weighting (dBA)
$L_A wm$	L_A without machining (dBA)
L_Z	Sound level in linear scale (dB)
$L_Z wm$	L_Z without machining (dB)
HRC	Rockwell hardness
RSM	Response surface methodology
ANOVA	Analysis of variance
v	Cutting velocity (m/min)
f	Feed rate (mm/rev)
d	Depth of cut (mm)
Ra	Average surface roughness (µm)
R^2	Coefficient of determination

CHAPTER 1
INTRODUCTION

1.1 Introduction

Surface finish of a product is one of the most important factors in determining the quality of the product. It affects the wear rate, corrosion resistance, and tribological properties of a machined work piece. For long, research on optimisation of machining parameters and inputs to find ways to achieve the best surface finish has been done for a variety of materials. It is a well known fact that CNC machines have the ability to produce jobs with utmost accuracy and fine surface finish. They are highly automated machines and can continue to work for many hours saving the operator from fatigue and resulting in fewer human errors and thus, greater accuracy. But in order to be able to perform high speed machining tasks and reduce the machining time while achieving the required surface finish, optimisation of machining conditions is done.

One of the most commonly used machines in the industries is the lathe machine. It can be used to perform a variety of operations such as turning, facing, centering, and grooving. Out of these, the most common operation is that of turning. It is basically used to create rotational parts such as shafts and any axis symmetric job.

In this work, EN 19 hardened alloy steel has been identified as the work material which is used for making tool bodies, connecting rods, jigs, bolts, crankshafts, axle shafts and piston rods amongst many other applications. It has been found that for hard turning, coated ceramic tools having properties such as resistance to thermal shock, toughness, hardness and fracture strength give a better surface finish and hence found suitable for this work. Within the suggested range of parameters optimised by Das et al. [6] where machining was done in a dry environment, this work has been extended for wet machining conditions so as to achieve better surface finish. Simultaneously, it has been observed that there must be some correlation between the noises encountered during turning with surface finish. So, the sound levels and frequency spectrums have also been investigated. An attempt has been made to find a correlation between noise and surface roughness. The results for optimised parameters for best surface finish and least noise generation have been determined and presented in various chapters of this thesis.

1.2 CNC Turning Centre

CNC stands for Computer Numerically Controlled. It is a technology by virtue of which the physical movements of a machine are controlled by a set of code instructions or a program generated using a computer. In this study machining has been performed on a CNC turning center, which is nothing but an automated version of a manual lathe machine. Conventionally, it is the operator who makes the decisions and adjusts the machining parameters such as cutting velocity, feed, depth of cut and others and manually controls the slide movements by handwheels or levers. In a CNC turning centre, these movements are accomplished by sending instructions to the motors using computer programs [27-28]. It can also be programmed to automatically change the tools with the help of an automatic tool changer (ATC).

CNC turning centres are extremely versatile and a variety of different types of product and materials can be machined on them. The precise abilities of a machine vary with power, size and rigidity. They have proved to be a boon in the world of automation and machining. They can be run continuously for hours or even days without causing any fatigue to the operator. They can make products with utmost accuracy and each part they machine will be almost exactly the same.

Figure 1.1: CNC Lathe Machine

A CNC turning centre can perform a variety of operations such as turning, boring, grooving, threading and drilling. But only turning process will be discussed here since that is the area of concern in this study. Turning process is a form of machining that is used to craft rotational parts by cutting away surplus material. The tool used for cutting is usually a non-rotary tool insert. The cutting tool moves linearly whereas the work piece rotates as shown in figure 1.2. Thus, the relative motion between them portrays a helical tool path.

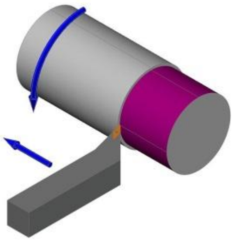

Figure 1.2: Turning process [http://en.wikipedia.org/wiki/Turning]

A variety of shapes can be generated by these processes such as straight, conical or curved shapes on work piece of different materials. In general, we use single-point cutting tools to perform turning operations.

1.3 Dynamics of Turning

i) Forces in turning operations

In a turning operation, it is important to consider the relative forces while designing the machine tool. The machine tool and its components must be designed in such a way that they have the ability to bear the various forces acting upon them without causing considerable vibrations/chatter or deflections, while machining. There are three most important forces during a turning process:

(a) The cutting force is the one which acts downwards on the tool tip and allows upward deflection of the work piece. It is also known as the tangential force. This force is responsible for providing the energy needed to perform the cutting operation.

(b) The axial force is the one which acts in the longitudinal direction. It is also known as feed force since it is acting in the direction of feed of the tool. It has a tendency to shove the tool away from the chuck.

(c) The radial force, also known as thrust force is the one which acts in the radial direction of the tool. It has a tendency to shove the tool away from the work piece.

ii) Machining parameters in turning

Cutting speed: It is described as the relative velocity (difference in speed) between the cutter and the work piece surface. It is expressed usually in meters per minute (m/min).

Feed: The relative velocity at which the cutter is moved forward along the work piece is called feed rate. Its units are distance per spindle revolution, i.e. millimeters per revolution (mm/rev).

Depth of cut: It is the thickness of material removed during the machining of a work piece and is usually measured in mm.

1.4 Cutting Tool

A cutting tool or cutter is any tool that is used to remove material from the work piece by means of shear deformation. There are a wide variety of tools available to be used in a CNC turning centre to perform various operations such as turning, boring, drilling and threading. Out of these, only the tools concerned with turning operations have been discussed here.

In a turning process, usually a single-point cutting tool is used. These tools may be classified into two types namely, solid tools and insert based tools. In CNC machining, we prefer the second type which is indexable insert based tools. These inserts are basically cutting tips and can be removed as they are not welded to the body of the tool. They are made to be symmetrical and so they can be flipped or rotated to provide a fresh cutting edge after the previous one wears out.

These inserts can be used in either coated or non-coated forms. There are a wide variety of advanced tool materials available such as cemented carbides, ceramics, cubic boron nitride (CBN) and diamond cutting tools. These tool materials may have coatings of hard materials such as titanium nitride, titanium carbide, aluminium oxide and titanium carbon nitride. Coating of inserts with such hard materials makes them more resistant to wear due to abrasion and provides a longer tool life.

For the machining of EN19 which is a hard alloy steel, we have recognized from the published literature that mixed ceramic inserts give better performance in high speed machining of hard steels as they can retain their hardness at elevated temperatures. Even though CBN and diamond tools may have better properties, but they are extremely expensive and not so feasible as compared to ceramics which are only moderately inexpensive. Therefore, in conducting this study, TiN coated mixed ceramic (Al2O3-TiCN) inserts have been selected for their superior properties and moderate cost.

1.5 Surface Roughness

The quality of machined surface is determined by how accurately the product can be manufactured with respect to the dimensions of the product specified by its designer. There is no machining process that does not leave an irregular pattern on the surface of the work piece by the cutting tool. This pattern is known as surface roughness. The irregularities on the surface of the work which are formed due to various machining processes combine to form surface texture. Lesser the roughness, smoother will be the texture and more will be the surface finish.

There are many different roughness parameters such as Ra, Rz and Rq which are used for measuring the surface roughness. They are usually expressed in microns. Ra represents the average departure of the surface from perfection. Rq represents the root mean square value of the roughness. Rz gives the value of vertical distance between the average of five highest crests and the average of five deepest troughs. Out of these Ra is the most commonly used parameter.

The surface roughness of the work piece depend upon the following factors:

i) The machining parameters viz. cutting velocity, feed rate, and depth of cut
ii) The material chosen for the work piece; the tool used for machining it; and their mechanical properties
iii) The tool geometry: rake angle, cutting edge, nose radius and side cutting edge angle
iv) The quality and type of the machine used
v) Vibrations between the cutting tool, work piece and the machine tool
vi) Auxiliary tooling
vii) The lubricant used

1.6 Types Of Lubrication Used In Turning

Turning operations can be performed under dry conditions, mist lubricating conditions or wet conditions. Dry cutting has been preferred for a long time in the industry because it causes an increase in the cutting temperature, which causes a reduction in cutting force required to machine the component. But the life of tool and surface finish are adversely affected in dry conditions. Mist conditions offer slight lubrication and cooling; and are preferred in cases where coolant is required in unreachable areas of the part. Wet conditions offer maximum lubrication and cooling, thus minimising tool wear as well as improving surface finish [13].

For turning of hardened EN 19 steel with a mixed ceramic tool, it has been observed from published literature [6] that optimisation of parameters for dry cutting conditions has been done. In the present study, optimisation of parameters under wet cutting conditions has been done to achieve a better surface finish.

There are a variety of cutting fluids available for lubrication and cooling such as mineral oils, semi-synthetic fluids and fully synthetic fluids. The most common is the semi-synthetic type which is also quite cheap and effective. They consist of an emulsion of oil droplets dispersed in water. Emulsifying agents are sometimes added in order to enhance the emulsion stability.

1.7 Effect Of Noise On Shop Floor

In the rapidly growing modern world of ours, one of the burgeoning problems is that of noise. Not only does noise cause sheer annoyance, but exposure to a strong sound field over an extended period of time can lead to the risk of having permanent hearing damage. This particular problem is gradually becoming a source of serious concern to industrial corporations, trade unions and companies. In industries, the major cause of noise is the machine tools.

Machining operations are always accompanied by some peculiar noise patterns. Such noises on the shop floor are common, especially in cases where CNC turning operations may continue for as long as a few hours or even days. A prolonged exposure to particular levels of noise of certain frequencies while machining may be hazardous for an operator working around such machines. It poses a risk to human health and may cause behavioural changes or permanent damage to hearing.

Thus, it is essential that noise should also be considered as an important factor in studies regarding optimisation of machining conditions for better surface finish at lower noise levels. The noise patterns emitted while machining can also be used for condition monitoring or as an indicator of surface finish levels if a correlation can be obtained.

In general, the following noise sources can be notable: noise from vibrations of tool, noise from vibrations of work piece, aerodynamic noise, noise due to interactions between the cutting tool and the work piece, and noise caused by material fracture. The noise levels radiated depend highly on the feed rate, the depth of cut, the resonance frequencies of the cutting tool and the work piece amongst other factors.

1.8 Characteristics Of Noise

Noise or sound is measured in Decibels which is the logarithm of a ratio of two quantities and therefore has no units..

1.8.1 Sound pressure level

A decibel (dB) is a logarithmic ratio, which defines the sound pressure level L_p as follows:

$$L_p = 20\ \log_{10}(P/P_0) \tag{1.1}$$

Where, P: Sound pressure measured

P_0: Reference sound pressure which is 20μPa (the threshold of hearing)

1.8.2 Frequency analysis

Sound signals can be broken down into frequency components. The human ear, apparently works as a natural frequency analyzer. Instruments can be made to examine sound signals too by breaking them into frequency components. Analysis of frequency is normally performed using (a) constant percentage filters and (b) constant frequency band filters. The former is more likely to work parallel to the way the human ear analyses sound.

If fU and fL are taken as upper and lower cut off frequencies; band centre frequency is denoted by fC; and Δf denotes the bandwidth of the frequency, then bandwidth is presented as

$$\Delta f = fU - fL \tag{1.2}$$

For most purposes where resolution of the exact frequency of a pure tone is not important, the frequency spectrum is built up from larger frequency intervals. The most common bandwidths are 1/1 octave bands and 1/3 octave bands.

For 1/1 octave bands, the range is such that the frequency of the upper limit of is double the frequency of the lower limit as shown below

$$f_{upper} = 2\, f_{lower} \tag{1.3}$$

In case of third octave bands, the limits are defined such that

$$f_{upper} = 2^{1/3}\, f_{lower} \tag{1.4}$$

An example of a frequency spectrum of 1/1 and 1/3 octave bands is shown in figure 1.3 and figure 1.4 respectively. The discretization of the 1/3 octave band is better than 1/1 octave band. All frequency bands are usually referred to a centre frequency which is the geometric mean frequency of the band

$$f_{centre} = \sqrt{(f_{upper}\, f_{lower})} \tag{1.5}$$

In this study, frequency spectrum based on 1/1 octave bands have been studied to investigate the noise patterns during the turning operation.

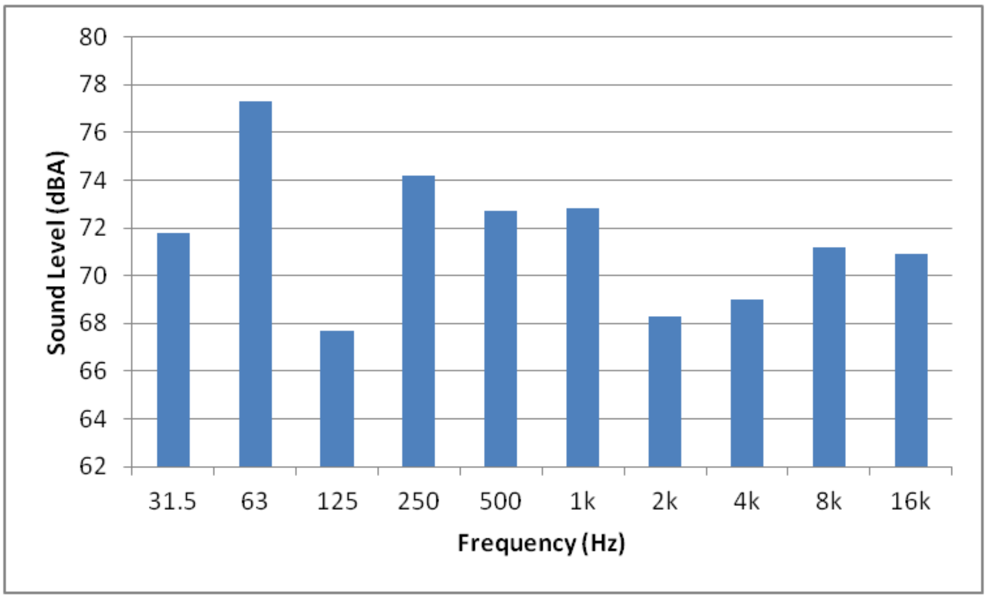

Figure 1.3: 1/1 octave band frequency spectrum

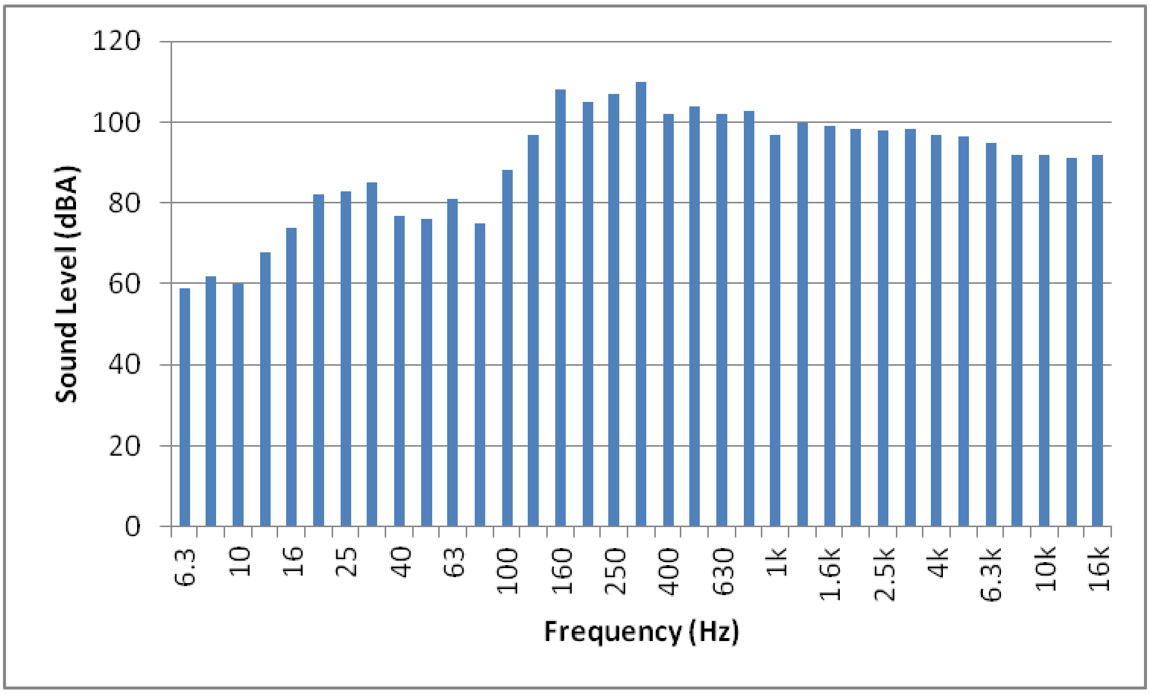

Figure 1.4: 1/3 octave band frequency spectrum

1.8.3 Weighting curves for sound level measurement

The response of the ear is not linear. So weighting filters are introduced which make it possible to take measurements that correlate well with the response of the ear. The most commonly used of these curves is the A- weighting curve, because it gives the best correlation between the measured values and the annoyance caused and harmful levels of the sound signal. Following are the different types of weighting scales:

(a) **A-weighting:** This is the most common weighting that is used in measuring noise. In this, the higher and lower frequencies that an average human being cannot hear are eliminated, just like the human ear. The term dBA or dB (A) is used to express the A-weighted measurements.

(b) **C-weighting**: The human ear's response is more flat at higher sound levels like 100 dB and above. Thus, this weighting is generally used for peak measurements. The term dBC or dB(C) is used to express C-weighted measurements.

(c) **Z scale:** Z Scale is a flat frequency response of 10 Hz to 20 kHz ±1.5 dB. Even though it gives a flat response but the frequency range over which the reading would be linear is defined. A graph of all these weighting curves is shown in figure 1.5

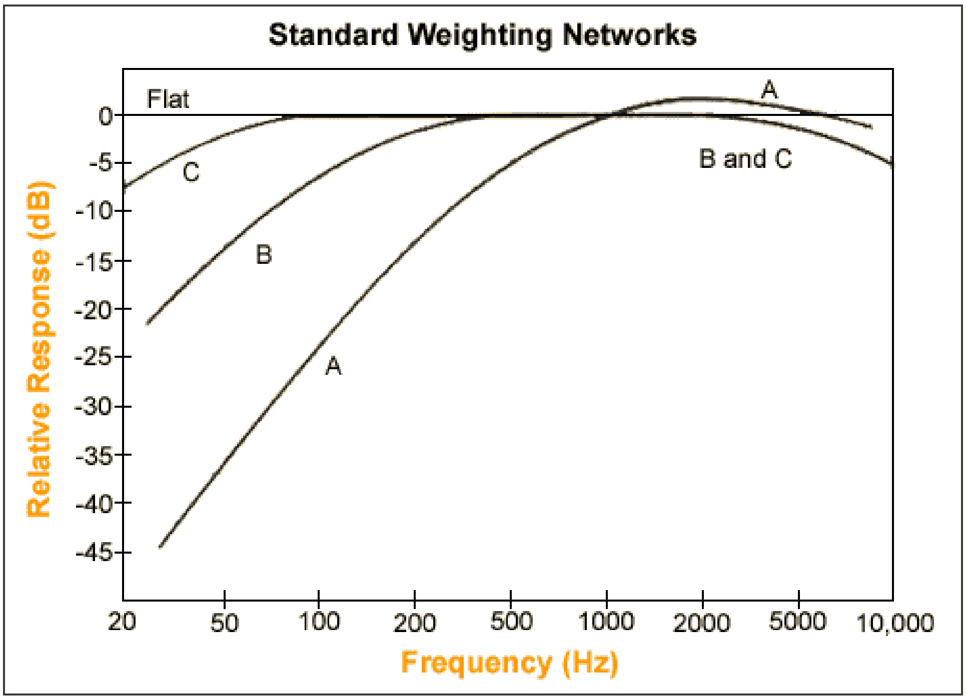

Figure 1.5: Weighting Curves

1.8.4 Equivalent continuous sound level (L_{eq})

L_{eq} is the A-weighted energy mean of the noise level averaged over the measurement period. It can be considered as the continuous noise which would have the same total A-weighted acoustic energy as the real fluctuating noise measured over the same period of time [26].

It is defined by the following expression,

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T \left[\frac{P}{P_{ref}}\right]^2 \qquad 1.6$$

Where, T: Total measurement time

P: A-weighted instantaneous acoustic pressure

P_{ref}: Reference acoustic pressure of 20µPa.

1.9 Sound Measurement

Sound measuring devices usually use a sensor to receive the sound signals coming from a source. There are many kinds of instruments available to measure sound levels but the one that is most commonly used is sound level meter (SLM). It is usually a handheld instrument which has a microphone. The microphone has a diaphragm which responds to changes in air pressure caused by the propagating sound waves. These deviations in the sound pressure levels are then converted into an electrical signal.

1.9.1 Background noise correction

While carrying out the sound level measurement for any machine, it is required to make sure that the level of background noise is low enough, so that it does not have any influence on the measurements. The test for measuring background noise is explained as follows:

Take measurements of the sound level from the required position while the machine is running (L_{S+N}). Then take the measurements while the machine is switched off (L_N). If the difference is greater than 10dB, in that case the background noise may be ignored. If the difference between the two measurements is lower than 3dB, no further measurements should be taken until the background noise has been reduced. If the difference is between 3 and 10 dB, then the measured value should be corrected using the background noise correction curve as shown in figure 1.6. or by using equation 1.7 [25].

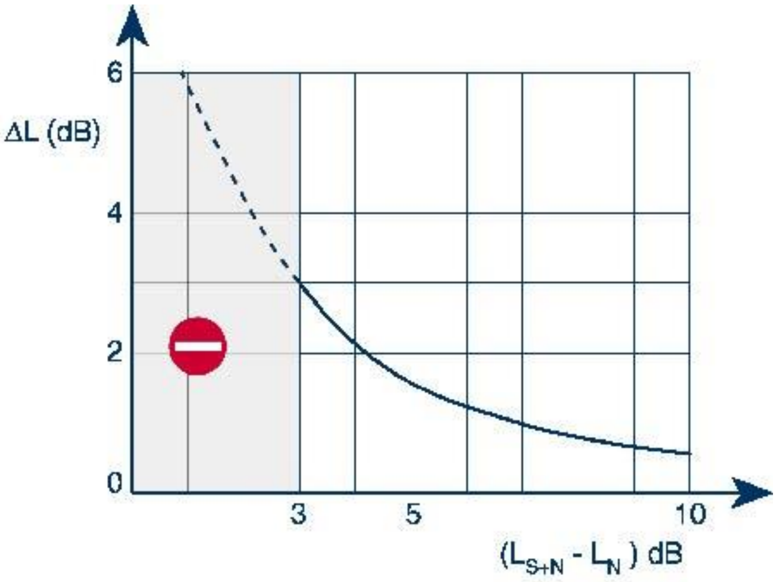

Figure 1.6: Subtraction of background noise in dB [Hand book of acoustical measurement and control and noise control]

In the graph above, the point where 'L_{S+N} - L_N' value intersects with the curve gives the corresponding value of 'ΔL' on y-axis. This value of ΔL is then subtracted from L_{S+N}.

The background noise corrections can also be done by the following expression:

$$L(corrected) = 10\log_{10}\left[10^{L_{measured}/10} - 10^{L_{background}/10}\right] \qquad 1.7$$

1.10 Present work

In this thesis work, high speed machining of a hard material has been performed under wet machining conditions with an aim of optimising the various cutting parameters viz. cutting velocity, feed rate and depth of cut, to achieve the best surface finish while simultaneously investigation of noise levels and frequency spectrum produced during machining has also been done to find out lower sound levels for machining.

The work material chosen is hardened EN 19 steel and the tool material chosen is Al_2O_3-TiCN mixed ceramic inserts with PVD TiN coatings. The initial cutting parameters have been derived from the reported work in literature [6] and the work has been extended for wet machining conditions to find out the efficient cutting parameters for best surface finish and low noise levels and find a possible correlation between the two.

This work has been carried out using MAXTURN PLUS + turning centre manufactured by MTAB, available in the Computer Aided Machining (CAM) lab of mechanical engineering department, Thapar University, Patiala. The literature review has been given in chapter 2. The methodology of the work has been systematically explained in chapter 3. The results have been discussed in chapter 4. Finally, the conclusion and future scope have been presented in chapter 5.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter covers the extensive literature survey of the research work that has been done in the past on different aspects of turning and machining noise. The aim of this literature survey was to identify the relationship between machining parameters and surface finish and to further correlate that with noise. To better present this survey, it has been divided into two sections as follows.

2.2 Effect Of Machining Parameters On Surface Roughness

Srithar et al. [1] performed and analyzed the machining of AISI D2 hardened steel using coated carbide inserts. The cutting parameters varied during the experiment were cutting velocity, depth of cut and feed rate and the outcome studied was surface roughness parameters (Rt, Ra, Rz). Results showed that as the velocity increases, the surface roughness decreases. Conversely, as the feed rate and depth of cut increase, the surface roughness increases. It was noted that feed rate was the primary control parameter that highly influenced the surface roughness parameters.

Kumar et al. [2] investigated the cutting parameters during CNC turning of carbon alloy steel and their effect on surface roughness. The machining was performed on five kinds of material which are SAE8620, EN8, EN19, EN24 and EN47 using carbide tool in wet conditions. The spindle speed as well as the feed was varied whereas the depth of cut was kept unvarying. They noted that the surface roughness got reduced with a rise in the spindle speed while it increased with a rise in the feed rate. Thus, concluding that improved surface finish may be attained by keeping the feed low and speed high.

Agrawal et al. [3] gave a model based on random forest regression to foretell the average roughness of the work surface in machining of AISI 4340 steel with a CBN tool. Correlation between the values obtained from the experiments and the model was quite good with a standard deviation of 0.0465 only. They observed that feed rate had the maximum influence on the roughness of the workpiece surface after which depth of cut and speed did.

Valera et al. [4] investigated the consumption of power and roughness in machining of EN 31 steel using a tungsten carbide tool with TiN+Al2O3+TiCN coating. It was noted that an increase in cutting velocity reduced the surface roughness, whilst an increase in depth of cut and feed led to an increase in the roughness value. At the same time power consumption was observed to have increased with increase in all the three parameters. Hence, cutting speed is the dominant cutting parameter here, which if raised can provide better surface finish, although at the expense of power consumed.

Elbah et al. [5] conducted studies on machining of hardened AISI 4140 hardened steel and made comparisons between surface roughness (Ra, Rz, Rt) of the wiper ceramic inserts with that of conventional ceramic inserts. It was seen that wiper ceramic inserts gave better surface quality than the conventional ones. Feed was seen as the most significant factor contributing to surface roughness. Optimal machining parameters for best surface finish were also determined.

Das et al. [6] investigated the turning of hardened AISI 4140 alloy steel using mixed ceramic inserts having PVD TiN coating, in dry cutting conditions. The parameters varied were cutting velocity, feed and depth of cut while the outcome measured was surface roughness. Results showed that change in feed had a major effect on surface roughness, followed by cutting velocity. Optimal set of parameters for lower surface roughness were determined.

Chakraborty et al. [7] conducted a comparative study of wear behaviour of carbide and ceramic tools (alumina and zirconium toughened alumina) in high speed machining of a low alloy steel. He observed that tool life of ceramic tools was more than that of carbide tool. Also, the surface finish value achieved with ceramic tools was quite superior to the one attained by cutting with the carbide tool. At high machining speeds, crater wear was identified as the type of wear mechanism in carbide tool, whereas ceramic tools exhibited minor nose wear and chipping of edges.

Mondal et al. [8] performed turning experiments on AISI 5117 steel using TiC-coated carbide inserts in both wet and dry machining conditions. Cutting velocity and feed were kept varying and it was noticed that the surface roughness got reduced with a reduction in feed rate for both dry and wet conditions, although the reduction was more in case of wet lubrication. Thus machining under wet conditions gives a better surface finish. At cutting speed as high as 268m/min, wide grooved carbide inserts had failed in dry conditions but performed well under wet conditions. Also, the tool wear rate was slower for the inserts in wet conditions and so better tool performance was achieved.

Ferreira et al. [9] performed turning on AISI H13 hardened steel and studied the effect of conventional and multi-radii ceramic tools. As expected, a rise in the feed rate led to an increase in roughness of the surface of work piece, while cutting speed had not so much influence on the roughness. The multi-radii ceramic tools performed better than the conventional ones in all the conditions.

Dureja et al. [10] conducted a study on hard turning of AISI D3 steel using a coated carbide tool and varied the cutting parameters to optimise them for better surface finish and tool wear. Feed was reported as the major factor affecting the roughness of the surface of work piece with 52.98% contribution amongst the input parameters. Mathematical models were developed for predicting the response factors and it was an excellent fit with the experimental values.

Meddour et al. [11] studied the turning of AISI 52100 steel with a ceramic tool and measured the cutting forces and surface roughness. Along with the normally varied parameters cutting velocity, feed and depth of cut, the tool nose radius was also taken as a variable in this case. It was observed that tool nose radius and feed were the most influencing parameters for roughness. It was suggested that feed be kept lower and tool radius larger to attain a better surface finish. As for the force components, depth of cut was noted as the dominant factor in affecting them.

Jang et al. [12] conducted studies on the effects of various machining parameters on ceramic tools in hard turning of AISI M2 steel under dry cutting conditions. Flank wear at the initial cutting stage was higher in case of high feed rates. Although flank wear was seen as the influencing factor for tool wear in ceramic tool, but crater wear was observed to be very less due to the ability of ceramics to resist any chemical reactions under high temperatures.

Abhang et al. [13] conducted experiments to study the effects of cutting parameters on surface roughness during turning of EN-31 steel under dry, MQL and wet lubrication conditions. He explained that as feed increases, so does the heat generated, causing an increase in roughness of the surface. As for depth of cut, the reason for increase in roughness at higher depth of cut is due to increased chatter. They also inferred that a greater tool nose radius gives better surface finish. Also, surface finish was better under MQL and wet lubrication conditions as compared to the dry conditions.

Pal et al. [14] studied the machinability aspects of hard turning of AISI 4340 using TiC coated mixed alumina ceramic tools and developed mathematical models for surface roughness. As expected, surface finish decreased with a rise in feed rate and improved when cutting speed was increased. Also, as depth of cut increased, the radial force also increased and caused lateral vibrations in the cutting tool leading to a rise in the surface roughness.

From the above studies, it is gathered that in most of the cases rate of feed given was the most dominant factor in influencing surface finish of machined components, followed by other cutting parameters. Turning operations performed in wet environment gave a better surface finish than those done in dry conditions. Also, performance of coated tools was better than that of uncoated ones in terms of wear and life of tool.

2.3 Effect Of Machining Conditions On Noise

Sexton et al. [15] studied that if the cutting speed is continually varied in a single point machining, then the problem of chatter can be reduced and stability can be achieved. They conducted a mathematical analysis of the problem of chatter by varying the cutting speed and deduced that modulating the cutting speed can improve stability and even provide a humble increase in the width of cut. They compared their results with those obtained from computer simulation of the machine/tool cutter system.

Hassan et al. [16] studied the relationship between cutting parameters and noise and vibration amplitudes. They found that when depth of cut was varied keeping the rotational speed constant, it had a larger effect on reduction of amplitudes of vibration than the case where rotational speed was varied and depth of cut was kept constant. They explained that this is the reason why variable depth of cut has more effect on cutting forces instead of variable speed. Thus sound pressure level during machining can be reduced by reducing the cutting forces.

Samraj et al. [17] conducting a study on working on a tool wear monitoring system by measuring the sound signals emitted during machining. The experiments were performed for two types of material namely aluminium and steel with a carbide too. The cutting speed and flank wear was varied, whereas feed and depth of cut were not. The sound signals measured are raw to perform any further analysis. Therefore, SVD was applied after which single value features were obtained. It was observed that the SVD features obtained from sound signals increased with a rise in the tool flank wear for both steel and aluminium. Thus, it is a potential method for on-line tool wear monitoring

Bhuiyan et al. [18] conducted a study to investigate the response of acoustic emission and vibration towards changes in the tool condition during a turning operation. The AE and vibration signals were modified using FFT to convert them from time domain to frequency domain. It was observed that the vibration components in x, y and z direction increased with rising feed and depth of cut, while a decline was noted in case of increase in cutting speed. A good correlation was observed between AE and tool wear. Also, the vibration component in the direction of feed seemed to correspond well to the roughness of surface of the work piece and may be used to represent surface roughness and monitor it.

Siddhpura et al [19] reviewed a few of the chatter detection, chatter stability prediction, and chatter control techniques for turning in order to find most suitable technique for reducing chatter. Chatter causes excessive vibrations and results in greater roughness of surface of machined part. It also produces high levels of noise and increases the rate of tool wear thus hampering productivity. They observed that stability lobe diagrams are the easiest and simplest way for the prediction of chatter. They concluded that limited literature is there on the effects of chatter on life of tool; and suggested that establishing a theoretical relationship between tool wear and chatter vibrations for the prediction of tool life can be researched upon.

Downey et al [20] studied if it is possible to determine the state of a cutting tool with the help of audible acoustic emission in a single point machining and if a tool in a good cutting condition can be differentiated from one that is worn out by monitoring the acoustic emissions in an audible range. They determined that the life of tool could be divided into three phases which are phase of optimum cutting, phase of normal cutting and phase of degraded cutting. They observed from the acoustic emission patterns that a shift in the phase could easily be detected from these patterns. They also observed that the change in AE began in advance of the actual degradation of the tool. Thus, AE can be used to indicate change prior to the actual decline in the cutting performance of the tool.

Maia et al. [21] put forward a methodology for determining the end of life of a cutting tool by measuring the acoustic emission signals in turning of AISI 4340 hard steel using both coated and uncoated carbide inserts. Initial AE signals were processed with amplitude modulation, auto covariance technique and finally PSD technique. The resultant obtained was found to be a good indicator of rate of tool wear. It increased at the beginning of tool life, then decreased in the middle as wear rate is low and finally increased at the end of life again when the wear rate is high. This approach is effective for tool wear monitoring.

Guo et al. [22] conducted an investigation on how sensitive are the main AE signal parameters (like RMS, count rate, amplitude, frequency) to white layer and the subsequent tool wear and surface finish. Turning operations were performed on AISI 52100 using round CBN inserts at constant cutting parameters in dry conditions. The results of the experiment showed that AE RMS, count rate and frequency are sensitive to the formation of white layer but amplitude of AE is not. Also, AE count does not respond to thickness of white layer. Thus it is possible to develop an online monitoring system for surface integrity based on this approach.

Chiou et al. [23] examined a dynamic model of RMS AE signal in the presence of tool flank wear during cutting. A few experiments were performed to inspect the validity of the developed model on a conventional lathe machine using a high speed steel tool to machine a 6061-T6 aluminum work piece. The experiments were performed with fresh as well as worn tools. The signals for AE RMS were higher for worn tools and lower for sharp tools.

Diniz et al. [24] performed experiments on turning with the aim of establishing a relationship between the acoustic emissions and work material's surface roughness in the turning operations which could be used as a foundation for knowing when to change the tool during machining. Turning experiments were done on AISI 1045 steel using TNMP 16 04 12 K-PI5 (uncoated) inserts. The relationship between numerous parameters of AE such as mean $AE_{rms,}$ zero crossing rate and standard deviation of AE_{rms} was established. AE proved to be a fine way for on line monitoring of surface roughness in finish turning.

Different studies have been done trying to correlate noise levels with tool wear and surface finish. The studies above indicate that level of noise emitted increases as the tool gradually wears out. A significant increase in the noise levels can be observed for a worn tool when compared with noise spectra of a sharp tool.

2.4 Summary

From the literature survey, it is understood that machinability is often assessed by surface finish attained. The factors which affect the surface finish are feed rate, cutting velocity, cutting fluid, tool nose radius and rake angles, out of which feed rate is the most influential.

Tool wear is another important factor to be taken into consideration while machining. Cutting velocity is seen to have the most dominating effect on tool wear. Different methods have been used to correlate tool wear and surface finish with acoustic emission and noise and some mathematical models have also been developed.

2.5 Gaps in Literature

As explained earlier, it is understood that there is a need to take noise levels into consideration in CNC machining. Noise levels can either be reduced so as to provide a better working environment to the operators on the shop floor; or they can be utilized for online monitoring of machining conditions or further as an indicator of surface finish levels if a correlation can be achieved between them.

From the previous studies, it is observed that most of the work has been done on chatter and vibration studies in CNC turning, but not much work has been done that focuses directly on noise. Most of the research and existing monitoring systems based on acoustic emission, vibration, et cetera are limited to tool fracture and wear. Limited work has been done on the monitoring of surface roughness. Limited work has been done on the correlation of noise levels with surface finish during machining.

CHAPTER 3
METHODOLOGY

3.1 Introduction

The objective identified was to study the surface finish of the machined surface along with the noise generated during a CNC turning operation. Machining was performed with varying levels of cutting velocity (v), feed rate (f) and depth of cut (d); and sound level and surface roughness were measured and studied. The specifications of the material and equipment used in carrying out these experiments along with the procedure followed have been systematically presented in this chapter.

3.2 Experimental Setup

The description and setup of the machine and equipment used to carry out the experiments are explained systematically in this section. The experimental setup is shown in the following figure:

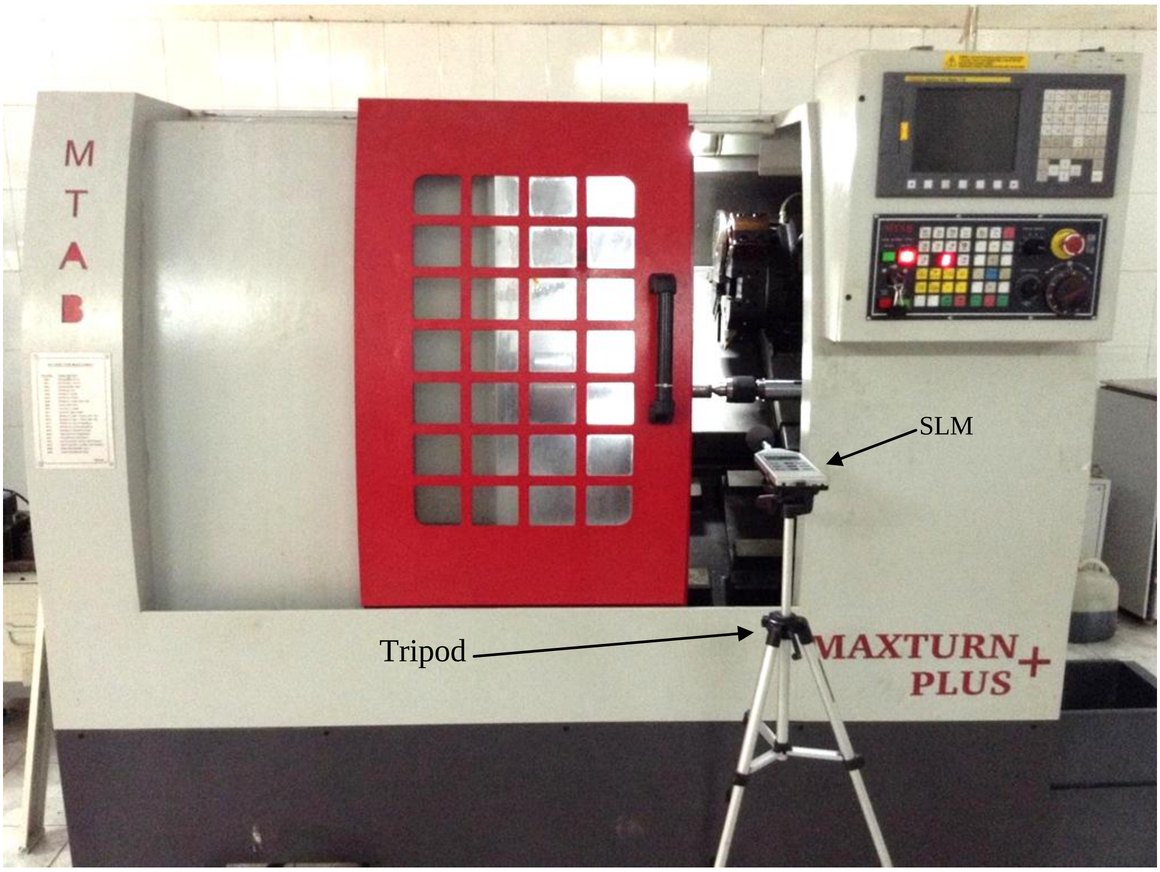

Figure 3.1: CNC turning centre with a sound level meter (SLM) in front resting on the tripod

3.2.1 CNC turning centre

The experiments were performed on a CNC turning centre manufactured by MTAB. The model name is MAXTURN PLUS+. The machining can be done both manually and automatically on this machine. For automated machining, a program needs to be fed to the computer. The technical specifications of MAXTURN PLUS+ are given in table 3.1.

Table 3.1: Specifications of MAXTURN PLUS + turning centre manufactured by MTAB

Capacity	
Size of chuck (hydraulic)	165 mm
Max. turning dia.	235 mm
Max. turning length	360 mm
Number of axes	2
Distance b/w centers	380 mm
Spindle	
Hole through spindle	52 mm
Range of Spindle speed	150 – 6000 RPM
Spindle motor	AC Servo
Tooling & Turret	
No. of stations	8 tools (BTP 80)
Cross section of tool	25 x 25 mm
Boring bar diameter	40 mm

Axes	
Travel in X axis	140 mm
Travel in Y axis	380 mm
Axis motor (X and Z axis)	AC Servo motors
Axis motor torque	7 Nm
Machine Dimensions	
L x W x H (mm)	2300 x 1600 x 2100
Lubrication system	Automatic lubrication
Weight	3000 kg (approximately)
Power Source	
Main power supply	415V ± 2% 50Hz, 3 Phase
CNC Details	
Control	SIEMENS / FANUC

3.2.2 Sound level meter

The measurement of sound level and frequency spectrum was done using the Sound Level Meter. The SC310 model SLM was used for the measurements of sound. It is basically a type 1 integrating sound level meter and is quite user-friendly. It can be used both as a sound level meter or a real time spectral analyser and can measure both 1/1-octave bands and 1/3 octave bands. It can measure all the functions concurrently, with all types of frequency weightings. It has one single range of 23 - 137dBA. The range for spectral analyzer is 31.5 Hz to 16 kHz for whole octave band and 20 Hz to 10 kHz for one third octave band.

The free memory space can be also configured as a circular memory. It is also possible to download data simultaneously to its storage. These features make this instrument a suitable platform for permanent acoustic monitoring.

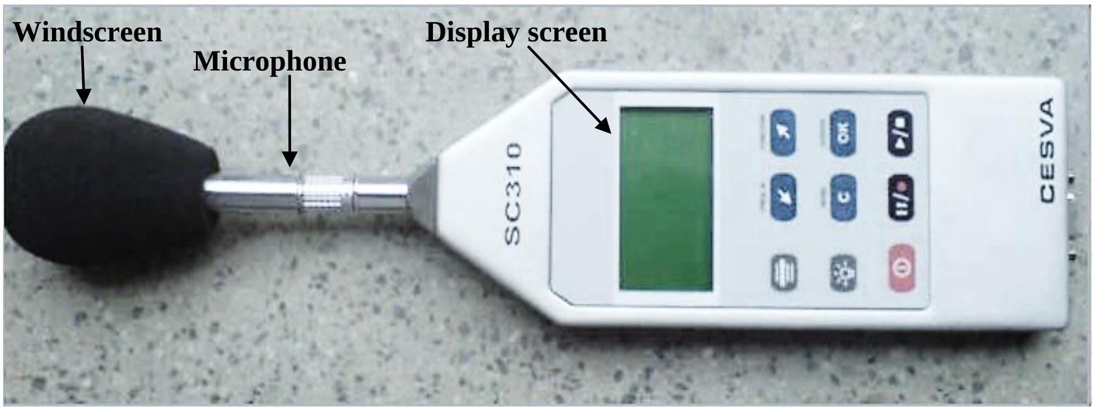

Figure 3.2: Sound Level Meter

3.2.3 Surface roughness tester

The measurement of surface roughness (Ra) was done with a surface roughness tester. It assesses surface finish using a stylus. The stylus is drawn along the surface to be measured and the motion of the stylus in perpendicular direction of the surface is registered. The profile thus registered is then used for calculating the roughness parameters.

The instrument used was Mitutoyo SJ-400 model. The SJ-400 Series detector uses interchangeable nosepieces such that skid or skid-less measurements can be taken depending upon the requirement.

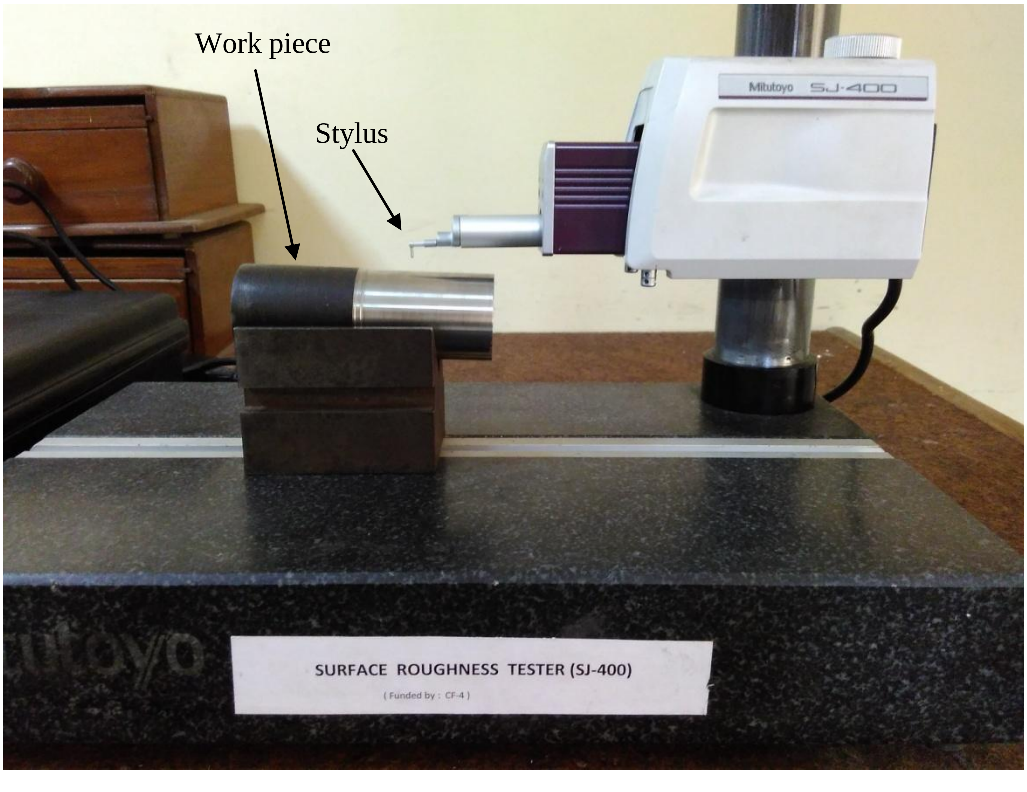

Figure 3.3: Surface roughness tester

Table 3.2 Specifications of surface roughness tester

Measuring Method	Skidless / Skid Measurement
Cut-off length	0.08, 0.25, 0.8, 2.5, 8mm
Measuring Speed	0.05, 0.1, 0.5, 1.0mm/s
Returning Speed	0.5, 1.0, 2.0 mm/s
Measuring Range	800µm, 80µm, 8µm
Detection method	Differential inductance method
Minimum resolution	0.000125µm
Stylus tip	Corn 90°, Radius 5µm, Diamond
Measuring force	4mN
Positioning	±1.5° (tilting), 10mm (up/down)

3.3 Experimental Plan

The selection of work material, cutting tool and cutting fluid along with their specifications have been explained in this section. Furthermore, the range of the operating parameters for experimentation has also been discussed.

3.3.1 Selection of work material

The material of the work was chosen to be EN 19 (AISI 4140) for its wide application in the metalworking industry. It is an alloy steel of high quality, well-known for its resistance to wear properties, good ductility and shock resistance. This material is suitable for making tool bodies, connecting rods, jigs, bolts, crankshafts, axle shafts and piston rods, studs and a wide range of other applications where a high tensile steel grade of good quality is required. The chemical composition of this material is given in tables 3.2 and mechanical properties in table 3.3. There were 27 round bars of EN 19 steel on which the experiments were performed.

Table 3.3: Chemical Composition of EN-19

Material	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Co	Cu	Pb	Sn	B	V
Wt %	97.3	0.4	0.26	0.57	0.03	0.19	0.90	0.19	0.16	0.01	0.05	0.02	0.03	0.02	0.04

Table 3.4: Mechanical properties of EN 19

Property	**Range**
Yield Stress	700 N/mm^2 (min.)
Max Stress	850-1000 N/mm^2
0.2% Proof Stress	680 N/mm^2 (min)
Impact KCV	55 Joules (min)
Elongation	9% (min)
Hardness	248-302 HB

Figure 3.4: Round bar of EN 19 steel workpiece

3.3.2 Selection of cutting tool

A single point cutting tool with indexable inserts was selected for machining. The inserts were Al_2O_3-TiCN mixed ceramic inserts having PVD TiN coating (as shown in figure 3.5); manufactured by Sandvik Coromant; model TNGA 160408S01525; grade 6050; having nose radius 0.8 mm. These inserts are chemically inert, stable, moderately inexpensive, and extremely resistant to heat. For these reasons this tool material was found suitable for machining of hard materials such as hardened EN19 steel, for which temperature elevation during machining is quite high. The tool holder used was MT JNL 2525- M16 model; manufactured by TRU-HOLD cutting tools and having a cutting angle of 93º.

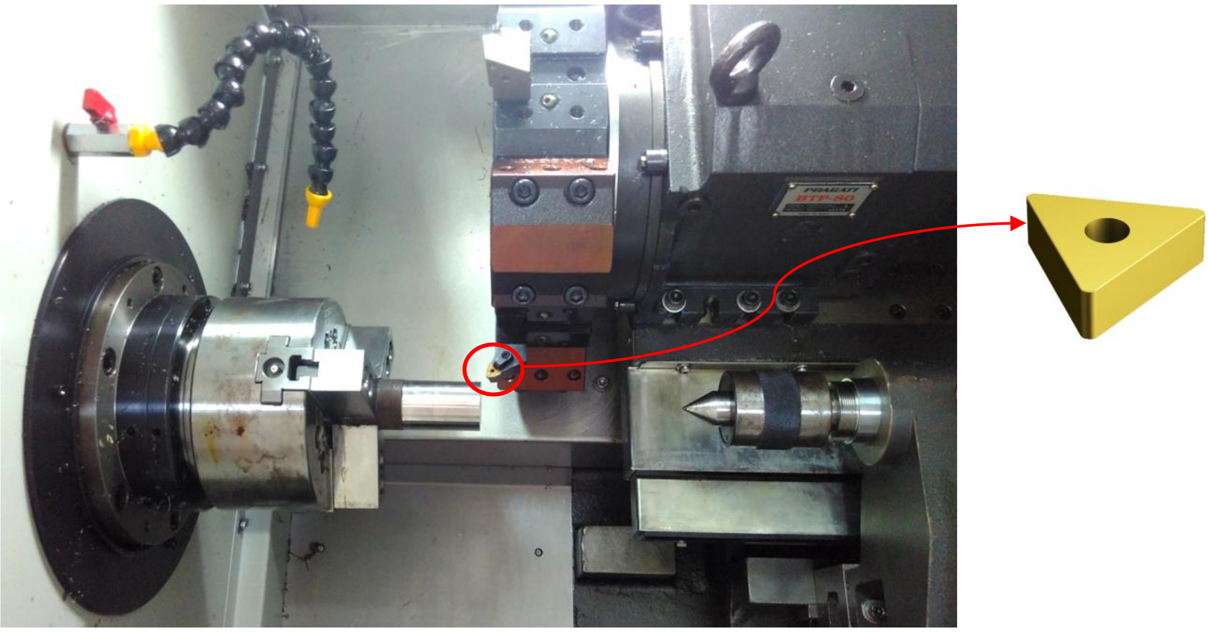

Figure 3.5 : Arrangement of tool and work piece in CNC turning centre with magnified view of mixed ceramic insert

3.3.3 Selection of cutting fluid

The cutting fluid used was Houghton Hocut B50S general purpose semi-synthetic metalworking coolant.

Hocut B50S is a combination of severely refined mineral oils, boron amine long life additives and corrosion inhibitors. Upon dilution, we get a translucent emulsion that offers excellent sump life and good machining characteristics.

Most metals and alloys can be effectively machined with emulsions and offer a good inter-stage corrosion protection. This micro fine semi-synthetic emulsion has brilliant detergency which keeps machines clean and is particularly effective for machining of cast iron.

This coolant has many advantages like low foaming, long sump life, and chemical stability and offers good corrosion protection. It is cost-effective, secondary amine-free, chlorine-free and biocide-free. Recommendations for use are 4% - 6% of oil in water for general machining. In this study, 5% oil in water mixture was used.

3.3.4 Selection of operating parameters

The variable operating parameters were cutting velocity (v), feed (f) and depth of cut (d). The range for these parameters has been derived from the published literature [6] where turning operations were performed for dry conditions. The optimum surface finish according to the literature was attained at speed 170 m/min, feed 0.05 mm/rev and cut depth 0.20 mm. These values were taken as the central values and the operating parameters were varied for three levels as shown below:

Table 3.5: Selected values of operating parameters

Parameters	**Levels**		
	1	**2**	**3**
v (m/min)	160	170	180
f (mm/rev)	0.025	0.050	0.075
d (mm)	0.15	0.20	0.25

The design of experiment followed was the Full Factorial Design, which has been explained in details in the next section. On applying the Full Factorial Design for these values, the following combinations of experimental runs were obtained:

Table 3.6: Combinations of parameters based on full factorial design

Exp no.	v (m/min)	f (mm/rev)	d (mm)
1	160	0.025	0.15
2	160	0.050	0.15
3	160	0.075	0.15
4	170	0.025	0.15
5	170	0.050	0.15
6	170	0.075	0.15
7	180	0.025	0.15
8	180	0.050	0.15
9	180	0.075	0.15
10	160	0.025	0.20
11	160	0.050	0.20
12	160	0.075	0.20
13	170	0.025	0.20
14	170	0.050	0.20
15	170	0.075	0.20
16	180	0.025	0.20
17	180	0.050	0.20
18	180	0.075	0.20
19	160	0.025	0.25
20	160	0.050	0.25
21	160	0.075	0.25
22	170	0.025	0.25
23	170	0.050	0.25
24	170	0.075	0.25
25	180	0.025	0.25
26	180	0.050	0.25
27	180	0.075	0.25

3.4 Design of Experiment

Design of Experiment is an organised method that involves designing a set of experiments, in which specified process parameters are varied analytically so as to help find a relationship between the varying parameters and some output(s). The results obtained from these experiments help to identify optimum operating conditions, the factors that most influence the results, and those that do not and other things such as interactions between different factors. The design of experiments selected for this study was the Full Factorial Design in which all the possible combinations of all the input parameters are formed.

3.4.1 Full factorial design with two and three levels

For a two level design, all input factors are considered and set at two levels viz. `low' and `high' having the codes `-1' and `+1' respectively. If a total of k factors are there, each having 2 levels, then there will be a total of 2^k runs. If each factor has 3 levels then it is known as a 3^k factorial design. The low, intermediate and high levels are numerically denoted by 0, 1, and 2 respectively.

3.4.2 The 3^3 design

As the name suggests, this design consists of 3 factors, each at 3 levels. There are 27 treatments in this model. Let's say there are three factors A, B and C all having levels 0, 1 and 2, then the combinations may be displayed as shown in table 3.7.

Table 3.7: The 3^3 Design

Factor- A	**Factor- B**	**Factor- C**		
		0	**1**	**2**
0	**0**	000	100	200
0	**1**	001	101	201
0	**2**	002	102	202
1	**0**	010	110	210
1	**1**	011	111	211
1	**2**	012	112	212
2	**0**	020	120	220
2	**1**	021	121	221
2	**2**	022	122	222

3.4.3 Analysis of variance

Analysis of variance (ANOVA) is a test of hypothesis that is apt for comparing means of a continuous variable in two or more comparison groups that are independent of each other. ANOVA is used in experiments where we are interested in knowing the difference of outcomes. The statistical significance of the experiment is determined by a ratio of two variances. The measure of variance is given as follows:

$$Variance = \frac{Sum\ of\ squares\ of\ deviations}{Degree\ of\ freedom\ of\ factor} \qquad 3.1$$

The following things need to be determined in order to carry out ANOVA:

1) Sum of squares

2) Degree of freedom

Sums of Squares help in the calculation of the variance estimates presented in ANOVA tables. They are used to form the mean squares by dividing them with their respective degree of freedom.

F-Value: This can be described as the ratio of two dissimilar measures of variance. When we consider the null hypothesis as real, then both these approximations of similar entities and their ratios would be one.

F-critical value: It is the tabular value of the F distribution that is based on the selected α level and the degree of freedom.

p-Value: The *p*-value is an observed function of the samples that results relative to a statistical model, which measures how extreme the observation is.

3.5 Experimental Procedure

The different steps taken in performing the experimental study and analysis are described below.

I. Initially, heat treatment of the work piece materials was done at 900 ºC for about 30 minutes and then they were oil quenched in ENCLO 68 hydraulic oil. Thereafter, tempering was done at a temperature of 400 ºC for two hours, after which it was cooled. This eliminates the residual stresses and helps achieve a homogeneous structure. After the heat treatment, a hardness of 50 HRC was obtained.

II. Then, turning operations were performed on those work pieces in different combination of parameters which are

   1) Cutting velocity
   2) Feed
   3) Depth of cut

III. The DOE employed was full factorial design which produced sets of combinations of these parameters. A total of 27 experiments were performed.

IV. Prior to performing each experiment, it was ensured that all the fans and air conditioners were switched off and the doors of the lab were closed properly to eliminate unnecessary background noise. While performing the turning operations, measurement of sound was done for each run using a sound level meter. The SLM was calibrated before every recording.

V. After machining, surface roughness for each work piece was measured using the surface roughness tester.

VI. The SLM was connected to a computer and all the recorded data were transferred for analysis using the software Cesva Capture Studio.

VII. Data was collected showing equivalent sound level values on A-scale and Z-scale as well as average surface roughness values (Ra) corresponding to different combination of parameters.

VIII. On the basis of design of experiment, ANOVA was applied on the collected using Minitab software. Also, frequency spectrum analysis was done for each run.

IX. Optimal parameters were found for achieving low sound level and low surface roughness.

X. Also a statistical model was made using regression for estimation of surface roughness based on the operating parameters.

CHAPTER 4
RESULTS AND DISCUSSION

After all the measurements are done, it is required to study the effect of the different operating parameters on the sound level obtained along with the surface finish achieved for the turning operations performed.

4.1 Experimental Determination Of Surface Roughness And Noise Levels

The combination of values of cutting velocity, feed and depth of cut for the experimental runs was determined in previous chapter and surface roughness measurements of the machined components were taken for those runs.

Table 4.1: Values of Equivalent Sound Level in A-weighting and Z-weighting scale

S.No.	Speed (mm/min)	Feed (mm/rev)	DOC (mm)	Ra (µm)	L_A (db)	L_Z (db)
1	160	0.025	0.15	0.39	77.6	82.9
2	160	0.05	0.15	0.62	80.4	83.8
3	160	0.075	0.15	0.89	77.2	82.2
4	170	0.025	0.15	0.25	75.2	81.9
5	170	0.05	0.15	0.51	77.2	81.9
6	170	0.075	0.15	0.7	77.7	82.5
7	180	0.025	0.15	0.31	76.2	80.9
8	180	0.05	0.15	0.47	77.4	83.1
9	180	0.075	0.15	0.36	77.9	81.7
10	160	0.025	0.2	0.25	76.8	80.1
11	160	0.05	0.2	0.69	77.8	83.4
12	160	0.075	0.2	0.81	76.7	81.9
13	170	0.025	0.2	0.3	77	82.4
14	170	0.05	0.2	0.53	78.1	84.7
15	170	0.075	0.2	0.63	79	88.9
16	180	0.025	0.2	0.27	78.2	82.9
17	180	0.05	0.2	0.39	83.6	84.7
18	180	0.075	0.2	0.27	78.9	84.4
19	160	0.025	0.25	0.4	77.2	80.6
20	160	0.05	0.25	0.61	77.6	83
21	160	0.075	0.25	0.8	75.9	83.1
22	170	0.025	0.25	0.2	77.6	82.6
23	170	0.05	0.25	0.42	78.9	84.2
24	170	0.075	0.25	0.59	79.8	86.8
25	180	0.025	0.25	0.28	78.1	82.7
26	180	0.05	0.25	0.37	78.7	84.4
27	180	0.075	0.25	0.16	78.7	87.3

For each experiment, the work piece was machined three times and the average value of surface roughness for each experiment was obtained. From the data recorded in the SLM, equivalent sound levels in A-weighted scale and in z-scale were also obtained. The values of all these response parameters are shown in the table below 4.1.

From the surface roughness values achieved for different runs, it has been observed that better surface finish has been achieved for the same work and tool material under wet lubrication conditions as compared to the previous work done [6] under dry cutting conditions.

4.2 Analysis Of Variance For Surface Roughness

The measured surface roughness values were collected. Using the MINITAB software and on the basis of full factorial design of experiments, ANOVA for mean of surface roughness and F-test was done. Following that, regression was applied and a statistical model was obtained. The ANOVA table has been presented in table 4.2:

Table 4.2: Analysis of Variance for Ra

Source	Degree of freedom	Sequential Sum of Squares	Adjusted Mean Square	F value	p-value
$\boldsymbol{v}$	2	0.369919	0.184959	87.92	< 0.0001
$\boldsymbol{f}$	2	0.398341	0.199170	94.68	< 0.0001
$\boldsymbol{d}$	2	0.024985	0.012493	5.94	0.0262
$\boldsymbol{v \times f}$	4	0.230815	0.057704	27.43	0.0001
$\boldsymbol{f \times d}$	4	0.011304	0.002826	1.34	0.3339
$\boldsymbol{v \times d}$	4	0.014215	0.003554	1.69	0.2446
Error	8	0.016830	0.002104		
Total	26	1.066407			

The regression equation obtained is as follows:

$$R_a = -3.15 + 0.0192v + 96.8f + 7.16d - (0.510v \times f) - (22.0f \times d) - (0.04v \times d) \quad 4.1$$

(Where v = cutting velocity, d =depth of cut, f =feed rate)

With R^2 = 90.8% and R^2 (adj) = 88.0%

The R^2 value of 90.8% depicts that good agreement is there between the experimental values and predicted values of the model.

From table 7, we gather that speed, feed, depth of cut and the interaction between speed and feed are the significant variables.

The percent contribution of each factor affecting surface roughness is shown in figure 4.1.

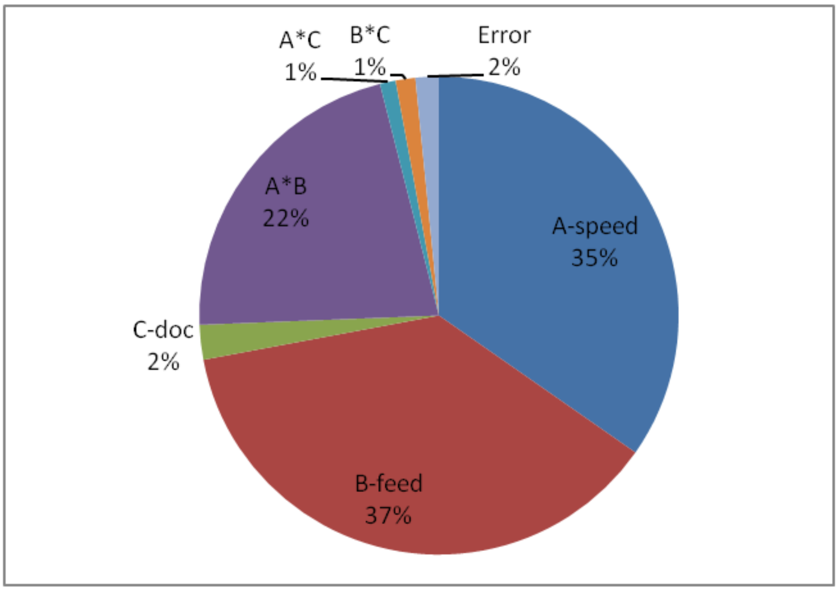

Figure 4.1: Contribution percentage of variables

The main effect of the input parameters can be represented graphically as shown in figure 4.2.

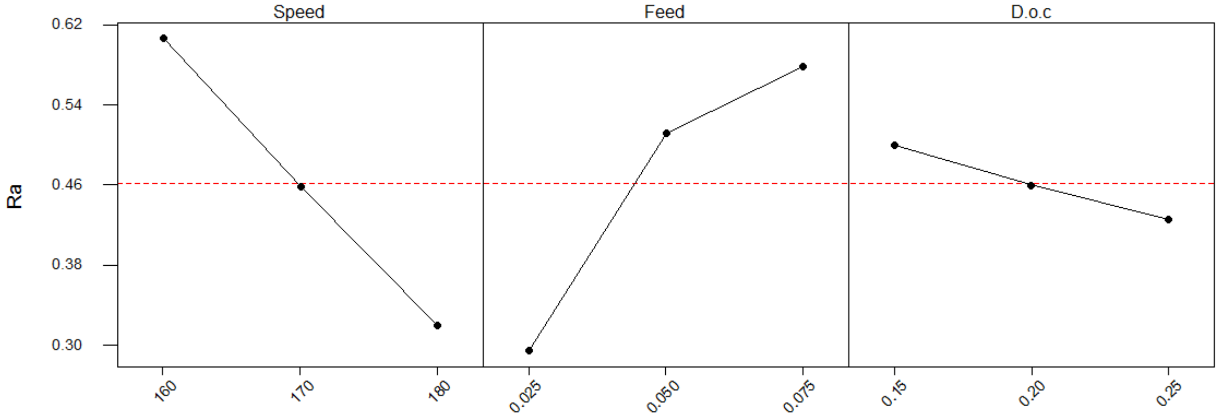

Figure 4.2: Main Effect Plots for surface roughness (Ra)

In the above graphs, the mean values of surface roughness (Ra) at various levels of machining parameters are shown. From the graph of surface roughness plotted against speed, it is clear that with an increase in the value of cutting speed from 160 m/min to 180 m/min, the roughness value decreases. From the graph of surface roughness plotted against feed, it is seen that with an increase in feed from 0.025 mm/rev to 0.075 mm/rev, the roughness also increases. From the graph of surface roughness against depth of cut, it is observed that there is a slight decrease in the surface roughness with an increase in the value of depth of cut from 0.025mm to 0.075mm.

4.3 Analysis Of Sound Level And Comparison With Surface Roughness

Background correction factor had to be applied to the values of sound level to eliminate the influence of background noise on the results as the difference between noise generated without machining and while machining was found to be less than 10 dB for almost all values. The formula used for correction of these values is as follows:

$$Corrected\ L_A = 10 \times \log[(10^{L_A}) - (10^{L_Awm})] \qquad 4.2$$

The corrected values for L_A are shown in the table 4.4.

Table 4.3: Corrected values of L_A

S.No.	v (m/min)	f (mm/rev)	d (mm)	Ra (μm)	L_A (dB)	L_Awm (dB)	ΔL_A (dB)	Corrected L_A (dB)
1	160	0.025	0.15	0.39	77.6	73	4.6	75.7
2	160	0.05	0.15	0.62	80.4	73	7.4	79.5
3	160	0.075	0.15	0.89	77.2	73	4.2	75.1
4	170	0.025	0.15	0.25	75.2	73.5	1.7	70.3
5	170	0.05	0.15	0.51	77.2	73.5	3.7	74.7
6	170	0.075	0.15	0.7	77.7	73.5	4.2	75.6
7	180	0.025	0.15	0.31	76.2	73.9	2.3	72.3
8	180	0.05	0.15	0.47	77.4	73.9	3.5	74.8
9	180	0.075	0.15	0.36	77.9	73.9	4	75.6
10	160	0.025	0.2	0.25	76.8	73	3.8	74.4
11	160	0.05	0.2	0.69	77.8	73	4.8	76.0
12	160	0.075	0.2	0.81	76.7	73	3.7	74.2
13	170	0.025	0.2	0.3	77	73.5	3.5	74.4
14	170	0.05	0.2	0.53	78.1	73.5	4.6	76.2
15	170	0.075	0.2	0.63	79	73.5	5.5	77.5
16	180	0.025	0.2	0.27	83.8	73.9	4.3	83.3
17	180	0.05	0.2	0.39	89.1	73.9	9.7	88.9
18	180	0.075	0.2	0.27	78.9	73.9	5	77.2
19	160	0.025	0.25	0.4	77.2	73	4.2	75.1
20	160	0.05	0.25	0.61	77.6	73	4.6	75.7
21	160	0.075	0.25	0.8	75.9	73	2.9	72.7
22	170	0.025	0.25	0.2	77.6	73.5	4.1	75.4
23	170	0.05	0.25	0.42	78.9	73.5	5.4	77.4
24	170	0.075	0.25	0.59	79.8	73.5	6.3	78.6
25	180	0.025	0.25	0.28	78.1	73.9	4.2	76.0
26	180	0.05	0.25	0.37	78.7	73.9	4.8	76.9
27	180	0.075	0.25	0.16	78.7	73.9	4.8	76.9

After obtaining the corrected values of L_A they were compared with the corresponding values of surface roughness and a graph was plotted are shown in the figure 4.3.

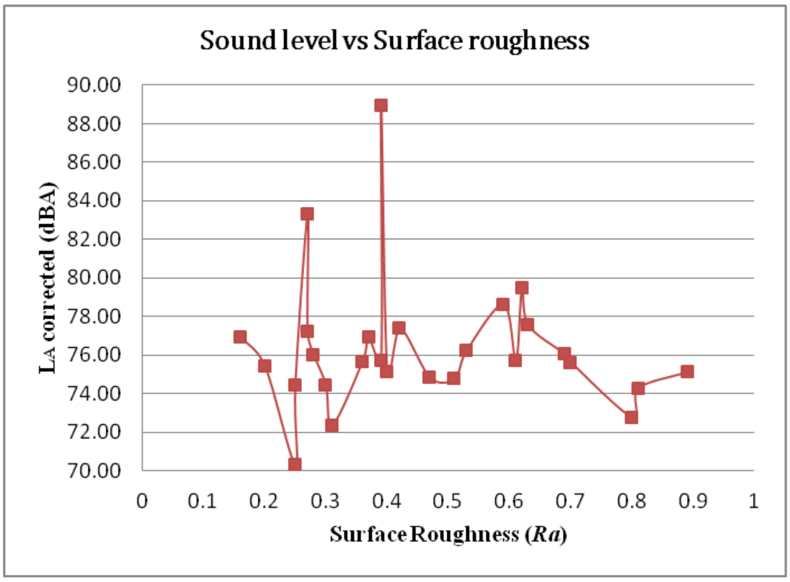

Figure 4.3: Graph of A-weighted sound level against surface roughness

Similarly, the background noise correction was done for Z-scale values as well because it is a flat frequency response and helps to compare the absolute values of sound level. Then they were compared with their corresponding surface roughness values. The formula used for correction of L_Z values is as follows:

$$Corrected\ L_Z = 10 \times \log[(10^{L\,z}) - (10^{Lzwm})] \qquad 4.3$$

The corrected values of L_Z are as shown in table 4.5 and the graph of surface roughness against L_Z is shown in figure 4.4.

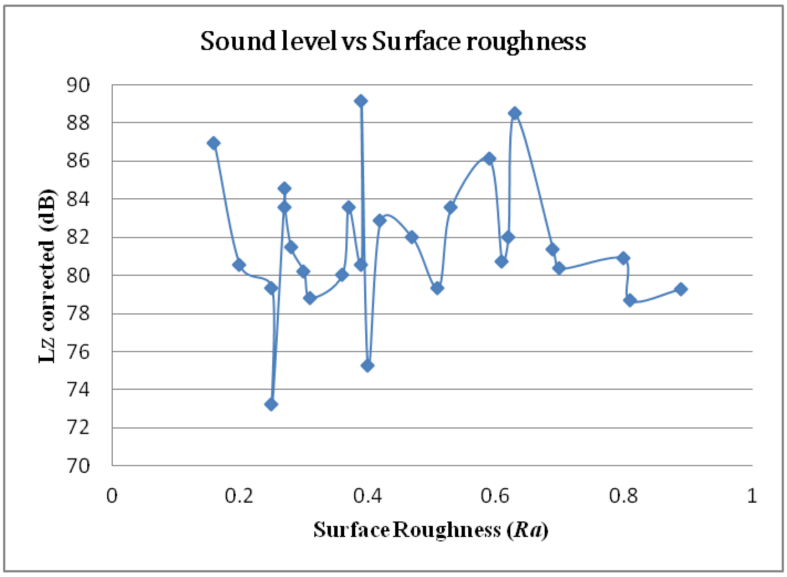

Figure 4.4: Graph of z-scale sound level against surface roughness

Table 4.4: Corrected values of L_Z

S.No.	v (m/min)	f (mm/rev)	d (mm)	Ra (µm)	L_Z (dB)	L_Zwm (dB)	ΔL_Z (dB)	Corrected L_Z (dB)
1	160	0.025	0.15	0.39	82.9	79.1	3.8	80.5
2	160	0.05	0.15	0.62	83.8	79.1	4.7	82.0
3	160	0.075	0.15	0.89	82.2	79.1	3.1	79.2
4	170	0.025	0.15	0.25	81.9	78.4	3.5	79.3
5	170	0.05	0.15	0.51	81.9	78.4	3.5	79.3
6	170	0.075	0.15	0.7	82.5	78.4	4.1	80.3
7	180	0.025	0.15	0.31	80.9	76.7	4.2	78.8
8	180	0.05	0.15	0.47	83.1	76.7	6.4	81.9
9	180	0.075	0.15	0.36	81.7	76.7	5	80.0
10	160	0.025	0.2	0.25	80.1	79.1	1	73.2
11	160	0.05	0.2	0.69	83.4	79.1	4.3	81.3
12	160	0.075	0.2	0.81	81.9	79.1	2.8	78.6
13	170	0.025	0.2	0.3	82.4	78.4	4	80.1
14	170	0.05	0.2	0.53	84.7	78.4	6.3	83.5
15	170	0.075	0.2	0.63	88.9	78.4	10.5	88.9
16	180	0.025	0.2	0.27	82.9	76.7	6.2	81.7
17	180	0.05	0.2	0.39	84.7	76.7	8	83.9
18	180	0.075	0.2	0.27	84.4	76.7	7.7	83.5
19	160	0.025	0.25	0.4	80.6	79.1	1.5	75.2
20	160	0.05	0.25	0.61	83	79.1	3.9	80.7
21	160	0.075	0.25	0.8	83.1	79.1	4	80.8
22	170	0.025	0.25	0.2	82.6	78.4	4.2	80.5
23	170	0.05	0.25	0.42	84.2	78.4	5.8	82.8
24	170	0.075	0.25	0.59	86.8	78.4	8.4	86.1
25	180	0.025	0.25	0.28	82.7	76.7	6	81.4
26	180	0.05	0.25	0.37	84.4	76.7	7.7	83.5
27	180	0.075	0.25	0.16	87.3	76.7	10.6	87.3

It is clear from the above graphs that there is no direct correlation of the surface roughness with sound level in A-weighting or sound level in Z-weighting. Pearson correlation values were calculated using MINITAB software. The values for pearson correlation range from +1 to -1. If a value of 0 is obtained, it means that no relationship exists among the variables. A value larger than 0 it implies that a positive correlation exists. A value less than 0 implies that a negative correlation is there which means that if the value of one factor increases, the value of the other will decrease.

Pearson correlation values between sound level and surface roughness are as follows:-

- Pearson correlation of Ra and L_A corrected = -0.045
- Pearson correlation of Ra and L_Z corrected = -0.009

These values indicate that there is negative correlation between sound level and surface roughness.

4.4 Analysis of frequency spectrums

Since no direct correlation between the surface roughness and sound level was obtained, the frequency spectrums of 1/1 octave band were analyzed for each run. The graphs of frequency spectrum are shown in figures.

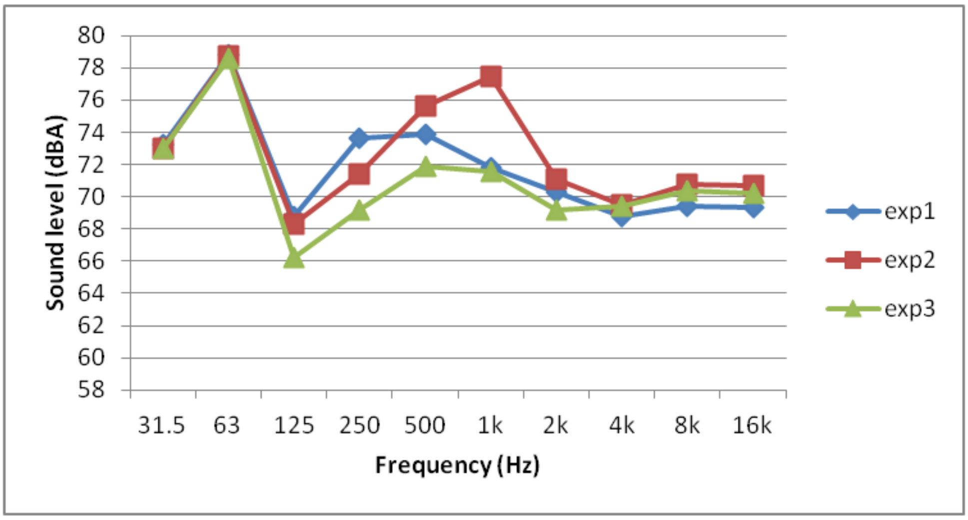

Figure 4.5: Frequency spectrums for experiments 1, 2, 3

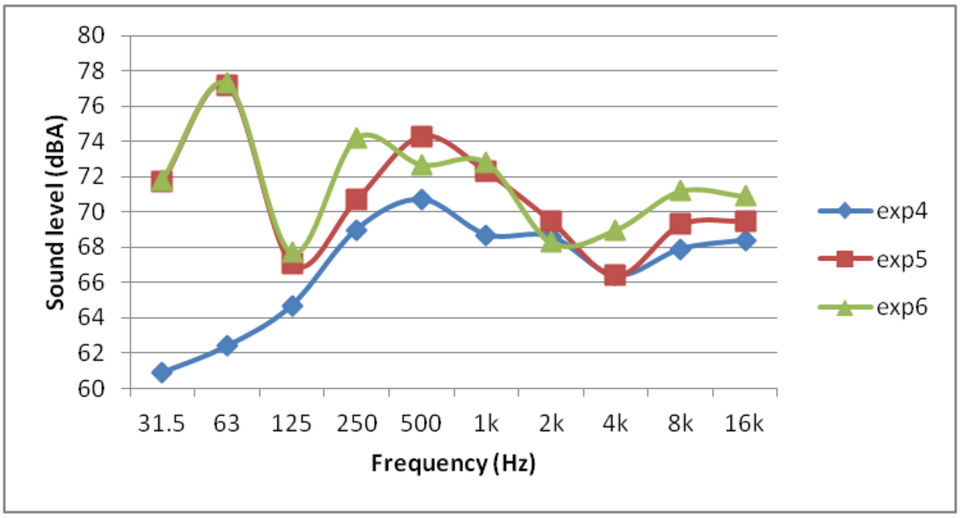

Figure 4.6: Frequency spectrums for experiments 4, 5, 6

The first nine experiments which have the same depth of cut (0.15 mm) are divided into three groups each having the same cutting speed within the group and varying feed. These are shown in figures 4.5, 4.6 and 4.7. It is observed from these graphs that high peak is observed in almost every case at 63 Hz except when the speed is 170m/min with feed 0.025mm/rev where sound level is extremely low for low frequencies. Peaks were also seen in the mid frequency range. Thereafter a dip is observed in the high frequency range.

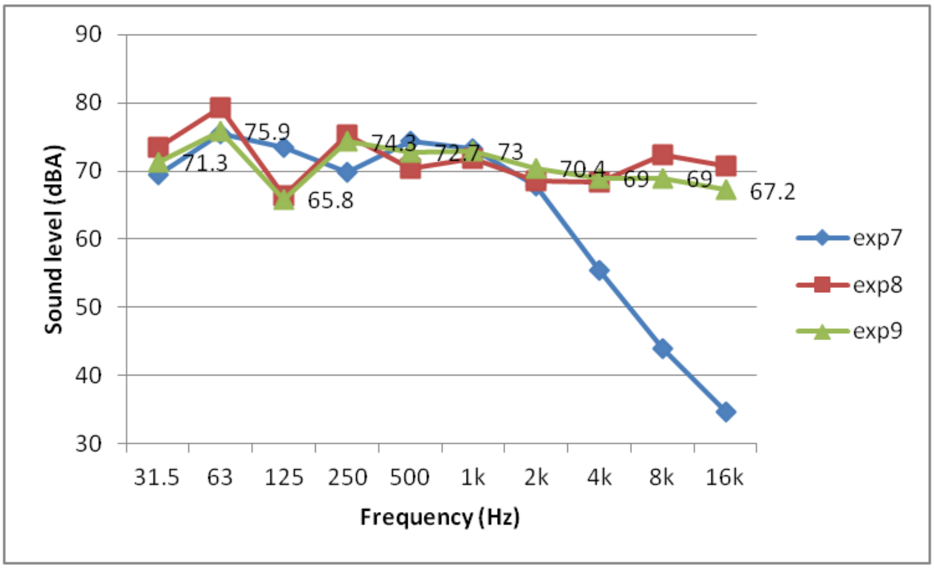

Figure 4.7: : Frequency spectrums for experiments 7, 8, 9

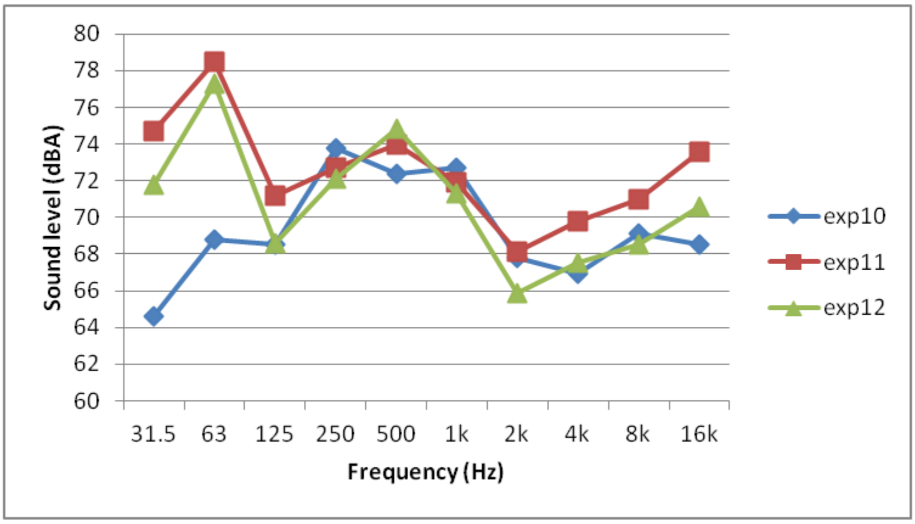

Figure 4.8: Frequency spectrums for experiments 10, 11, 12

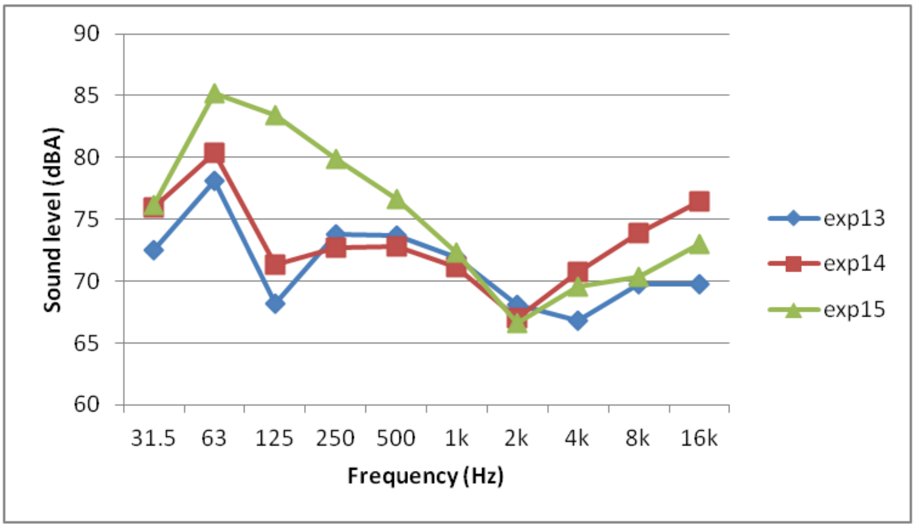

Figure 4.9: Frequency spectrums for experiments 13, 14, 15

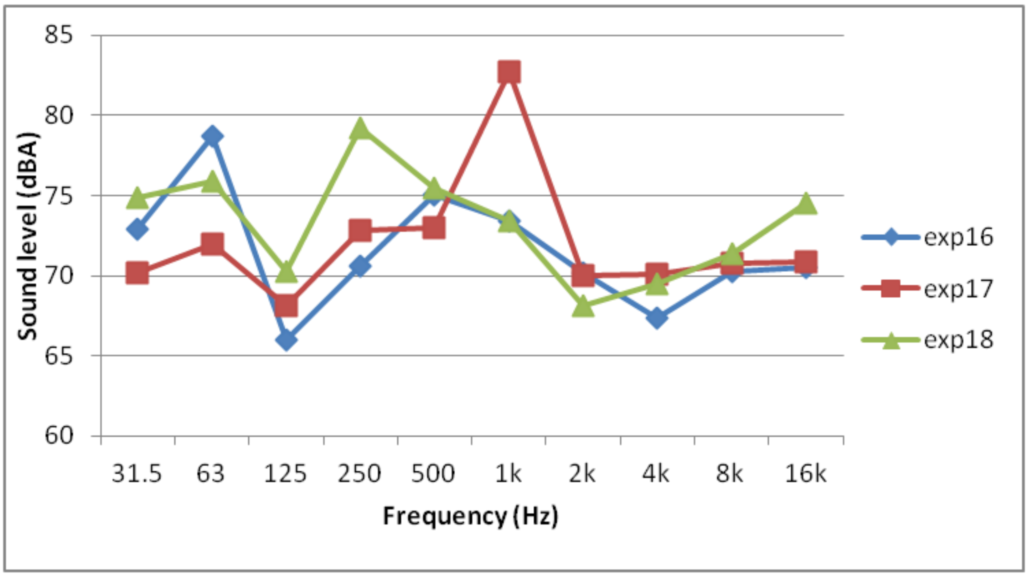

Figure 4.10: Frequency spectrums for experiments 16, 17, 18

Similarly, the next nine experiments having the same depth of cut (0.20 mm) were divided in three groups having the same cutting speed, but varying feed within the group as shown in figures 4.8, 4.9 and 4.10. It is observed from these graphs that in this case also, the high peaks are obtained specifically at 63Hz and in the mid frequency range. A dip is observed after that with a slight peak again specifically at 16k Hz, though this increase is minimal for the speed 180 m/min. This shows that with an increase in the level of depth of cut, peaks are obtained even at high frequency range.

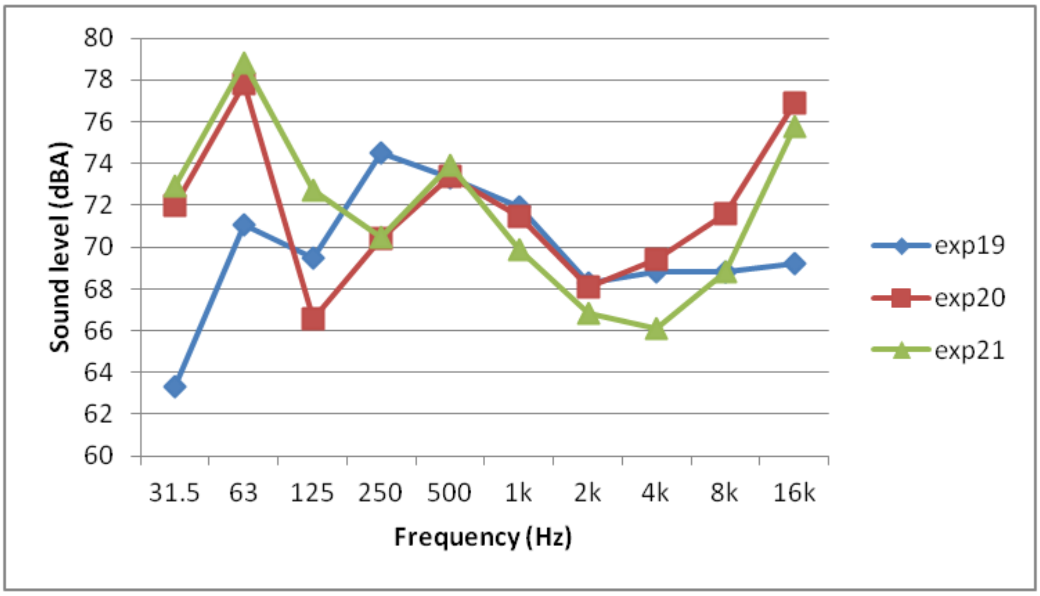

Figure 4.11: Frequency spectrums for experiments 19, 20, 21

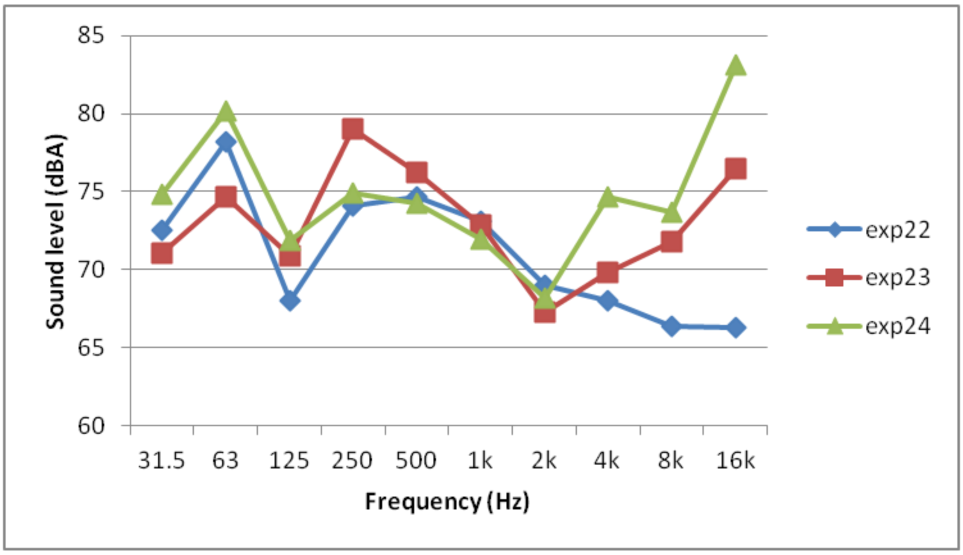

Figure 4.12: Frequency spectrums for experiments 22, 23, 24

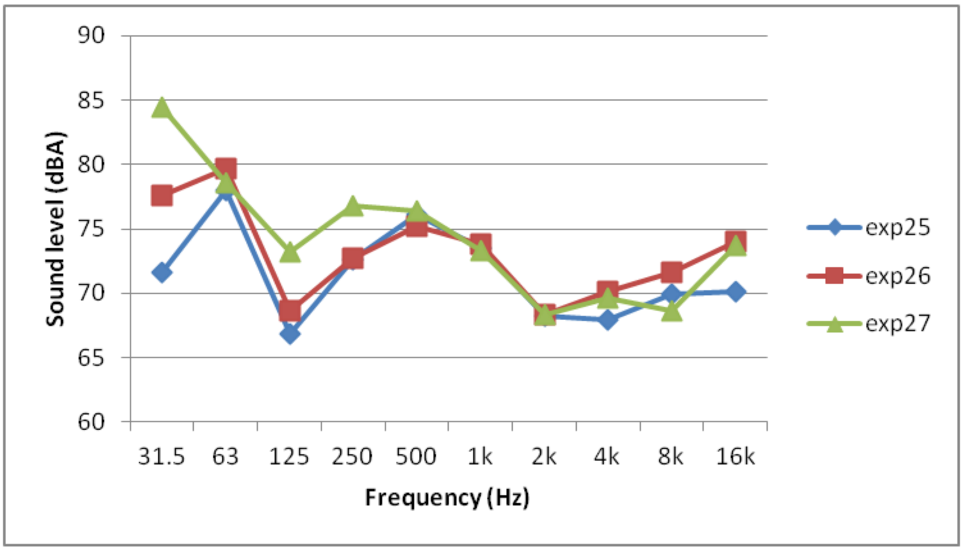

Figure 4.13: Frequency spectrums for experiments 25, 26, 27

The last nine experiments were grouped in the similar manner. From the graphs shown in figures 4.11, 4.12 and 4.13, we again see that high peaks were observed at 63 Hz and in the mid frequency range, followed by a dip and an increase in the sound level at 16k Hz except for when the speed is 180m/min.

It is evident from the above graphs that the high peaks are obtained in the low frequency zone in almost all the cases. Therefore, sound absorbing materials which have higher absorption coefficient at the lower frequencies can be selected while designing noise barriers or planning noise mitigation strategies.

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

In the present study, hard turning was performed on EN 19 steel using Al_2O_3-TiCN mixed ceramic inserts with PVD TiN coating, in wet machining condition. The operating parameters varied were cutting speed, feed and depth of cut. The response parameters measured were surface roughness and sound level. The full factorial design was employed and a total of 27 experiments were performed. After taking the measurements as explained in the previous chapters and doing the analysis, the following conclusions were drawn:-

1. From the main effect plots, it is understood that surface roughness is mainly affected by feed and speed whereas the depth of cut has an insignificant impact on it. Roughness of the surface of work piece increases with an increase in feed and decreases with an increase in cutting speed.
2. It is clear from ANOVA results that feed is the major variable affecting surface roughness with a contribution of 37%, followed by speed with a contribution of 35%. The interaction effects between speed and feed are also significant with a 22% contribution.
3. The best surface finish (0.16 µm) was attained at cutting speed of 180 m/min, feed of 0.075 mm/rev and depth of cut of 0.25mm.
4. On comparing the values of sound level (after applying background correction factor) with the surface roughness values, it was seen that no direct correlation existed between the two responses.
5. The lowest sound level (70.3 dBA) was obtained for cutting speed of 170m/min, feed of 0.025mm/rev and depth of cut of 0.15mm. The surface roughness (Ra) for this combination is 0.25 µm. This value is quite close to the lowest roughness obtained i.e. 16 µm which gives a sound level of 76.9 dBA. So if there is a requirement of low sound level and the corresponding surface finish is acceptable, this combination can be employed.

5.2 Future Scope

The present work can be extended in different directions. Some of them are listed below:

1. The present work can be extended for analyzing the effect of cutting forces and temperature of the coolant and even higher cutting speeds. Other factors such as tool nose radius can also be taken into account.
2. This study can also be conducted for varying work material and tool inserts.
3. The cause of the high peaks observed in the low frequency range can be studied, and control measures can be considered to reduce the noise.

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