Thesis

On

INVESTIGATION OF NOISE GENERATED DURING TURNING OPERATION ON A CNC LATHE

Submitted in partial fulfilment of the requirements for the award of degree of

MASTERS OF ENGINEERING

IN

PRODUCTION AND INDUSTRIAL ENGINEERING

Submitted By

RAHUL BHARDWAJ

Roll No. 801182021

Under the Guidance of

ANIRBAN BHATTACHARYA	**Dr. S.P.NIGAM**
Assistant Professor	**Visiting Professor**
Mechanical Engineering Department	**Mechanical Engineering Department**
Thapar University, Patiala	**Thapar University, Patiala**

DEPARTMENT OF MECHANICAL ENGINEERING
THAPAR UNIVERSITY,
PATIALA-147004, PUNJAB
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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled **"INVESTIGATION OF NOISE GENERATED DURING TURNING OPERATION ON A CNC LATHE"** in partial fulfillment of the award of **Master's Degree in Production & Industrial Engineering** submitted in Mechanical Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. S.P. Nigam, Visiting Professor, Mechanical Engineering Department** and **Anirban Bhattacharya, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala.**

The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Dated: 15/07/2013

(Rahul Bhardwaj)

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

(Dr. S. P. NIGAM)
Visiting Professor
Mechanical Engineering Department
Thapar University, Patiala-147004

Anirban Bhattacharya
(ANIRBAN BHATTACHARYA)
Assistant Professor
Mechanical Engineering Department
Thapar University, Patiala-147004

Countersigned By:

(Dr. AJAY BATISH)
Professor and Head
Mechanical Engineering Department
Thapar University, Patiala-147004

(Dr. S. K. MOHAPATRA)
Dean of Academic Affairs
Thapar University, Patiala-147004

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Rahul Bhardwaj

Roll No. – 801182021

ABSTRACT

The state of a cutting tool is a crucial factor in the process of metal cutting as the increase in expenses in terms of scrapped components, machine tool fissures and unscheduled downtime result from worn tool usage. Monitoring the tool flank wear without affecting the throughput is considered as the prudent method in production technology.

The objective of this thesis work is to analyse the variation in the noise generated during turning operation of En24 steel on a CNC machine with the progression of tool wear. The turning operations are performed for different combination of parameters like cutting speed, feed and depth of cut and noise is recorded. The combination values of the three parameters are obtained using design of experiments. Effect of different parameters on noise is found using ANOVA. Optimal parameters are found for lowest sound level. At optimal parameters condition 1/1 frequency spectrum analysis is done and shift of peak frequency from 500 Hz to 1000 Hz is found. It is concluded that the sound level has direct correlation with tool wear. Sound level increases with increase in tool wear as expected.

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NOMENCLATURE

SYMBOLS	**DESCRIPTION**
Hz	Hertz
f_{upper}	Frequency of Upper Limit
f_{lower}	Frequency of Lower Limit
c_{centre}	Centre Frequency
Pa	Pascal
SPL	Sound Pressure Level
SL	Sound Level
dB	Decibel
dB (A)	A-Weighted Decibel
L_{eq}	Equivalent Continuous Sound Level
VB	Flank wear

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO NOISE

In our modern world, rapidly expanding environment one of the developing problems is that noise. Apart from the pure annoyance factor of noise, exposure to an intense sound field over a long period of time presents the risk of permanent damage of hearing. This particular problem is becoming a source of serious concern to industrial corporations, trade unions and companies.

The major sources of noise are:

1. Industrial Noise
2. Traffic Noise
3. Community Noise

Out of the above three sources, the source that affect the most is industrial noise. In industrial noise, mainly the noise is contributed by the machine tools and the machine tool which is most commonly used in factory/workshop is the lathe machine.

i. **Noise**: Noise is conveniently and concisely defined as "unwanted sound". [13]
ii. **Sound:** Sound waves are pressure variations produced as a result of mechanical disturbance in a material medium.
iii. **Decibel:** Decibel is the logarithmic of a ratio of two quantities and therefore has no units.

Decibel is defined by expression as $10\log_{10} (P/P_0)^2$.

Where,

P is the sound pressure amplitude of the measured sound.

P_0 is a reference pressure, 20μPa.

Table 1.1 Environmental Conditions at different SPL [12]

Sound Pressure (N/m^2)	Sound Pressure Level (dB)	Environmental Conditions
10^2	134 dB	Threshold of pain
10	114 dB	Loud automobile horn (distance 1m)
1	94 Db	Inside Subway Train
10^{-1}	74 dB	Average Traffic on street corner
10^{-2}	54 dB	Living room, Typical business office
10^{-3}	34 dB	Library
10^{-4}	14 dB	Broadcasting studio
$2*10^{-5}$	0 dB	Threshold of hearing

1.2 SOUND SOURCES

A distinction is made between three different types of sound sources: [13]

1) Point source
2) Line source
3) Plane source

1.2.1 Point source: A sound source can be considered as appoint source, if its dimensions are small in relation to distance to the receiver and it radiates an equal amount of energy in all directions. Typical point sources are industrial plants, aircraft and individual road vehicles. The sound pressure level decreases 6dB whenever the distance to a point source is doubled.

1.2.2 Line source: A line source may be continuous radiation such as from a pipe carrying a turbulent fluid, or may be composed of a large number of point sources so closely spaced that their emission may b considered as emanating from a notional line connecting them. The sound pressure level decreases 3dB, whenever the distance to a line source is doubled.

1.2.3 Plane source: A plane source can be described as follows, if a piston source is constrained by hard walls to radiate all its power into an element tube to produce a plane wave, the tube will contain a quantity of energy numerically equal to the power output of the source. In the ideal situation there will be no attenuation along the tube. Plane source are very rare and only found in e.g. duct systems.

When two sources radiate sound energy, they will both contribute to the sound pressure level a distance away from the sources. If they radiate same amount of energy and the distance from the point of measurement to the source is the same, the level will increase by 3dB compared with the level created by source alone.

1.3 PHYSICAL PROPERTIES OF SOUND

1.3.1 Sound Power: When sound is produced, a transfer of energy from the source to the surrounding air molecules takes place. The rate of energy transfer is called sound power. The unit of sound power is W (Watt).

The audible range of sound power extends from 10^{-9} W to more than 1000W. 10^{-9}W is the lowest level which can be heard by a listener close to the source, and 1000W will create immediate hearing damage. Lower levels can also create hearing damage, if the listener is exposed for a long period of time.

1.3.2 Sound Intensity: when a source produces sound power (P) it will create certain sound intensity (I) at a distance away from the source. The intensity is a measure for the amount of power through a certain area at this distance.

None of these units can be measured directly. Their values can, however, be calculated after measurement of the sound pressure level, knowing the area over which measurements are being made. The relationship between sound pressure (p), intensity (I) and sound power (P) can be written as,

$$P^2 \propto I \propto P \tag{1.1}$$

1.3.3 Sound pressure level: Decibel (dB) is logarithmic ratio which defines the sound pressure level L*p* as follows:

$$Lp = 20 \log_{10} P/P_0 \tag{1.2}$$

Where, P is the sound pressure measured.

P_0 is the reference sound pressure i.e. 20µPa (the threshold of hearing).

This logarithmic scale has several advantages over a linear scale. The most important advantages are:

1. A linear scale would lead to the use of some enormous and unwieldy numbers.
2. The ear responds not linearly, but logarithmically to stimulus.

1.4 CHARACTERISTICS OF SOUND

1.4.1 Background Noise

When sound measurement for a machine is carried out, it is important that the background noise level is so low, that it does not have any influence on the result. This can be tested in the following manner. Measure the sound at the position where it should be measured with the source (machine) running. Switch off the machine and measure the sound level without the machine running.

If the difference is less than 3dB measurements should be stopped until the background noise has been reduced. If the difference is between 2 and 10 dB use the curve to correct the measured value. If the difference is more than 10dB, the background noise may be ignored.

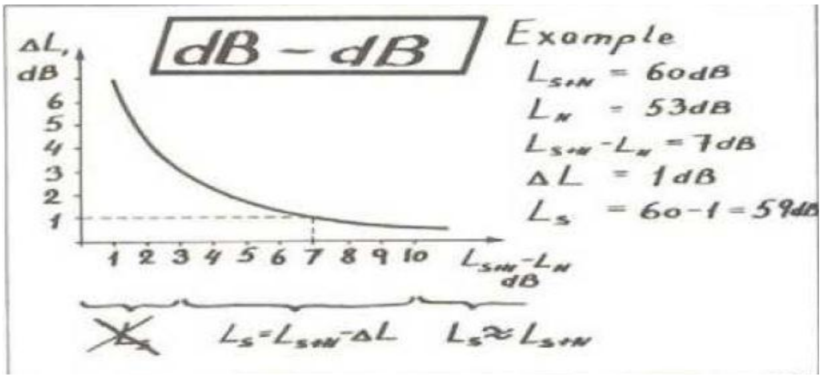


Fig 1.1 Subtraction of background noise in dB [12]

1.4.2 Loudness

Loudness is subjectively perceived attribute of sound which enables listener to order its magnitude on scale from soft to loud. It is defined as subjective intensity of sound. Based on these curve of equal loudness, the “phon” scale was logically conceived as a measure of loudness level. The loudness level of a sound is the sound pressure level in dB is $2x10^{-5}N/m^2$ of a pure tone. [19]

Non linear response of the ear:

a) 1000 Hz tone of 40dB(40 phon) is of same loudness as

63 Hz tone of 58dB

Or

4000 Hz tone of 31 dB

b) Increase in loudness for a corresponding increase in sound level depends upon frequency and on level also.

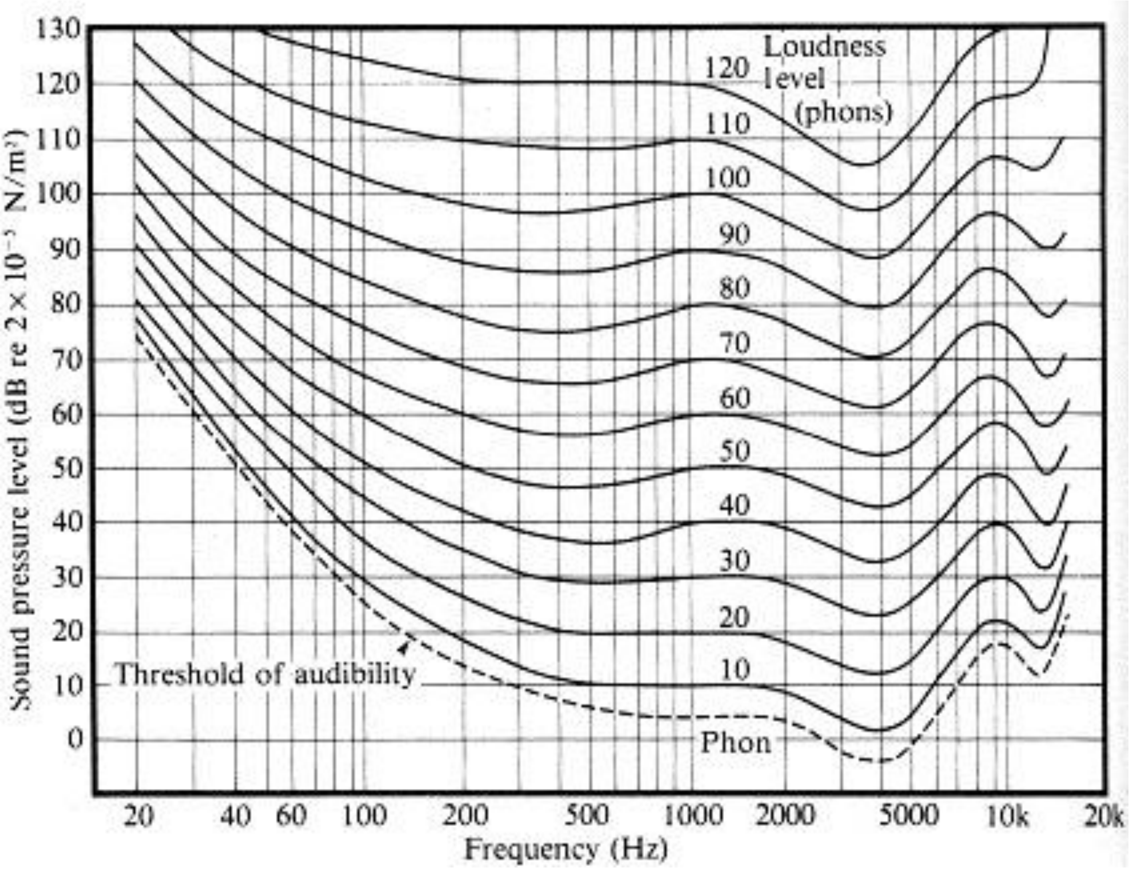
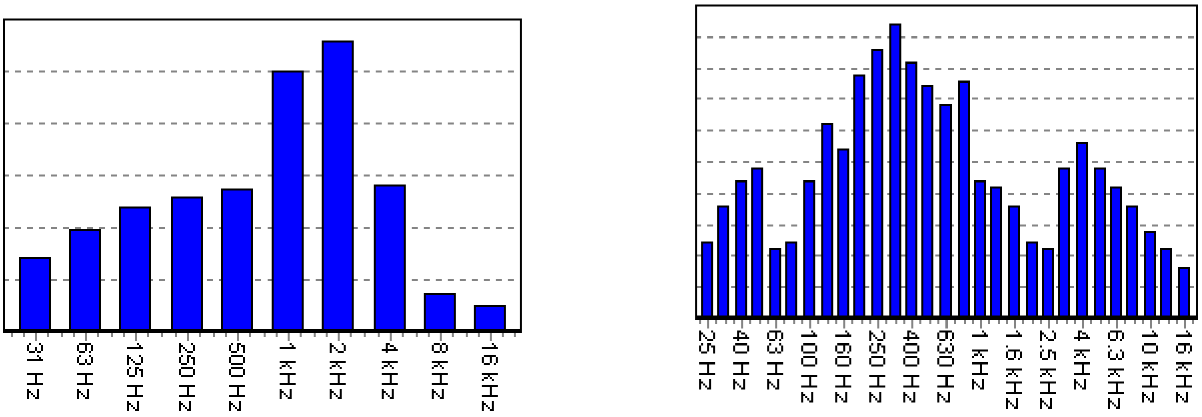


Fig 1.2 Equal Loudness Contours [19]

1.4.3 Frequency Analysis

Sound signals can be combined, but they can also be broken down into frequency components as shown by Fourier over 200 years ago. The ear seems to work as a frequency analyzer. We also can make instruments to analyze sound signals into frequency components. Frequency analysis is commonly carried out using (a) constant frequency band filters and (b) constant percentage filters. The constant percentage filter (usually one-octave or one-third-octave band types) most parallels the way the human auditory system analyzes sound and, although digital processing has mostly overtaken analog processing of signals, it is still frequently used. f_L and f_U are the lower and upper cutoff frequencies, and f_C and Δf are the band center frequency and the frequency bandwidth, respectively. Thus, $\Delta f = f_U - f_L$.

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 being octave bands and third octave bands. Octave bands contain a range of frequencies the upper limit of which is double the frequency of the lower limit (or $f_{upper} = 2\, f_{lower}$). The third octave band is defined by the limits $f_{upper} = \sqrt[3]{2}\ f_{lower}$ (or $f_{upper} = 2^{1/3}\ f_{lower}$). All frequency bands are usually referred to a Centre Frequency which is the geometric mean frequency of the band ($c_{entre} = \sqrt{f_{upper} f_{lower}}$).



(a) (b)

Fig 1.3 Frequency Spectrum (a) 1/1 octave band (b) 1/3 octave band [21]

1.4.4 Weighting Curves

The non linear response of the ear has lead to the introduction of weighting filters, making it possible to carry out measurements, which 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 and harmfulness of the sound signal. It follows approximately the 40phons curve in fig 1.2. The B-weighting and C-weighting curve follow more or less 70 phons and the 100 phons curves. The D- weighting curve follows a contour of perceived noisiness, and is used for aircraft noise measurement. Weighting filters can easily be built into portable Sound Level Meters, and the sound level measured is then given in dB (A) in case where an A–weighting filters has been used etc.

some sound level meters also have octave filters built in, or provision for connection of external filters.

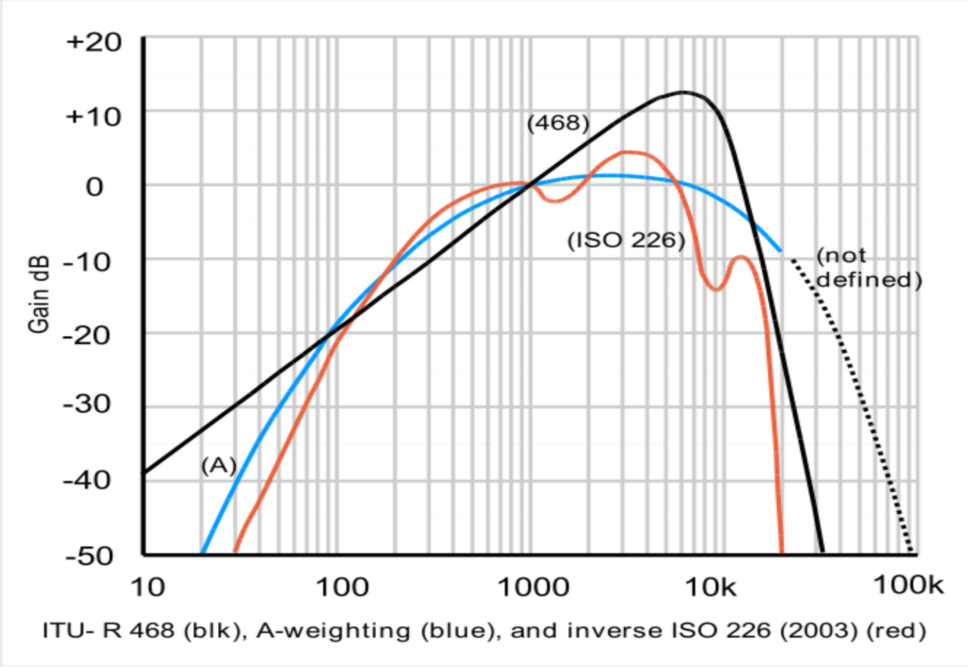


Fig 1.4 Weighting Curves [22]

1.4.4.1 A-Weighting: The most common weighting that is used in noise measurement is A-Weighting. Like the human ear, this effectively cuts off the lower and higher frequencies that the average person cannot hear. A-weighted measurements are expressed as dBA or dB (A). A graph of the frequency response shown in fig.1.5

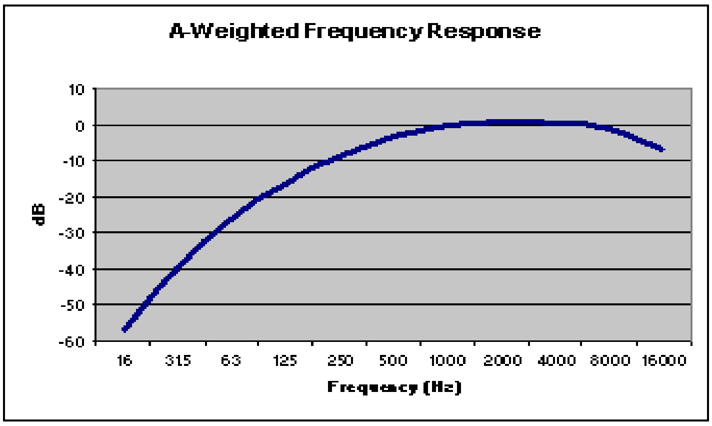


Fig.1.5 A-weighted frequency response [23]

1.4.4.2 C-Weighting: The response of the human ear varies with the sound level. At higher levels, 100 dB and above, the ear's response is flatter, as shown in the C-Weighted Response to the right.

Although the A-Weighted response is used for most applications, C-Weighting is also available on many sound level meters. C Weighting is usually used for Peak measurements and also in some entertainment noise measurement, where the transmission of bass noise can be a problem. C-weighted measurements are expressed as dBC or dB(C)

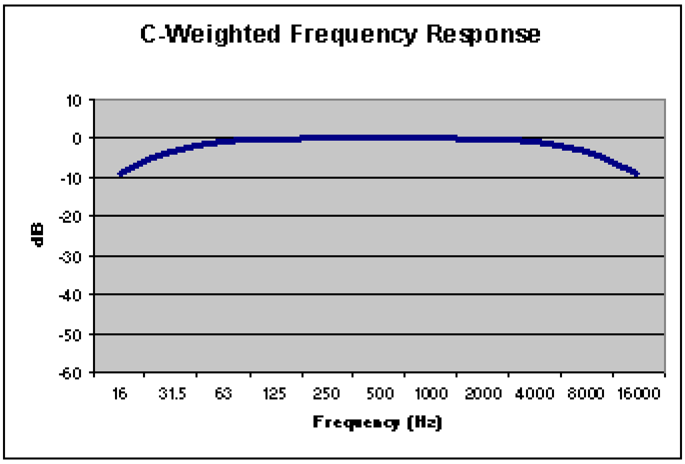


Fig.1.6 C-weighted frequency response [23]

1.4.5 Equivalent Continuous Sound Level (Leq)

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 and is defined as,[13]

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T \left[\frac{p}{p_{ref}} \right]^2 \qquad (1.3)$$

Where, T is the total measurement time,

P_A (t) is the A-weighted instantaneous acoustic pressure

P_0 is the reference acoustic pressure of 20µPa.

1.5 USEFUL APPLICATIONS OF NOISE.

1.5.1 Masking effects: Sometimes, it is necessary that nobody should hear the conversation between the two persons. For this, masking effect is used. For example, in the doctor's chamber, doctor wants that nobody should hear his conversation with the patient so doctor uses masking effect by putting a more noisy exhaust fan which makes noise outside the room.

1.6 NOISE MEASURING INSTRUMENT

Noise measuring devices typically use a sensor to receive the noise signals emanating from a source. The sensor, however, not only detects the noise from the source, but also any ambient background noise. Thus, measuring the value of the detected noise is inaccurate, as it includes the ambient background noise. There are so many different types of instrument available to measure sound levels and most widely used are sound level meters.

1.6.1 Elements of sound level meter

1.6.1.1 Microphone: Most measurement microphone generates a voltage that is proportional to the sound pressure at the microphone and is the electrical analog of sound waves impinging on the microphone's diaphragm. The particular mechanism that converts the pressure variation into sound waves signal. Different types of microphones are:

a) Capacitor (Condenser) Microphone
b) Pre-polarized Microphone
c) Piezoelectric Microphone

1.6.1.2 Amplifier: It amplifies the signal from microphone sufficiently to permit measurement of low SPL. It amplifies sound over a wide frequency range. It maintains the amplification constant.

1.6.1.3 Rectifier: It rectifies the signal from analog signal to digital signal.

1.6.1.4 Smoothing circuit: The circuit through which the sound waves are passes.

1.6.1.5 Meter: It is the part of sound level meter by which we can take observations.

Fig 1.7 Sound level meter with wind screen

1.6.2 Steps of Measurement System

a) Calibration: Check the sensitivity (Calibration) of the measuring instrument before and after the each measurement.

b) Measure the acoustical noise level

1.) Correction for background noise.
2.) Correction for reflection of nearby surfaces.
3.) Correction for ambient pressure.

c) Out Door Measurement Use of Windscreen Wind can be significant influence on outdoor acoustical measurement. Wind generated Noise can be reduced significantly by fitting a wind screen.

CHAPTER 2

MACHINE TOOL NOISE

2.1 INTRODUCTION

A frequent problem in the manufacturing industry today is the vibrations or chatter induced in machine tools during machining; for example, in turning, milling, boring, and grinding. The vibration of machine tools may be divided into three different classes: (1) free or transient vibrations of machine tools excited by other machines or engagement of the cutting tool, (2) forced vibrations usually associated with periodic forces within the machine tool, for example, unbalanced rotating masses, and (3) self excited chatter that may be explained by a number of mechanisms. These mechanisms include, among others, the regenerative effect, the mode coupling effect, the random excitation of the natural frequencies of the machine tool caused by the plastic deformation of the work piece material, and/or friction between the tool and the cut material. Vibrations in machine tools affect the result of machining, particularly the surface finish. Furthermore, machine tool life can be correlated with the degree of vibration and acoustic noise introduced. Machine tool chatter may be reduced by selective passive or active modification of the dynamic stiffness of the tooling structure and/or by the control of cutting data to maintain stable cutting. [16]

2.2 CONTINUOUS METAL-CUTTING PROCESSES

Metal-cutting machines that fall into this category include saws, drills, lathes, and milling machines. Modern lathes and milling machines are generally not considered as occupational noise problems because an operator of these machines is rarely subjected to an overall A-weighted sound pressure level exceeding 85 dB. In particular, for most milling machines, both the cutting tool and the work piece (product) are completely enclosed for containing liquid coolants and for safety. These enclosures provide substantial noise reduction. In general, the following noise sources can be distinguished: aerodynamic noise, noise due to vibrations of cutting tool, noise due to vibrations of work piece, noise due to impact/interactions between the cutting tool and the work piece, and noise due to material fracture. The radiated noise level is highly dependent on the feed rate of the work piece, the depth of cut, the resonance frequencies of the cutting tool and the work piece, the geometry of the cutting tool and the work piece, and the radiation efficiencies at the resonance modes.

2.2.1 Aerodynamic Noise Source

Aerodynamic noise in cutting tools is generated due to the vortex shedding off a spinning tool, such as the teeth in a high-speed rotating saw, producing a whistling noise. If the vortex shedding frequency coincides with the blade natural frequency, the noise radiated can be significantly amplified. It has been found by Bies [18] that the radiated noise for an idling circular saw is characterized by dipoles and the radiated sound power, proportional to the tooth area, increases with the rotational speed to a fifth power. Consequently, it is not unusual that the aerodynamic noise radiated from an idling circular saw at high speeds exceed an A-weighted sound pressure level of 100 dB. The strong aerodynamic noise source in an idling circular saw has been attributed by Martin and Bies to the interaction of the vortex shed by an upstream tooth with the leading edge of the following downstream tooth. Hence this noise is dependent on the tooth geometry. Various control options to minimize the aerodynamic noise (as applied to a circular saw) are available. By reducing the interactions between vortices and teeth using a variable pitch instead of a fixed pitch, a noise reduction of about 20 dB is possible. Saw blades made of high-damping alloys have been used to reduce blade vibrations at resonance and hence the radiated noise. It has been shown that a noise reduction up to between 10 and 20 dB could be achieved over a range of the peripheral velocity from 30 to 60 m/s. generally; applications of damping disks to saw blades might provide noise reduction up to 10 dB.

2.2.2 Noise due to Structural Vibrations

Noises due to structural vibrations include noise due to vibrations of the cutting tool, to the work piece, and to the interactions between the two. In terms of reducing the noise due to vibrations of the cutting tool, for example, in the case of a circular saw, the structural resonance frequencies could be shifted away from the vortex shedding frequency by designing blades with different hole patterns, widened gullets and irregular pitch or novel tooth design. In terms of reducing the noise due to vibrations of the work piece, appropriate clamping and application of damping plates to the work piece has been found to be useful. The interactions between the cutting tool and the work piece might cause instability. In most machining operations such as milling and turning, the cutting forces are highly dependent on the geometry of the cutting tool, the work piece feed rate, the spindle speed, and the depth of cut. Under certain combinations of these parameters, self-excited instability, known as regenerative chatter, occurs [15]. As a result of regenerative chatter, not only the quality of the surface finish degraded and the wear of the cutting tool accelerated, but the radiated noise could be also significantly increased. Regenerative chatter and hence noise due to the interactions between the cutting tool and the work piece could be significantly reduced by proper selection of the spindle speed, spindle speed variation, and the geometry of the cutting tool, as well as active control.

2.3 MACHINE TOOL CHATTER AND VIBRATION

Free or transient vibrations of machine tools may be excited by other machines in the environment via the machine tool base or/and by rapid movements of machine tables, engagement of the cutting tool.The forced vibrations are usually associated with periodic forces within the machine tool, for example, unbalanced rotating masses, the intermittent tooth pass excitation in milling. This type of vibration may also be excited by other machines in the environment of the machine tool via its base [17]. Machine tool vibrations during machining operations are usually termed *self-excited chatter* or *tool vibration.* Depending on the driving force of tool vibration, the vibration is generally divided into one of two categories: regenerative chatter (secondary chatter) and non regenerative chatter (primary chatter). Extensive research has been carried out on the mechanisms that control the induction of vibrations in the cutting process. The majority of this research has been carried out on dynamic modeling of cutting dynamics focusing on the analytical or a numerical model. Usually, the purpose of these works is dynamic models that enable to predict cutting data that enables stable cutting and maximize the material removal rate.

2.3.1 Chatter Mechanisms and Properties

The two most widely used theories explaining self excited chatter are the regenerative effect and the mode coupling effect. These theories are generally explained based on the dynamic interaction of the cutting process and the machine tool structure, that is, the basic cause of chatter. Self-excited chatter and two of its energy-providing mechanisms, the regenerative effect and the mode coupling effect, are usually described as follows: During cutting, a force $Fr(t)$ is generated between the tool and the work piece; see Figure. 2.1

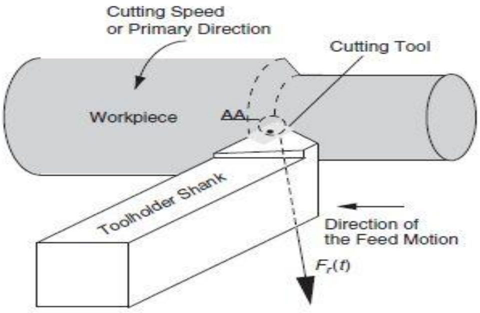


Figure 2.1 External longitudinal turning [15]

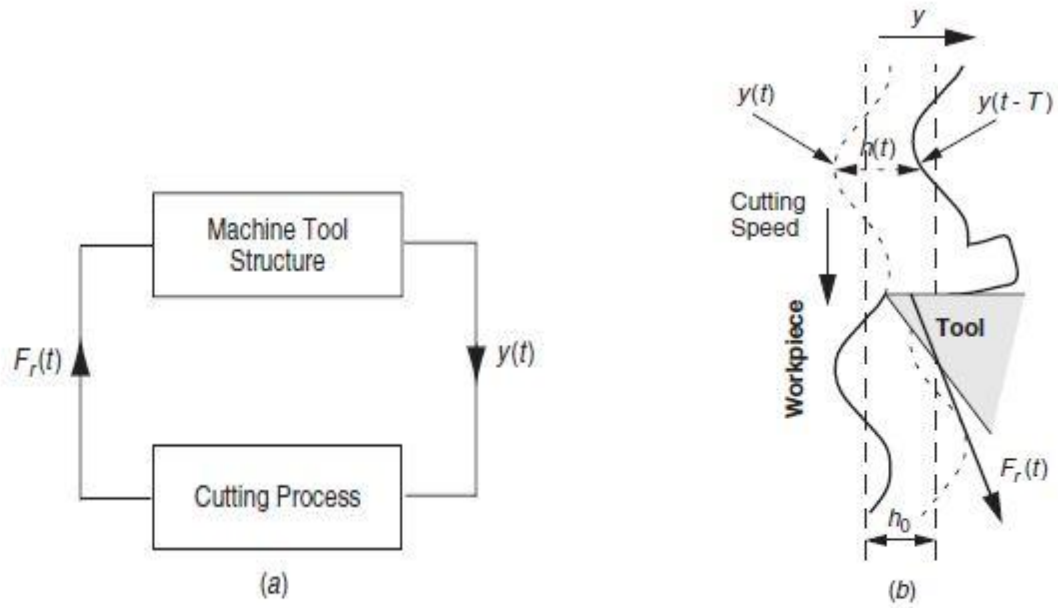


Figure 2.2 (*a*) Simplified block diagram of the closed-loop cutting- process structural system and (*b*) the principle for cutting tool regenerative chatter. [15]

The cutting force will strain the structure elastically and may cause a relative displacement of the tool and the work piece, which alters the tool and work piece engagement. This, in turn, indicates a feedback system relation between the cutting force *Fr (t)* and the relative displacement of the tool and the work piece; see Fig. 2.2a. This justifies a possibility for the initial vibration to be self-sustaining (unstable) and increase, with the machine oscillating in one of its natural modes of vibration. Basically, the closed-loop cutting process structural system is considered unstable if a mechanism exists for transferring energy into the structure to maintain vibration. The regenerative effect is considered to be the dominant mechanism of instability and chatter. It may occur when successive passes of the cutting tool overlap, that is, when the tool at any instant is removing an undulation on the work piece surface that was cut on the previous pass of the tool or revolution of the work piece. This is illustrated in

Figure 2.2b where h_0 is the intended chip thickness, $h(t)$ is the actual chip thickness at time t, $y(t)$ is the displacement of the tool in the y direction at time t, and $y(t - T)$ is the displacement of the tool in the y direction at previous pass of the tool or revolution of the work piece. [15]

Depending on the phase between these waves on the work piece surface, the force variation and excitation energy may increase after successive passes of the tool and the vibration will build up.

The limit of stability as a function of frequency—a stability chart—may be produced from

$$1 = -G_{yr}(f)[k_1(1 - \mu_c e^{-j2\pi fT}) + k_2 2\pi/\Omega \, j2\pi f] \qquad (2.1)$$

Where, $G_{yr}(f)$ is the cross receptance between the cutting force $Fr(t)$ and the tool response $y(t)$ (m/N), k_1 is the cutting stiffness coefficient (N/m), μ_c is the overlap factor, k_2 is a constant (N/m), Ω is turning the rotational speed of the work piece (rad/s), and f is frequency (Hz).

2.4 TOOL WEAR MECHANISM

It is important to identify the different tool failure modes in order to select appropriate operating machining conditions for machining. The most widely researched tool failure modes are flank wear, breakage (fracture), crater wear and plastic deformation. Other modes including notching (groove wear), cracking and chipping. Figure 2.3 displays the tool wear modes. Flank and crater wear are generally accepted as the normal tool failure modes, because the other failure modes can be avoided by selecting the proper machining parameters. The growth of flank and crater wear are directly related to the cutting time (orlength of cut), unlike some of other failure modes which can occur unexpectedly, even with a new tool.

- Flank wear is the volumetric loss at the top of the tool tip edge, and is mainly caused by abrasion. It is of course normal that a tool wears out at some or the other stage, depending on the type of work it has been subjected to.
- Fracture is a mode of failure characterised by break away of material on the tool edge. Fracture occurs when the feed rate is too high, or when a tool is used with tool low fracture strength.

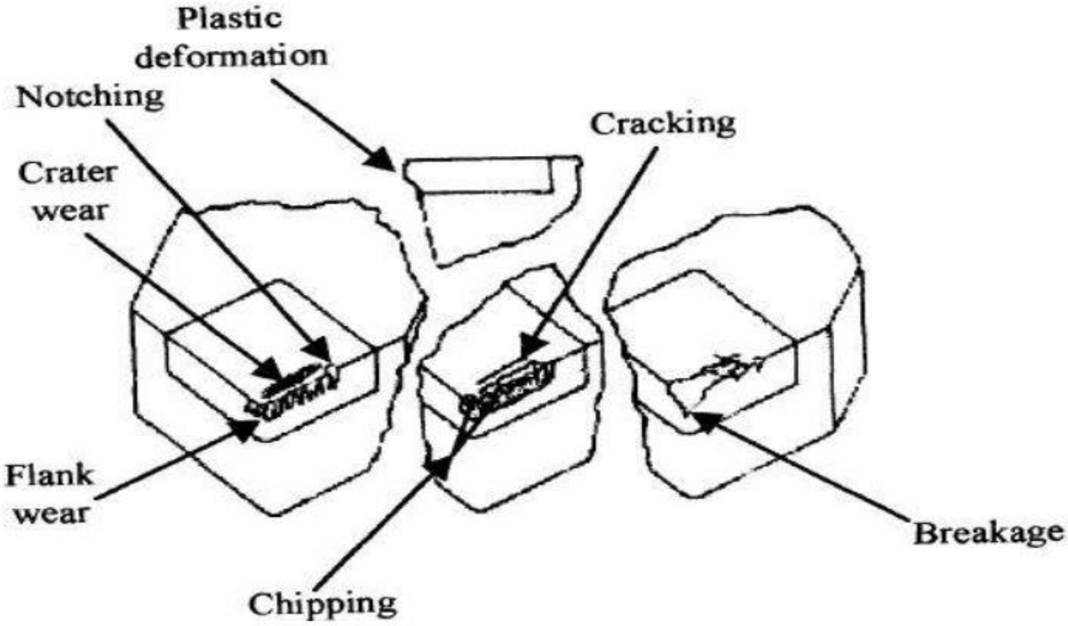


Figure 2.3 Tool Failure Modes

- Crater wear is a mode of failure predominantly caused by diffusion of tool material into the chip when operating at high speeds. The tool chip interface temperature governs this mode of failure.

CHAPTER 3

LITERATURE REVIEW

Monitoring of manufacturing process plays a very important role to avoid down time of the machine, or to prevent unwanted conditions such as excessive tool wear or tool breakage. This is also very important in the unwanted machining environment, where the process must be absolutely reliable, and be able to operate non-stop without checking for errors. To understand the proper behaviour of tool wear with respect to noise few researches has been carried out. The following are the gist of various researches.

Sexton et al. [1] studied the rate at which metal can be removed by a machine tool is often limited by the onset of an instability commonly called ‘chatter’. It has been suggested that greater widths of cut could be achieved without chatter on a given machine by modulating the spindle speed continuously. A stability analysis is presented which gives, for any mean spindle rotation speed and degree of modulation, the limiting width of cut for chatter-free cutting. The machine tool is represented by a simple mass/spring/damper system, only the case of a single cutter is considered; however, extension of the analysis to more complex models is straightforward. The analysis indicates that a modest increase in useable width of cut is given by using spindle speed modulation. Results are compared with corresponding results obtained from an analogue computer simulation of the machine tool/cutter system.

Jeyapalan and Halliwell [2] presented a simple method of predicting the L_{eq} sound pressure levels in the operator's position for a machine, whilst the latter was still at the design stage. Simple acoustic models were used to estimate mean values for the transfer functions between vibrational response and sound pressure at a point. Given a force input to a structure (machine) and the subsequent vibration response, which can be calculated by finite element or other means, it provides a quick and easy method of accurately predicting overall rms sound levels. The method is applied and provided with data obtained from a full-scale industrial drop hammer. It is applicable to any machine which can be identified as a distribution of separate sound sources

Lee [3] investigated the relationship between noise emission and tool wear for tungsten carbide P30 and HSS tools and AISI 1045 and AISI 4340 steels. Results showed that a characteristic frequency of around 4kHz–6 kHz exists for a wide range of tool-work piece materials and cutting conditions. The sound pressure level at the characteristic frequency is distinctly higher than machine and background noise for tungsten carbide tools and shows a good correlation with the flank wear. The noise level falls just before the tertiary wear zone and provides a tremendous potential for tool failure prediction.

Sadat and Raman [4] designed an experimental program to monitor tool flank wear using low frequency noise spectra resulting from the rubbing action of the tool and work piece. In this investigation work pieces of AISI 1045 steel, 76.2 mm in diameter and 1.0 m in length, were machined using a 5 h.p. Webb Precision Hydro shift lathe. The work pieces were machined with high speed steel cutting tool under dry unlubricated conditions at cutting speeds of 30 – 70 m/min, a feed rate of 0.09 mm/rev, a depth of cut of 0.254 mm and with tool overhangs of 20 - 40 mm.

- The results were presented as a plot of acoustic noise level (dB) vs. frequency (kHz).
- The results of the investigation showed that the level of noise emitted (in the frequency range 2.75kHz - 3.50 kHz) due to the rubbing action of the tool and work piece increases with increasing tool wear.
- A significant increase in the noise level was observed (9 - 24 dB) from comparisons of the noise spectra of a sharp tool with a worn tool.

Lai et al. [5] investigated the effectiveness of noise abatement enclosures for roll former shears in the sheet metal industry under the production environment. Measurements were taken over a considerable period of time on various machines before and after the installation of noise enclosures. All sound pressure level measurements were made using a Bruel & Kjaer (B&K) type 2231 sound level meter fitted with a BZ7110 Integrating Module. Three generic noise abatement enclosures, which represent different types of construction and design, were assessed. The microphone was placed at a height of 1.5m for all tests. For each test the A-weighted sound pressure was recorded digitally at 10 kHz by passing the signal from the sound level meter to a Boston Technology PC30PGL analog to digital data acquisition card installed in a Toshiba T3200SXC laptop computer.

- Results indicate that noise abatement enclosures, when used to enclose roll former shears, achieve a noise reduction of 4-5 dB (A) at the operator's position, virtually independent of the designs and materials. It has been shown that the rather poor performance of enclosures in this application is essentially due to structure- borne paths whereby vibrations are transmitted through the metal sheet product itself from the inside of the enclosure to the outside.

Kopac and Sali [6] aimed to build a simple model for tool wear monitoring during the machining process. Sound pressure at 0.5 m distance from cutting zone during the turning was measured by condenser microphone and analyzed in frequency domain from 0 to 22 kHz. Depth of cut was constant whereas cutting speed, feed rate and flank wear of the tool were variables.

- The discrete amplitude spectrum of the recorded noise calculated with fast Fourier transform (FFT) technique

$$S'(m\Delta f) = \frac{T}{N}\sum_{n=0}^{N-1} f(n\Delta t)\, e^{-j2\pi mn/N}$$

Where, m = 1,2,3….,½N

Δf = frequency line spacing

T = time of recording

N = no. of samples, Δt= time interval between samples

f ($n\Delta t$)= digital value of record at point n

- The increase in tool flank wear resulted in an increase of sound pressure amplitude in a relatively high frequency range (6 to 20 kHz).
- Alterations in cutting speed have a much smaller effect on the amplitude spectrum of the noise during turning.
- Tool wear monitoring is more favorable when relatively large variation in cutting speed and relatively small variation in feed rate expected during turning.

Lu and Elijah [7] addressed the issue of monitoring tool wear using audible sound to enable faulty conditions associated with wear to be identified during the process before the part quality gets out of specification. Audible sound generated from the cutting process is analyzed as a source for monitoring tool wear during turning, assuming adhesive wear as the predominant wear mechanism. The analysis incorporates the dynamics of the cutting process. In modelling the interaction on the flank surface, the asperities on the surfaces are represented as a trapezoidal series function with normal distribution. The effect of changing asperity height, size, spacing, and the stiffness of the asperity interaction is investigated and compared with experimental data. The interaction between the asperities is considered to be the source of system excitation that generates sound signals. It was shown that a change in the asperity form leads to a change in energy distribution of the signal frequencies. Based on the simple model used, the asperity height was found to decrease as tool wear increases. Under these circumstances, the dominant and harmonic signals move to higher frequencies.

Salgado and Alonso [8] presented a tool condition monitoring system (TCMS) for on-line tool wear monitoring in turning. The monitoring signals were the feed motor current and the sound signal. The former was used to estimate the feed cutting force using the least squares version of support vector machines (LS-SVM). Singular spectrum analysis (SSA) was used to extract information correlated with tool wear from the sound signal. Feed cutting force and the SSA decomposition of the sound signal alone with the cutting conditions constitute the input data to the TCMS.

Result showed that the accuracy of the proposed TCMS increases with high values of the cutting speeds and feed rates. The results obtained in this work validate the use of LS-SVM method for TCM, and of the feed motor current and the sound signal.

Raja et al. [9] worked to determine tool flank wear using the sound signals emitted during the turning process. Cutting speed, feed rate and the depth of cut were constant whereas the flank wear was a variable. The work-piece material was aluminium and the cutting insert was made of carbide. The emitted sound signal of a fresh tool (0 mm flank wear) a slightly worn tool (0.2 mm flank wear) and a severely worn tool (0.4 mm flank wear) during turning process were measured separately using a high sensitive microphone.

Singular Value Decomposition analysis was performed on these sound signals.

- Results show that the squares of Singular Value Decomposition features produced out of the sound signals clearly determines the flank wear condition of the tool.
- An increase in tool flank wear correlates with an increase in the SVD features.
- One more advantage of this method is the time taken to make a decision on the condition of the tool is very small like 1 second.

Samraj et al. [10] proposed a novel work that was used to determine tool flank wear by observing the sound signals emitted during the turning process. Work piece materials were steel and aluminum, and cutting insert was of carbide material. Two different cutting speeds were used in this work. The feed rate and the cutting depth were constant whereas the flank wear was a variable. The emitted sound signal of a fresh tool (0 mm flank wear) a slightly worn tool (0.2 -0.25 mm flank wear) and a severely worn tool (0.4mm and above flank wear) during turning process were recorded separately using a high sensitive microphone. Analysis using Singular Value Decomposition was done on these sound signals to extract the feature sound components. An increase in tool flank wear correlates with an increase in the SVD features. It was observed that wear monitoring of tool flank during turning process using SVD features with the Fuzzy C means classification on the emitted sound signal is a potential and relatively simple method.

Raja et al. [11] results of investigation on the relationship between emitted tool sound signal and tool flank wear during turning process are reported. . Work piece materials were steel and aluminum, and cutting insert was of carbide material. The tool emitted sound signal with a fresh tool, a slightly worn tool with 0.2 mm flank wear and a severely worn tool with 0.4 mm flank wear were captured.

  - The captured sound signals were analyzed using Hilbert Huang Transform (HHT)
  - Given below were the four major stages used in this research

    1. Recording the emitted sound signal during turning operation with fresh, slightly and severely worn tools by using an ICP microphone.

    2. Decomposing each multi-component sound signal into mono-component IMFs by using EMD.

    3. Obtaining the local energy (amplitude) of each instantaneous frequency found in IMF by applying Hilbert Transform.

    4. Constructing the Hilbert spectrum using all the IMFs, and the marginal spectrums on selected IMFs for final analysis.

- The amplitudes of a few relevant IMF components of the emitted tool sound signal increase with increasing tool flank wear. The results of the investigation confirmed that HHT based emitted tool sound signal analysis can be confidently applied to tool flank wear monitoring.

3.1 Literature summary

- Level of noise emitted due to the rubbing action of the tool and work piece during cutting operation increases with increasing tool wear.

- Tool wear monitoring is more favorable when relatively large variation in cutting speed and relatively small variation in feed rate expected during turning.
- Significant increase in the noise level was observed from comparisons of the noise spectra of a sharp tool with a worn tool.
- The increase in tool flank wear resulted in an increase of sound pressure amplitude in a relatively high frequency range.

3.2 Gap in literature

- From the previous studies it is observe that lot of work was done by taking flank wear as a variable and keeping other variables like feed rate ,cutting speed and depth of cut as a constant.
- No specific studies has been carried out on different materials.

CHAPTER 4

DESIGN OF EXPERIMENT

4.1 INTRODUCTION TO DESIGN OF EXPERIMENT

Design of Experiment (DoE) is a structured, organized method that is used to determine the relationship between the different factors (Xs) affecting a process and the output of that process (Y). This method was first developed in the 1920s and 1930, by ***Sir Ronald A. Fisher,*** the renowned mathematician and geneticist.

Design of Experiment involves designing a set of experiments, in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify optimal conditions, the factors that most influence the results, and those that do not, as well as details such as the existence of interactions and synergies between factors.

DOE methods require well-structured data matrices. When applied to a well-structured matrix, analysis of variance delivers accurate results, even when the matrix that is analyzed is quite small.

Experimental design is a strategy to gather empirical knowledge, i.e. knowledge based on the analysis of experimental data and not on theoretical models. It can be applied whenever you intend to investigate a phenomenon in order to gain understanding or improve performance.

Design of Experiments (DoE) is widely used in research and development, where a large proportion of the resources go towards solving optimization problems. The key to minimizing optimization costs is to conduct as few experiments as possible. DoE requires only a small set of experiments and thus helps to reduce costs.

There are many types of design of experiments applied in research and development but out of which the most efficient and commonly used method of design of experiment is “Taguchi Method”.

4.1.1 Taguchi Method:

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

4.1.1.1 Orthogonal Arrays:

Taguchi’s orthogonal arrays are highly fractional designs, used to estimate main effects using only a few experimental runs. These designs are not only applicable to two level factorial experiments, but also can investigate main effects when factors have more than two levels.

An orthogonal array is a type of experiment where the columns for the independent variables are “orthogonal” to one another.

The Taguchi arrays can be derived or looked up. Small arrays can be drawn out manually; large arrays can be derived from deterministic algorithms. Generally, the arrays are selected by the number of parameters (variables) and the number of levels (states). Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic. The data from the arrays can be analyzed by plotting the data and performing a visual analysis, ANOVA, bin yield and Fisher's exact test, or Chi-squared test to test significance.

4.1.1.2 Taguchi Method Design of Experiments

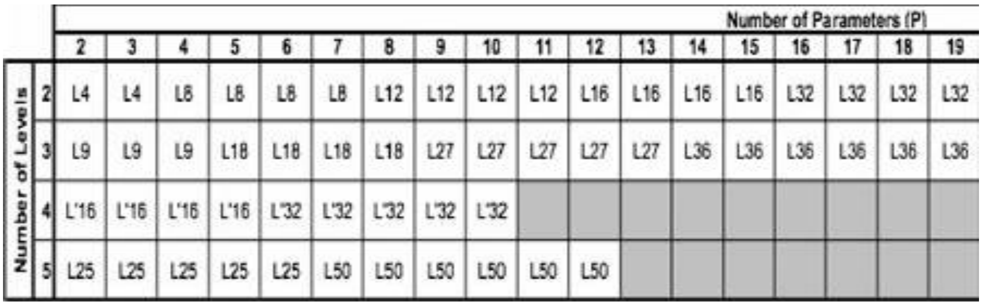
1. The general steps involved in the Taguchi Method are as follows:
2. Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum.
3. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified.
4. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter.
5. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
6. Complete data analysis to determine the effect of the different parameters on the performance measure.

4.1.1.3 Determining Parameter Design Orthogonal Array

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then fewer values can be tested or the values tested can be closer together. For example, if the temperature of a reactor jacket can be varied between 20 and 80 degrees C and it is known that the current operating jacket temperature is 50 degrees C, three levels might be chosen at 20, 50, and 80 degrees C. Also, the cost of conducting experiments must be considered when determining the number of levels of a parameter to include in the experimental design. Typically, the number of levels for all parameters in the experimental design is chosen to be the same to aid in the selection of the proper orthogonal array.

Knowing the number of parameters and the number of levels, the proper orthogonal array can be selected. Using the array selector table shown below, the name of the appropriate array can be found by looking at the column and row corresponding to the number of parameters and number of levels. Once the name has been determined (the subscript represents the number of experiments that must be completed), the predefined array can be looked up. These arrays were created using an algorithm Taguchi developed, and allows for each variable and setting to be tested equally. For example, if we have three parameters (voltage, temperature, pressure) and two levels (high, low), it can be seen the proper array is L4. The levels designated as 1, 2, 3 etc. should be replaced in the array with the actual level values to be varied and P1, P2; P3 should be replaced with the actual parameters (i.e. voltage, temperature, etc.)

Table 4.1 Array selector



		Number of Parameters (P)																	
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Number of Levels	2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32
	3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36
	4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32									
	5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50							

In our experiment, the lathe sound pressure level of noise depends upon the different operating parameters such as depth of cut, feed and spindle speed. The possible values for each are as follows:

Table 4.2 Levels of Parameters

Parameters	**Levels**			
	1	**2**	**3**	**4**
Cutting speed (m/min)	175	200	225	250
Feed (mm/rev.)	0.05	0.1	0.15	0.2
Depth of cut (mm)	0.5	0.75	1	1.25

In this case, there are 3 parameters, and each one has 4 levels. The highest number of levels is 4, so using the array selector table 4.1; the appropriate orthogonal array is L16:

Table 4.3 Orthogonal array

Exp. no.	**Cutting speed (m/min)**	**Feed (mm/rev.)**	**Depth of cut (mm)**
1	175	0.05	0.50
2	175	0.10	0.75
3	175	0.15	1.00
4	175	0.20	1.25
5	200	0.05	0.75
6	200	0.10	0.50
7	200	0.15	1.25
8	200	0.20	1.00
9	225	0.05	1.00
10	225	0.10	1.25
11	225	0.15	0.50
12	225	0.20	0.75
13	250	0.05	1.25
14	250	0.10	1.00
15	250	0.15	0.75
16	250	0.20	0.50

4.2 ANALYSIS OF VARIANCE (ANOVA)

Analysis of Variance (ANOVA) is a statistical method used to compare two or more means. It may seem odd that the technique is called "Analysis of Variance" rather than "Analysis of Means". The name is appropriate because inferences about means are made by analyzing variance.

$$\text{Variance} = \frac{\text{Sum of squares of deviations}}{\text{Degree of freedom of factor}} \tag{4.1}$$

For analysis of variance of the collected data on the effect of operating parameters, first to determine the followings:

1) Sum of squares

2) Degree of freedom

4.2.1 Sum of squares:

In the experiment, calculate sum of squares for different parameters such as depth of cut, feed and speed. The formulae are as follows:

- **Factor Sum of Squares (SS_A)** - Squared deviations of factor (*A*) averages from overall average.

$$SS_A = \left[\sum_{i=1}^{k_A} \left(\frac{A_i^2}{n_{Ai}} \right) \right] - \frac{T^2}{N} \tag{4.2}$$

Where,

A = Factor,
A_i / n_{Ai} = Average of all observations under A_i level,
T = Sum of all observations,
$\overline{T}$ = Average of all observations = T/N,
n_{Ai} = Number of all observations under A_i level.

- **Total sum of square:** Sum of squares of observations from overall average.

$$SS_T = \sum_{i=1}^{N} (\mathrm{y_i} - \overline{T})^2 \tag{4.3}$$

- **Error Sum of Squares**: Squared deviations of observations from factor (A) averages.

$$SS_{(\mathrm{Error})} = SS_T - \sum_{i=1}^{N} (SS_A) \tag{4.4}$$

Where,

SS_{Ai} = Facor sum of square of i_{th} factor.

4.2.2 Degree of freedom:

Rules:

1) The overall mean always uses one degree of freedom.

2) For each factor A, B, C…..; if the number of level are nA, nB, …, for each factor**, the degree of freedom = number of levels – 1;** for example, **the degree of freedom** for factor **A = n_A-1 and B = n_B-1.**

3) For any two factor interaction, for example, **AB** interaction**,**

the degree of freedom = (nA-1)*(nB-1).

In the experiment,

Number of experiment = 16

Number of factor = 3

Number of levels = 4

Now,

Total degree of freedom = 16 – 1 = 15

Degree of freedom for each factor = 4 – 1= 3

Degree of freedom for all factors = 3* 3 = 9

Degree of freedom for error = 15 – 9 = 6

4.2.3 F-Test: The F- test is most commonly used in Analysis of Variance (ANOVA). The formula is**,**

$$F = \frac{\text{variance of factor}}{\text{variance of error}} \qquad (4.5)$$

4.2.4 T–Test: A statistical test comparing the distribution of two means or proportions for the purpose of determining whether they are significantly different.

4.2.5 F–critical value: It provides the significant status of the individual factor which affecting the measure, whether the factor is significant or not.

CHAPTER 5

EXPERIMENTAL SET–UP AND MEASUREMENTS

5.1 EXPERIMENTAL SET-UP

To study the noise generated by CNC lathe machine during turning operation, the parameters like sound pressure level and frequency spectrum are required to study in different combination of operating conditions like cutting speed, feed and depth of cut. Experimental set up of CNC lathe machine is shown in figure 5.1.

Figure. 5.1 CNC Lathe Machine

The machine was manufactured by MTAB. The model name is MAXTURN PLUS +. This CNC lathe machine consists of various control panels to control feed, cutting speed and depth of cut.

The technical specifications of MAXTURN PLUS + are as follows:

Capacity

Chuck size (hydraulic)	165 mm
Maximum turning diameter	235 mm
Maximum turning length	360 mm
Number of axes -	2
Distance between centers	380 mm

Spindle

Spindle nose taper -	A2-5
Hole through spindle mm	52
Spindle speed range	150 – 6000 rpm
Spindle motor -	AC Servo

CNC Details

Control	SIEMENS / FANUC

Turret & Tooling

Number of stations	8 tool (BTP 80)
Tool cross-section	25 x 25 mm
Boring bar size	Dia 40 mm

Axes

X axis travel	140 mm
Z axis travel	380 mm
Axis motor (X and Z axis)	AC Servo motors
Axis motor torque	7 Nm

Machine Dimensions

L x W x H	2300 x 1600 x 2100 mm
Lubrication	Automatic lubrication system
Weight	3000 kg (approx)
Power Source	
Main supply	415V ± 2% 50Hz, 3 Phase

- **MATERIAL AND TOOL**

Work piece Material	En24 series steel
Work piece Dimension	50 mm Diameter , 250 mm Length
Tool Material	Carbide

5.2 MEASUREMENTS

Measurement procedure of different noise parameters contain calculation of sound power, measurement of sound pressure level at different operating parameters and measurement of sound pressure level for frequency spectrum in 1-1 octave band are discussed below:

5.2.1 Measurement of Sound Level

Measurement of sound level is done by using Sound Level Meter. In the experiment set up the sound level meter is placed at 0.5 m distance from the cutting zone during turning operation and it measured the sound levels for different combination of cutting speed, feed and depth of cut corresponding to selected orthogonal array (L_{16}). Value of Sound level is measured in A-weighting at slow response. The measured data are given in table in APPENDIX-A.

5.2.3 Measurement of Sound Level for Frequency Spectrum in 1-1 Octave

The value of sound level at 1-1 octave band gives the maximum and minimum value at particular frequency.

Fig. 5.2 Sound level meter

Frequency spectrum analysis has been carried out at different cutting speed, feed and depth of cut. The data of SPL is recorded in software “CESVA CAPTURE STUDIO”. Frequency spectrum analysis has been also carried out at optimal condition calculated using ANOVA with the progression of tool wear.

CHAPTER 6

RESULT AND DISCUSSION

After all the measurements, it is required to study the effect of different operating parameters for En24 steel material during turning operation. Analysis has been done for sound level and for frequency spectrum in 1/1 octave band.

In the investigation of noise generated during turning operation followings steps are followed:

Step 1

Collect the data showing sound level values corresponding to different combination of parameters shown in Table 1 in APPENDIX-A.

Step 2

On the basis of Taguchi design of experiment, analysis of variance and F- test were applied on the collected data of sound level using Minitab 16 software.

Frequency spectrum analysis is also done for different combination of parameters and the graph for 1/1 octave band are shown in Figures (6.2 to 6.17).

Step 3

Optimal parameters are found for lower sound level.

Step 4

On the optimal parameters the frequency spectrum analysis is also done with progression of tool wear and the graphs for 1/1 octave band are shown in the Figures (6.18 to 6.23).

6.1 ANALYSIS OF SOUND LEVEL

Analysis of sound level was carried out for different combination of parameters like cutting speed, feed and depth of cut. In the experiments depth of cut varied from 0.5 mm to 1.25 mm, feed varied from 0.05 mm/rev. to 0.20 mm/rev. and cutting speed varied from 175 m/min to 250 m/min.

Table 6.1 Values of sound levels (Leq) in dB (A) for different combination of parameters

S.No.	Cutting Speed (m/min)	Feed (m/rev)	Depth of cut (mm)	SL1 dB(A)	SL2 dB(A)	Mean
1	175	0.05	0.5	94.4	95	94.70
2	175	0.1	0.75	92.7	92.5	92.60
3	175	0.15	1	91.7	91.1	91.40
4	175	0.2	1.25	83.2	83.5	83.35
5	200	0.05	0.75	92	91.9	91.95
6	200	0.1	0.5	89.5	88.9	89.20
7	200	0.15	1.25	82.8	83	82.90
8	200	0.2	1	83.3	83.6	83.45
9	225	0.05	1	94.4	95.1	94.75
10	225	0.1	1.25	92.2	93.1	92.65
11	225	0.15	0.5	95.8	95.6	95.70
12	225	0.2	0.75	85.4	85.2	85.30
13	250	0.05	1.25	96	96.4	96.20
14	250	0.1	1	94.9	94.7	94.80
15	250	0.15	0.75	93.7	93.6	93.65
16	250	0.2	0.5	94.8	94.6	94.70

Now, on the basis of Taguchi design of experiment, the analysis of variance for mean of sound level and F- test for En24 has been done. The values are shown below:

Table 6.2 Analysis of variance for means

Source	DoF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed (m/min)	3	132.65	132.65	44.218	9.10	0.012
Feed (m/rev)	3	127.02	127.02	42.339	8.71	0.013
Depth of cut (mm)	3	46.32	46.32	15.441	3.18	0.106
Error	6	29.15	29.15	4.858	-	-
Total	15	335.14	-	-	-	-

From the table 6.2 the values of F and P show that the most affecting parameters on noise out of all the parameters are cutting speed and feed.

The main effect of parameters can be shown graphically as:

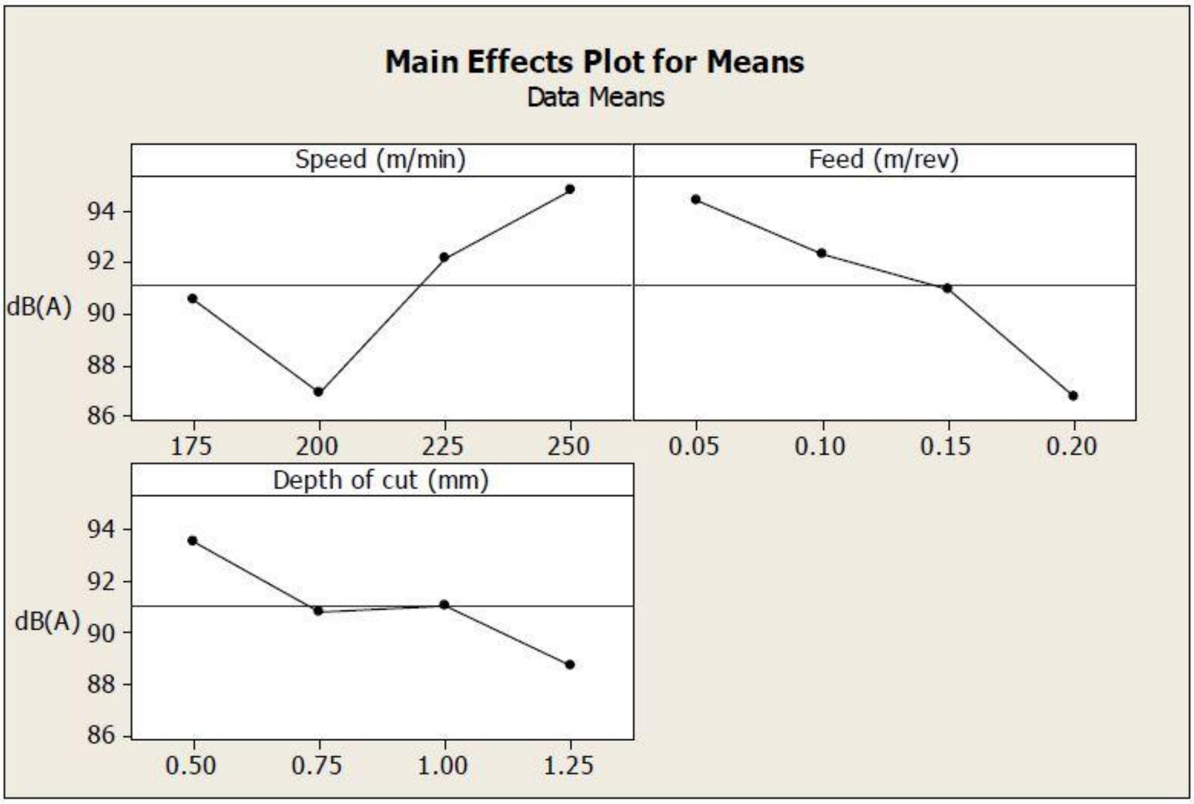


Figure 6.1 Main effect Plot for Means

In the above graphs the average values of sound level at different speeds, feed and depth of cut are shown. From the graph of sound level plotted against speed, it is observed that the sound level has highest value at 250m/min and lowest value at 200m/min cutting speed. From the graph of sound level plotted against feed, it is found that the sound level is high when the feed is 0.05mm/rev. and low at 0.2mm/rev., and from the graph of sound level plotted against depth of cut, it is found that the sound level is high at depth of cut of 0.5 mm and high at 1.25 mm.

So from the above analysis it is found that the sound level is low at 200m/min cutting speed, 0.2mm/rev. feed and 1.25mm depth of cut. These are the optimal values of parameters for lower sound level.

6.2 ANALYSIS OF FREQUENCY SPECTRUM

For every combination of parameters obtained from orthogonal array the cutting operation is performed and frequency spectrum is analysed for 1/1 octave band. In this analysis the graph are plotted between sound level and frequency. The measured data for the frequency spectrum is given in APPENDIX-B.

Figures 6.2 to 6.5 shows frequency spectrum for constant cutting speed 175 m/min and other parameters feed and depth of cut varying.

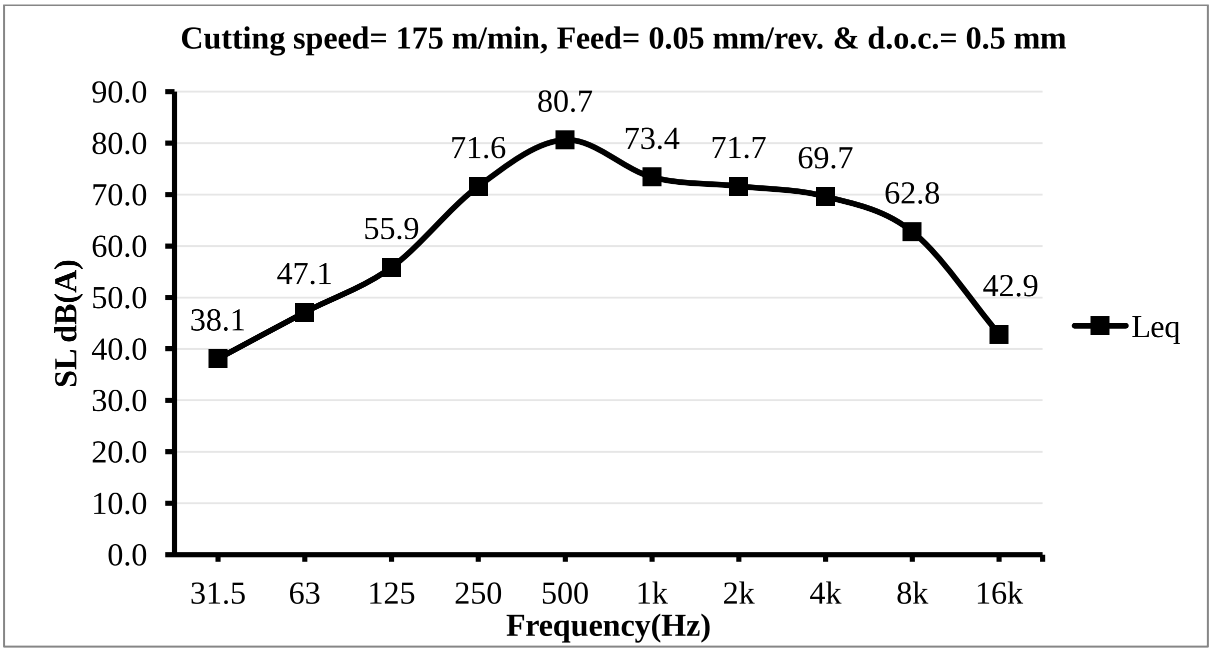


Figure 6.2 Sound Level Vs Frequency

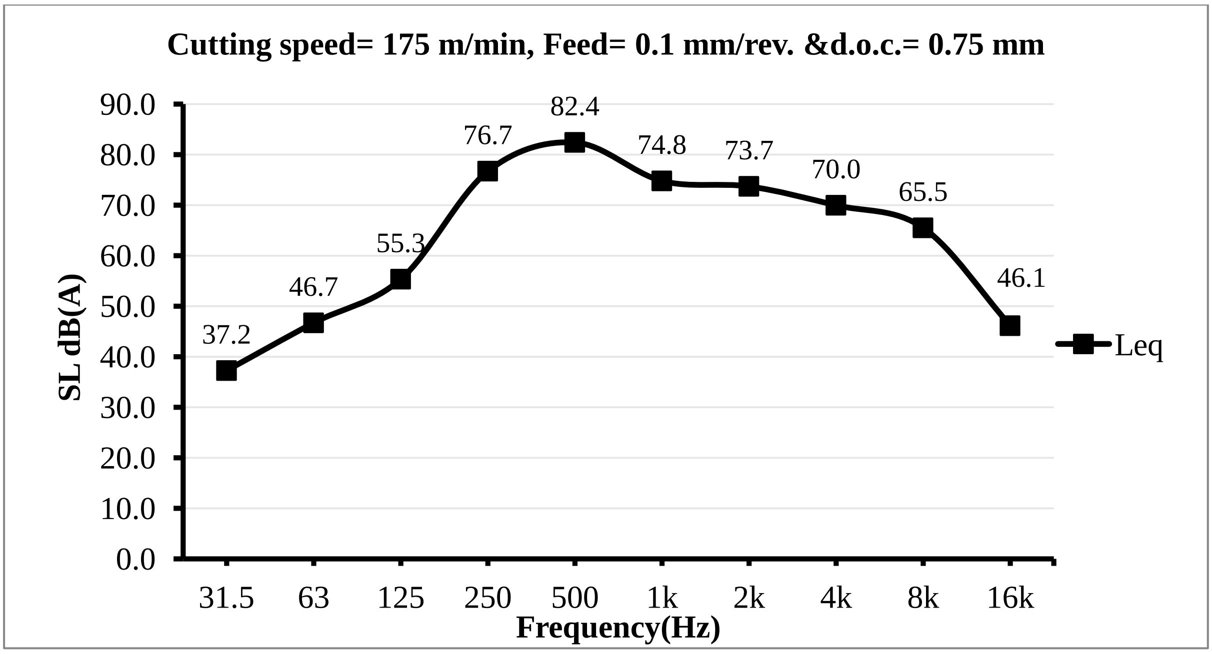


Figure 6.3 Sound Level Vs Frequency

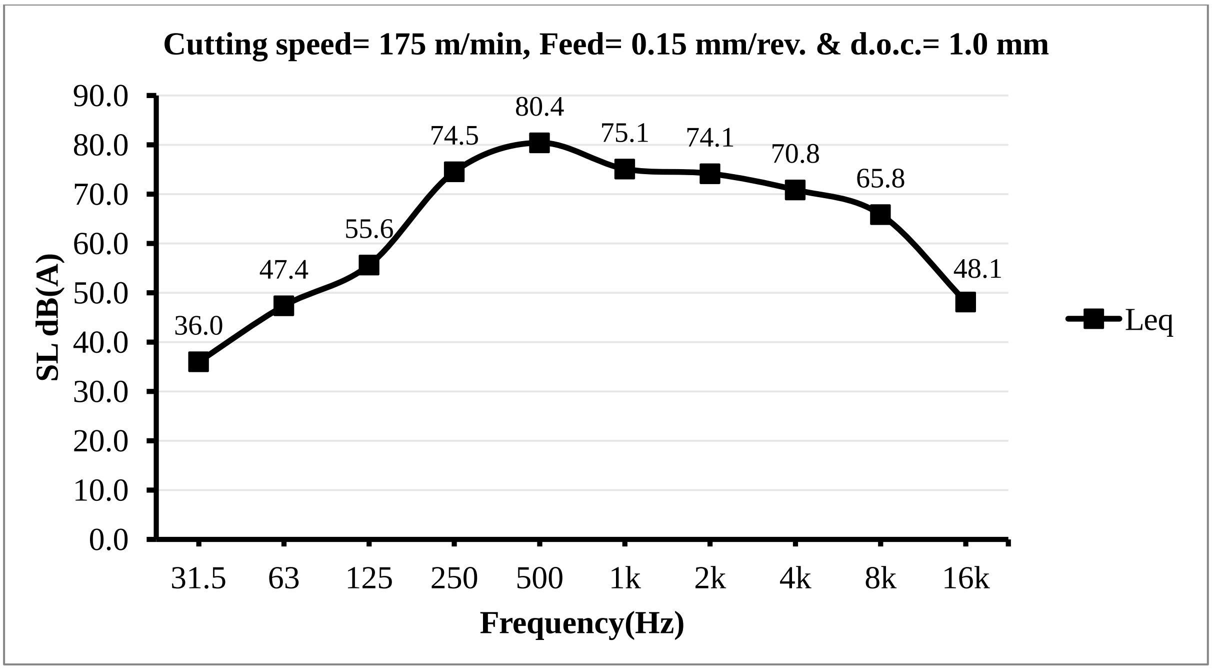


Figure 6.4 Sound Level Vs Frequency

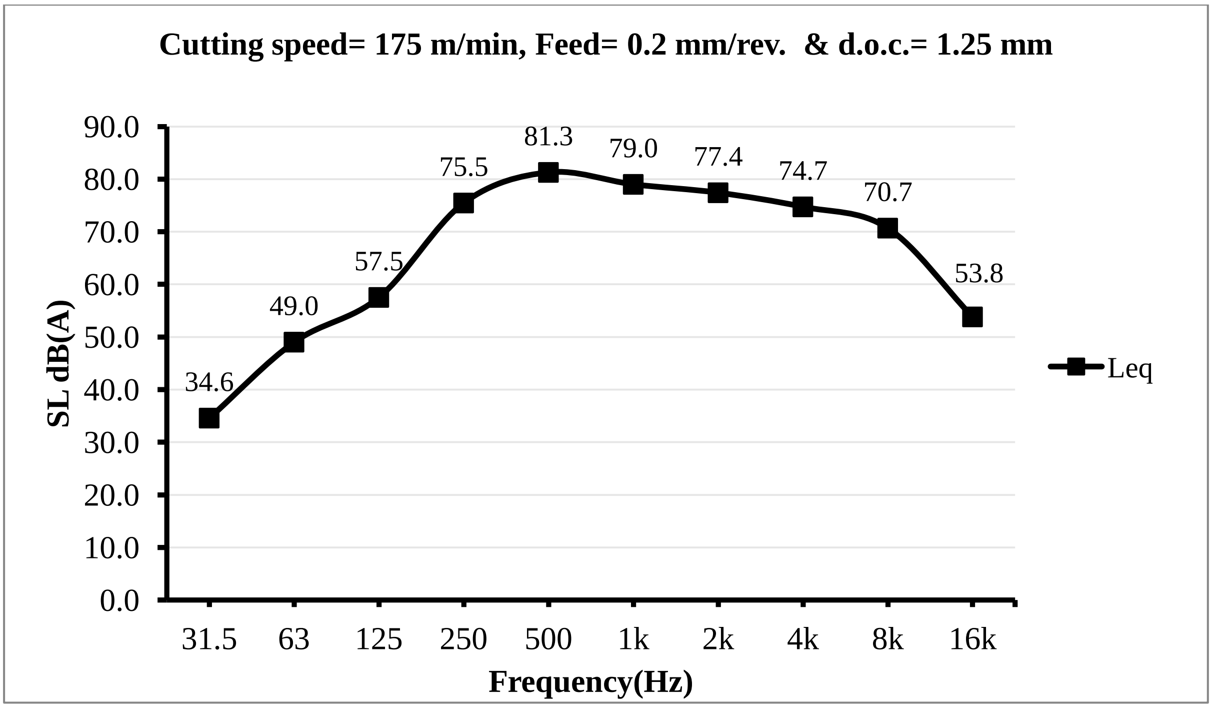


Figure 6.5 Sound Level Vs Frequency

From the graphs plotted it is found that the sound level was peak at frequency 500 Hz in all the cases. At the low frequency sound level was quite small and also at 16000 Hz sound level was low. The maximum sound level at peak frequency was found to be 82.4 dB (A).

Figures 6.6 to 6.9 shows frequency spectrum for constant cutting speed 200 m/min and other parameters feed and depth of cut varying.

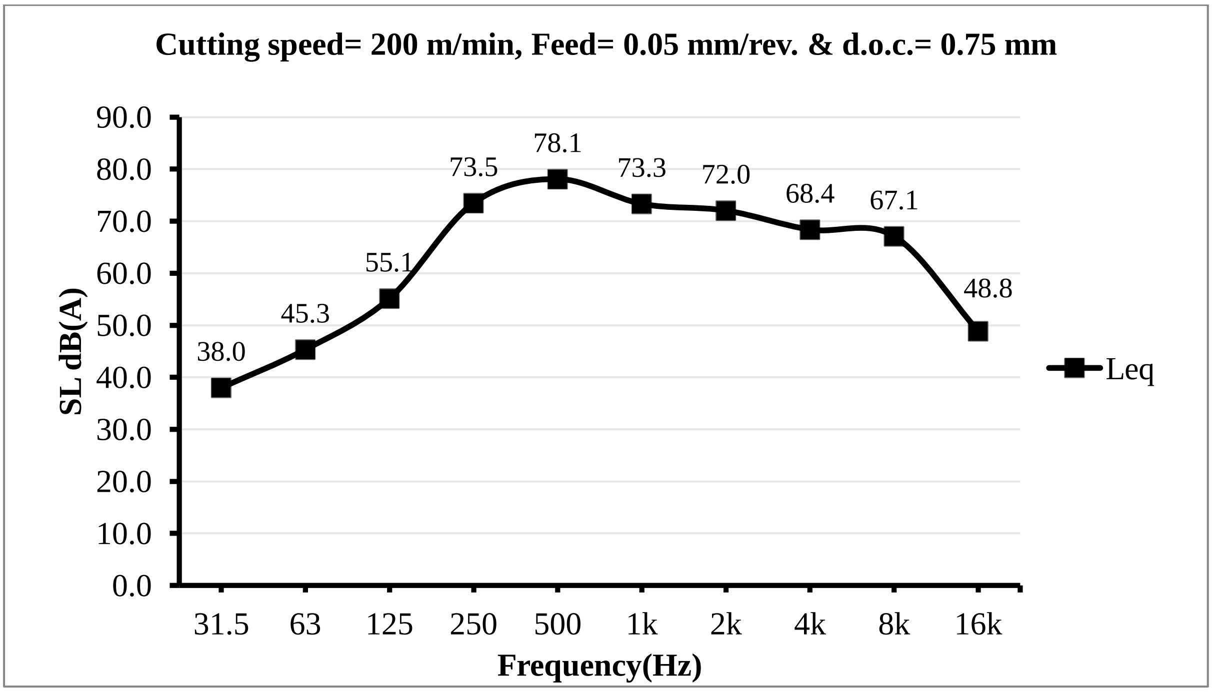


Figure 6.6 Sound Level Vs Frequency

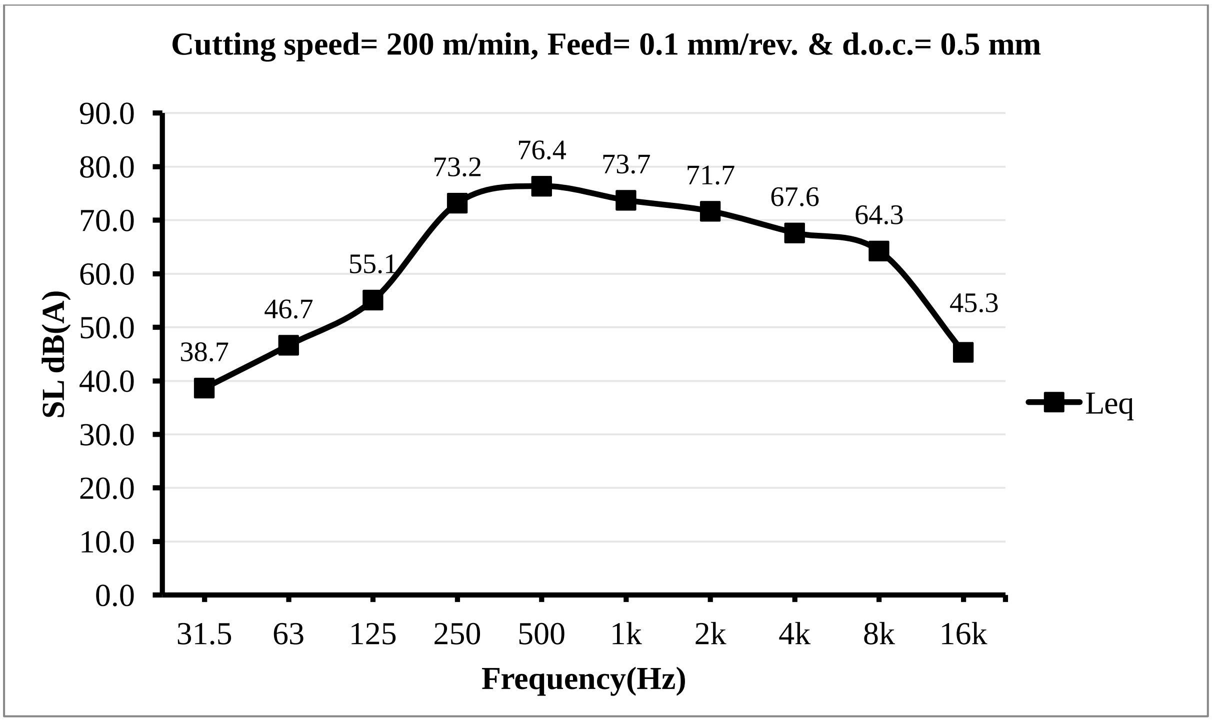


Figure 6.7 Sound Level Vs Frequency

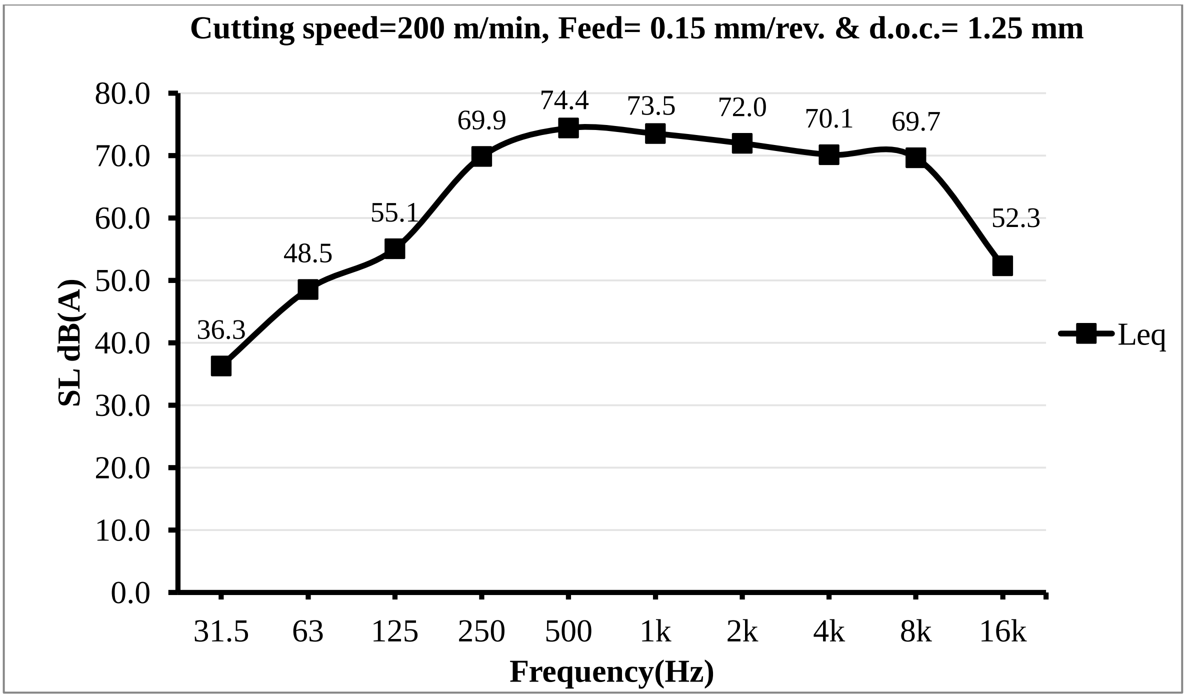


Figure 6.8 Sound Level Vs Frequency

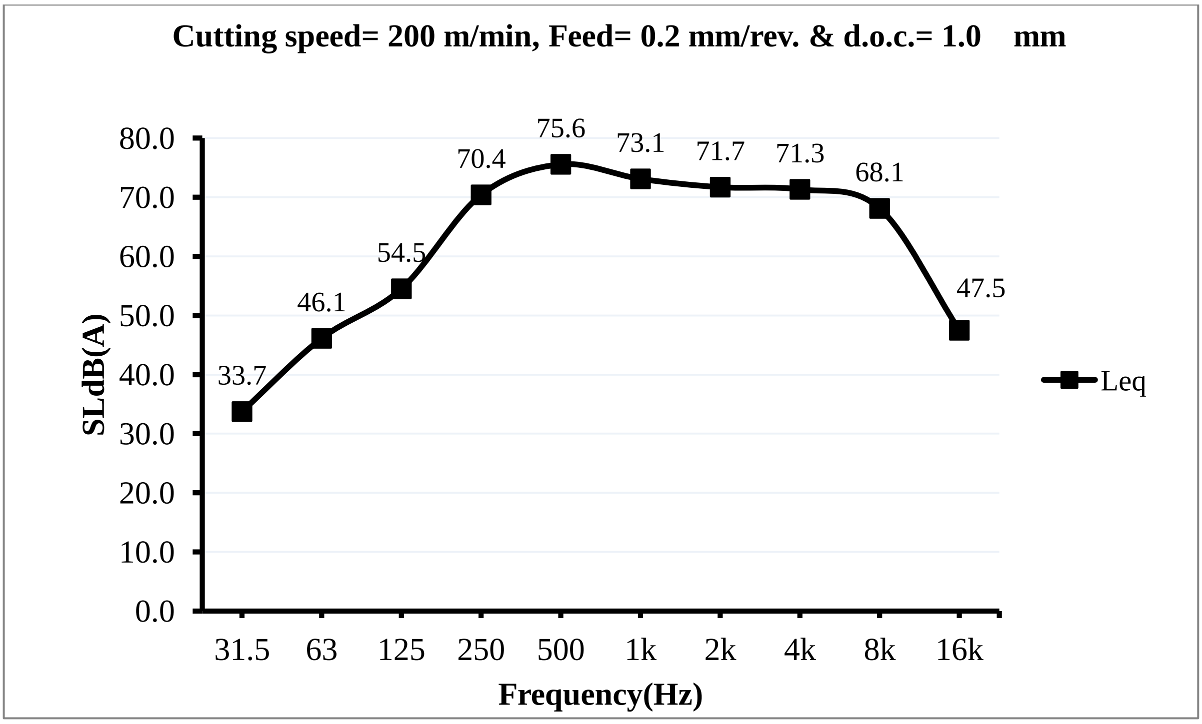


Figure 6.9 Sound Level Vs Frequency

From the graphs plotted it is found that the sound level was peak at frequency 500 Hz in all the cases At the low frequency sound level was quite small and also at 16000 Hz sound level was low. The maximum sound level at peak frequency was found to be 78.1 dB (A).

Figures 6.10 to 6.13 shows frequency spectrum for constant cutting speed 225 m/min and other parameters feed and depth of cut varying.

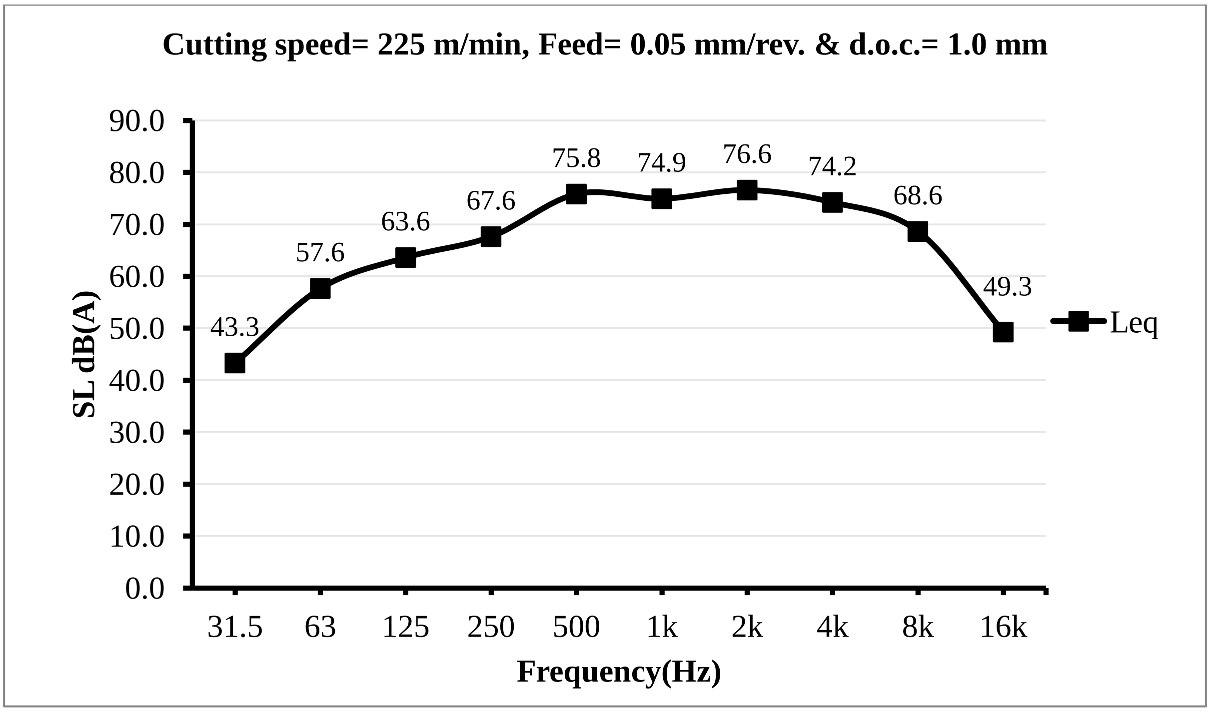


Figure 6.10 Sound Level Vs Frequency

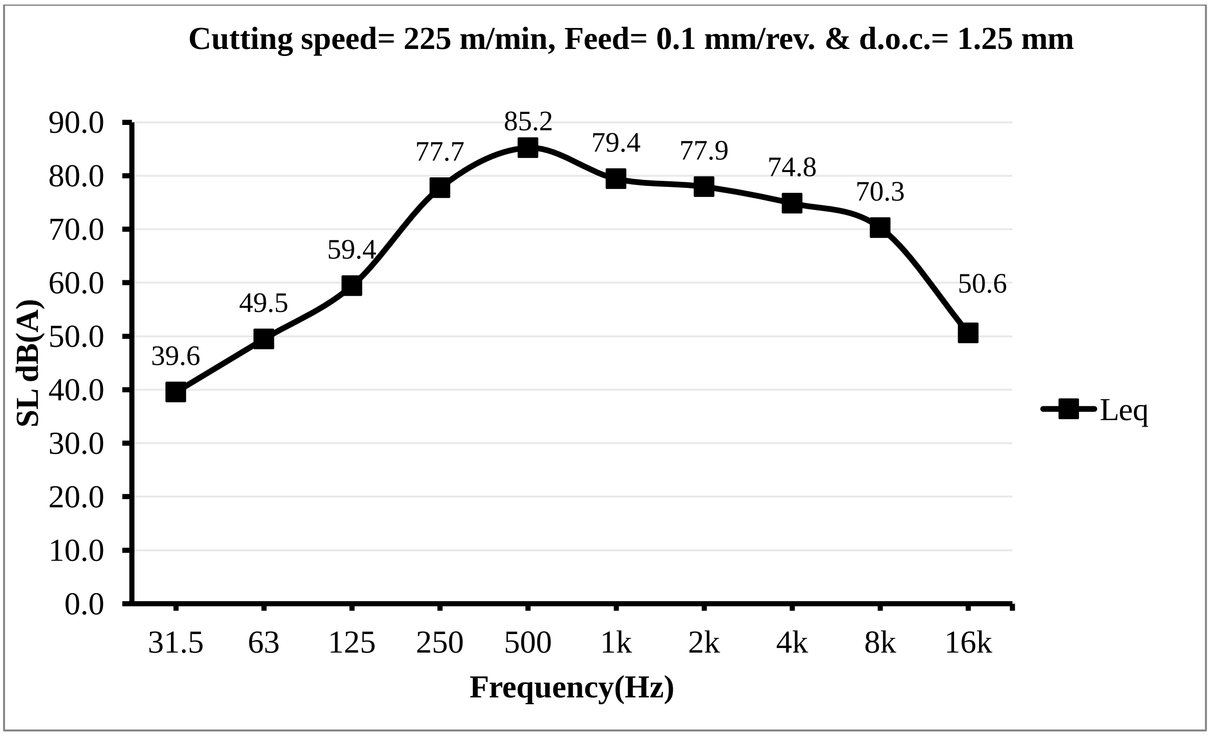


Figure 6.11 Sound Level Vs Frequency

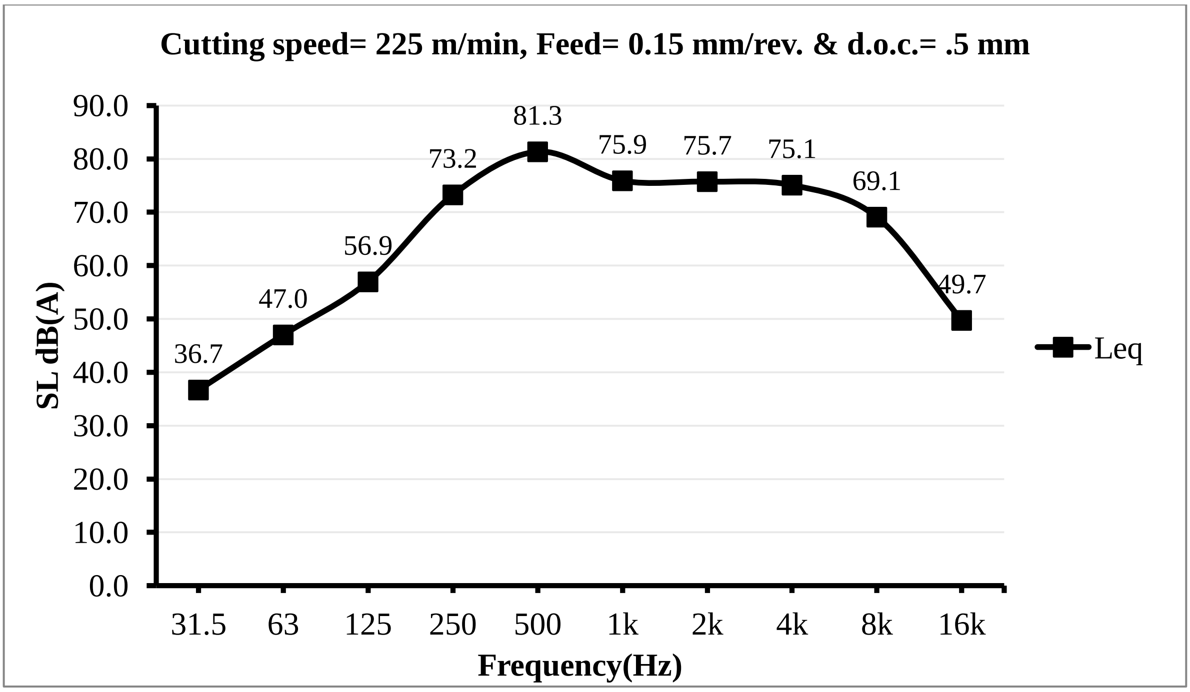


Figure 6.12 Sound Level Vs Frequency

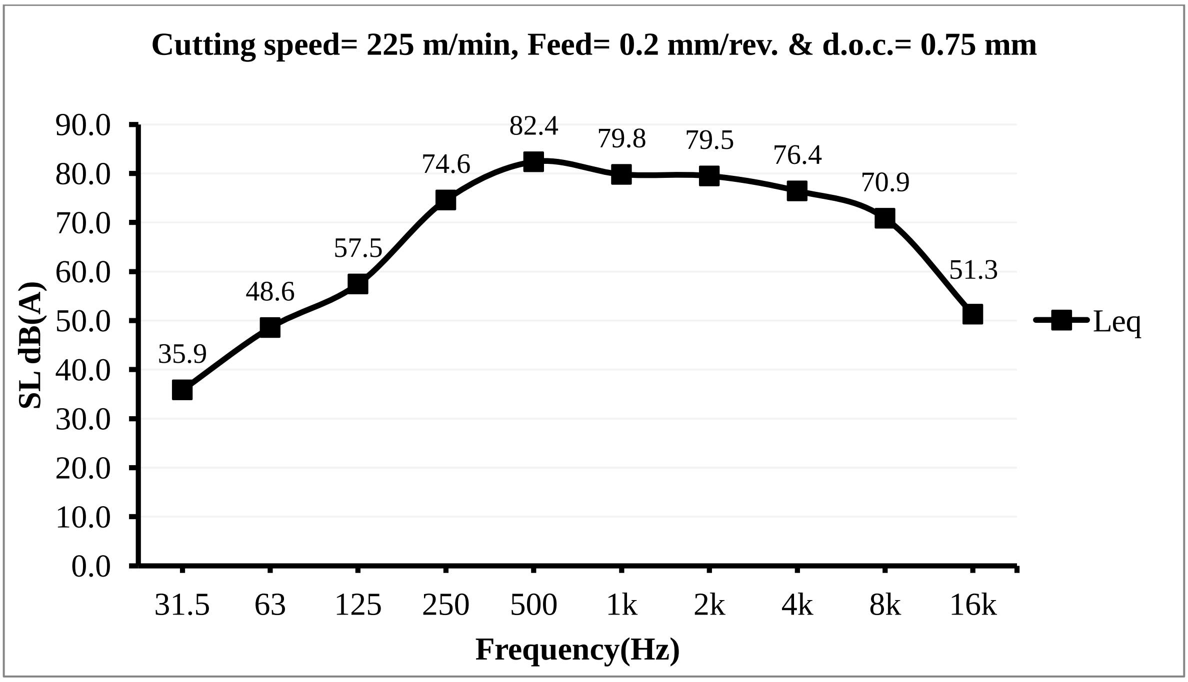


Figure 6.13 Sound Level Vs Frequency

From the graphs plotted it is found that the sound level was peak at frequency 500 Hz in all the cases. At the low frequency sound level was quite small and also at 16000 Hz sound level was low. The maximum sound level at peak frequency was found to be 85.2 dB (A).

Figures 6.14 to 6.17 shows frequency spectrum for constant cutting speed 250 m/min and other parameters feed and depth of cut varying.

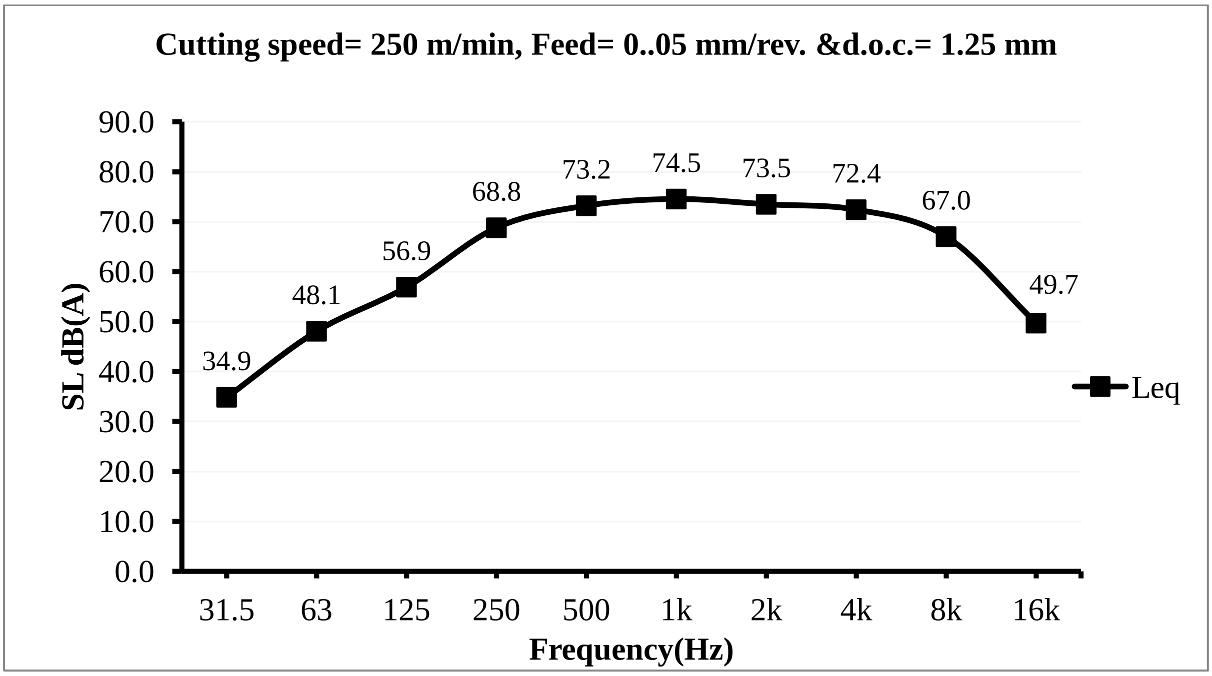


Figure 6.14 Sound Level Vs Frequency

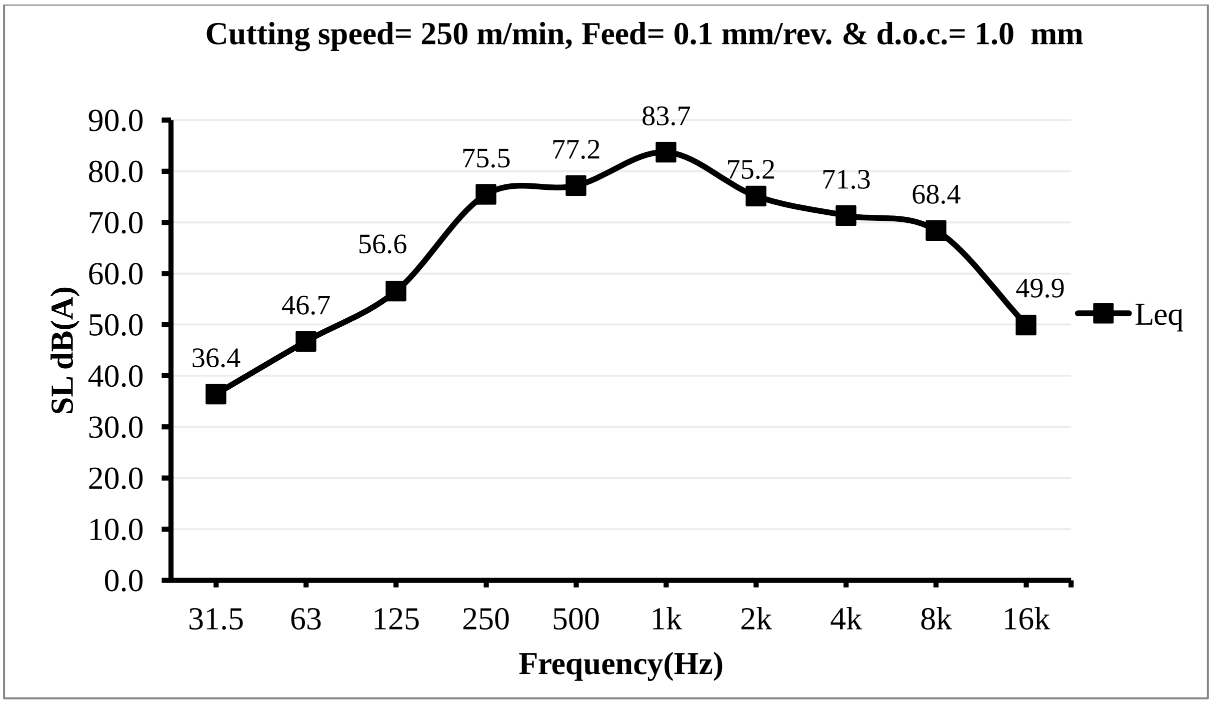


Figure 6.15 Sound Level Vs Frequency

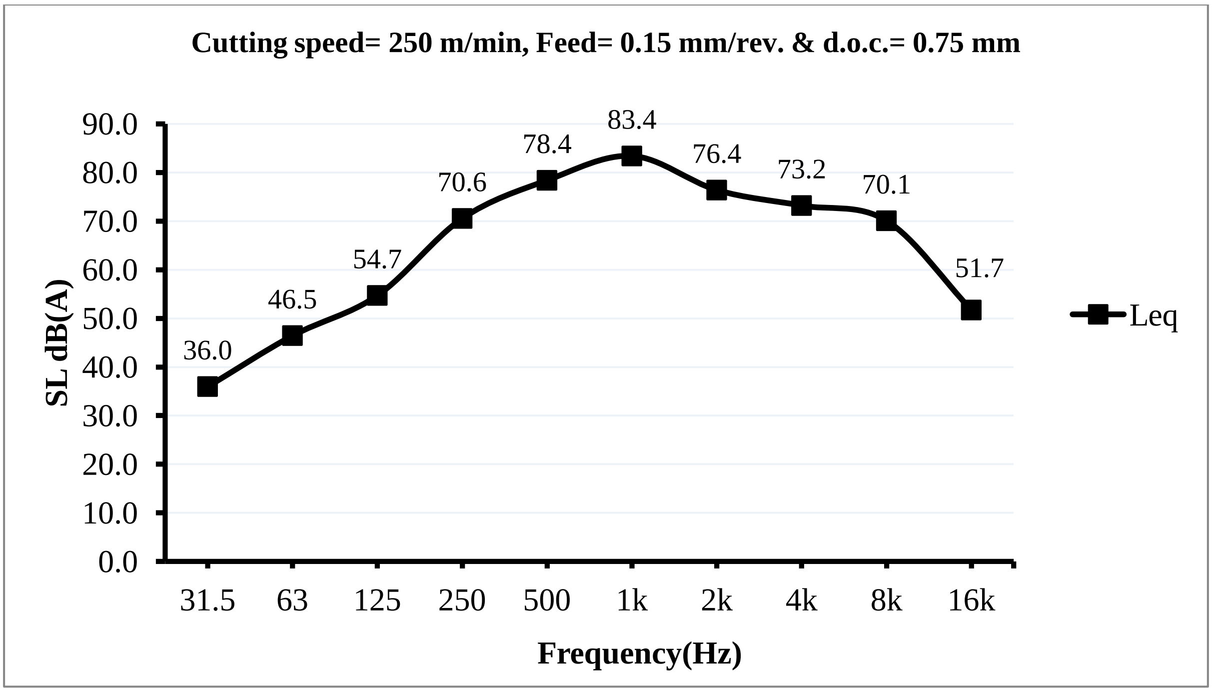


Figure 6.16 Sound Level Vs Frequency

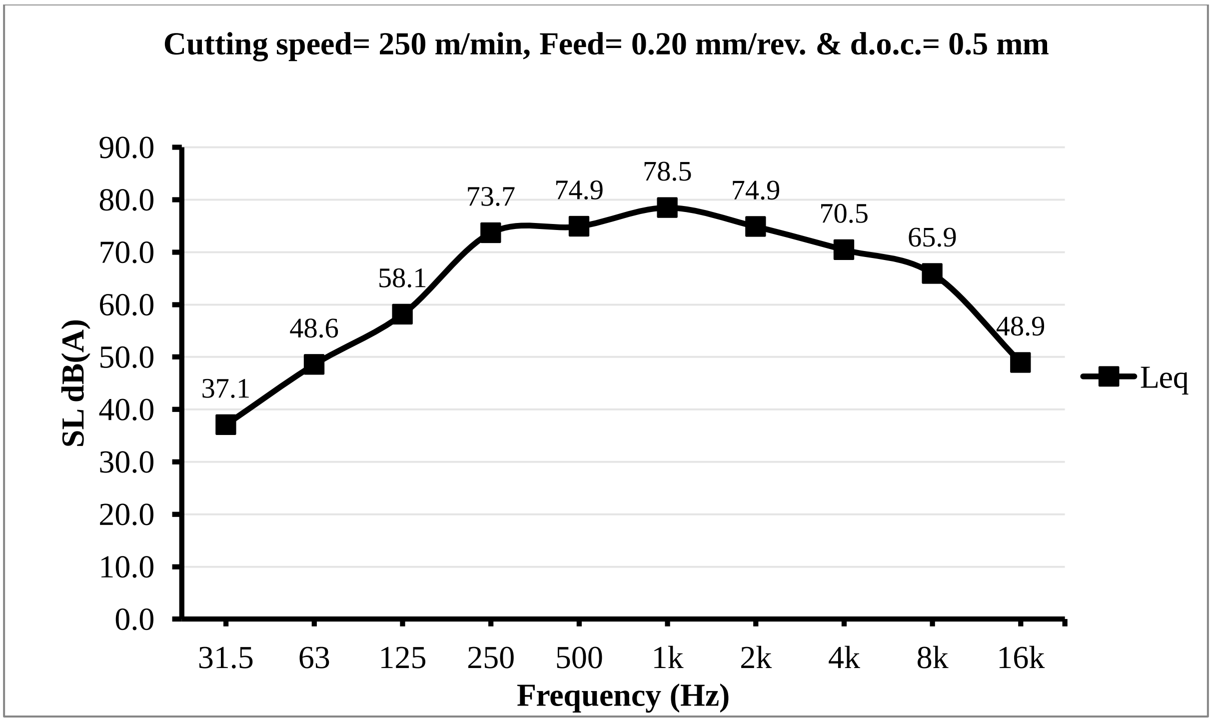


Figure 6.16 Sound Level Vs Frequency

From the graphs plotted it is found that the sound level was peak at frequency 1000 Hz in all the cases. At the low frequency sound level was quite small and also at 16000 Hz sound level was low. The maximum sound level at peak frequency was found to be 83.7 dB (A).

From the frequency spectrum analysis it was found that maximum peak frequency was 500 Hz. When the cutting speed varied from 225 m/min to 250 m/min peak frequency shifted from 500 Hz to 1000 Hz.

6.3 FREQUENCY SPECTRUM ANALYSIS WITH TOOL WEAR

After obtaining optimal parameters for lower sound level using analysis of variance, the cutting operation is performed on this optimal condition. During cutting operation the frequency spectrum analysis is done with the progression of flank wear (VB) of tool and data shown in APPENDIX-C. The flank wear of tool is measured using microscope.

Figure 6.18 to 6.23 show frequency spectrum for optimal parameters along with tool wear.

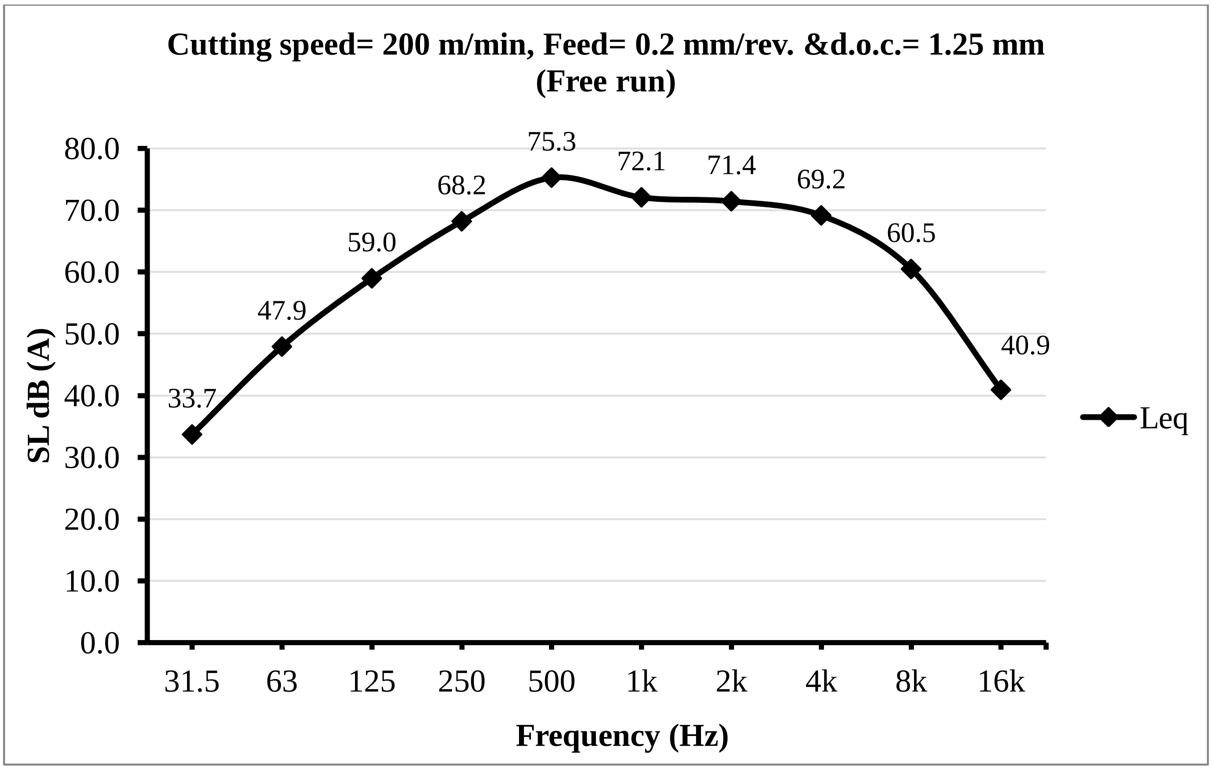


Figure 6.18 Sound Level Vs Frequency

Figure 6.18 shows frequency spectrum of sound when the machine tool was in free run (i.e. cutting was not performed) and the sound recorded referred as background noise. During free run the peak frequency was 500Hz and sound level corresponding to this frequency was 75.3 dB (A).

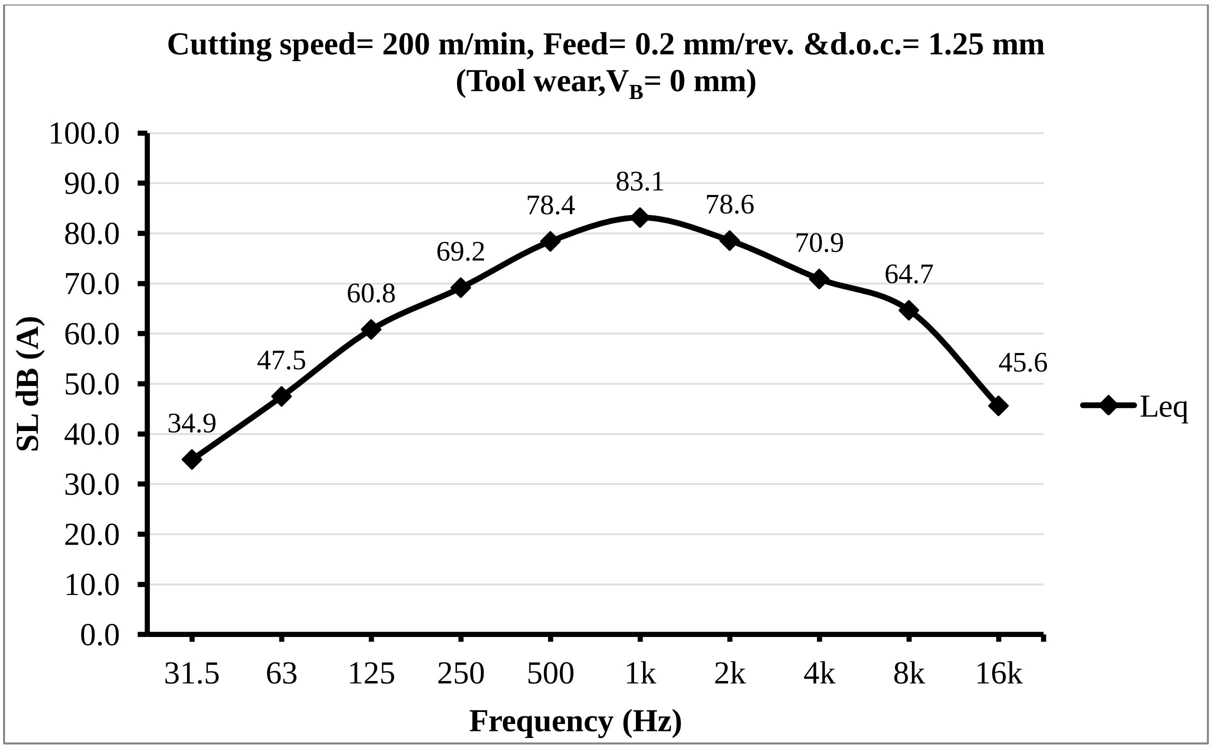


Figure 6.19 Sound Level Vs Frequency

Figure 6.19 shows frequency spectrum of sound when cutting operation is performed with fresh tool having zero flank wear (VB= 0 mm). During cutting operation the peak frequency was 1000 Hz and sound level corresponding to this frequency was 83.1 dB (A).

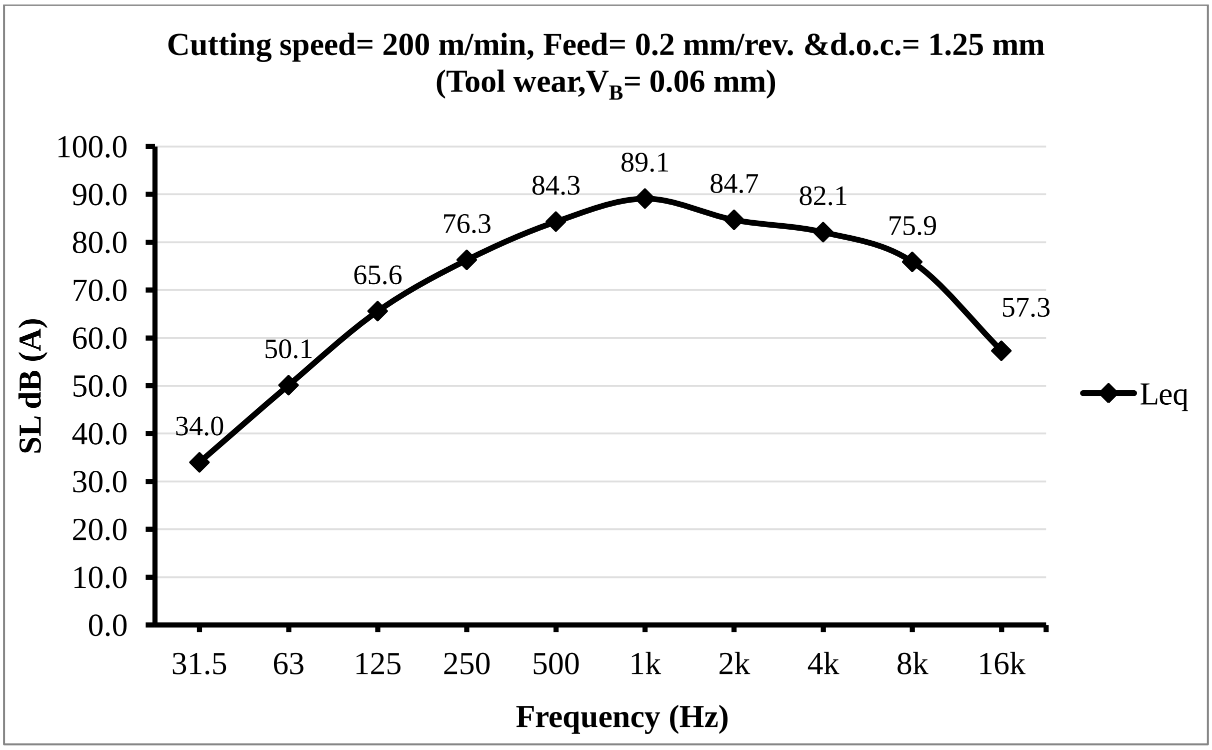


Figure 6.20 Sound Level Vs Frequency

Figure 6.20 shows frequency spectrum of sound when cutting operation is performed with cutting tool having flank wear of 0.06 mm (i.e. VB= 0.06 mm). During cutting operation peak frequency was 1000 Hz and sound level corresponding to this frequency was 89.1 dB(A).

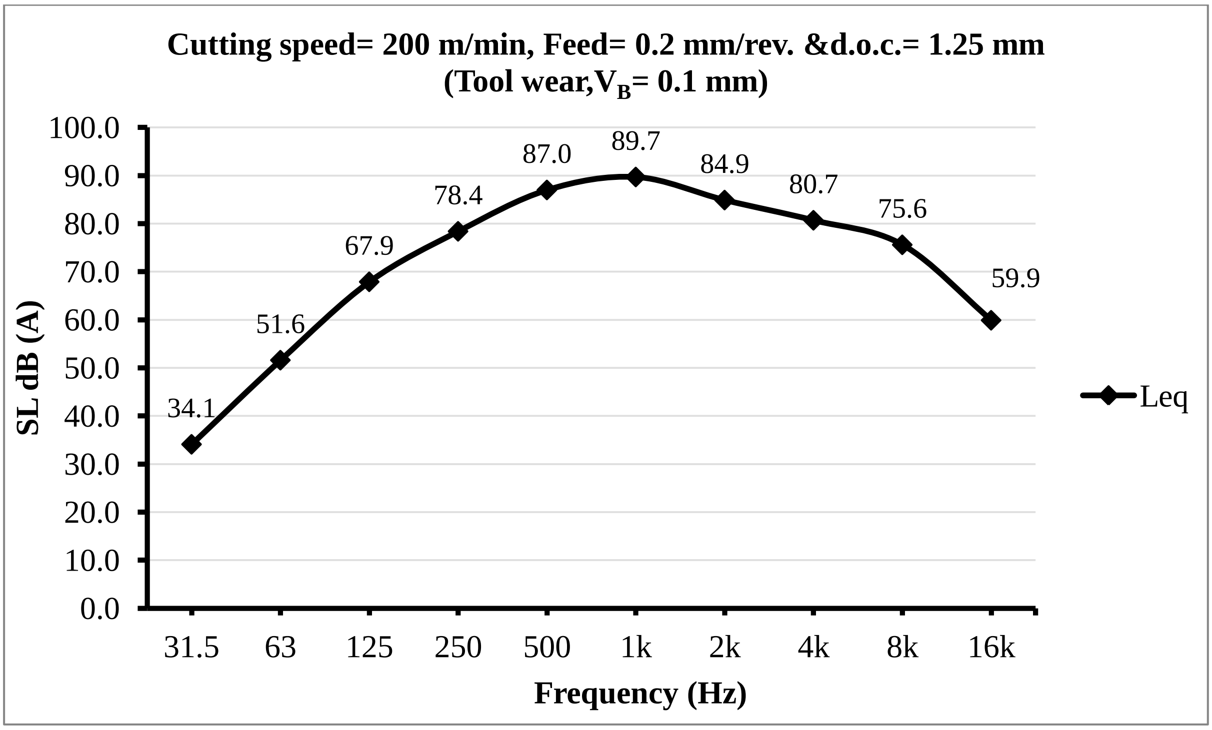


Figure 6.21 Sound Level Vs Frequency

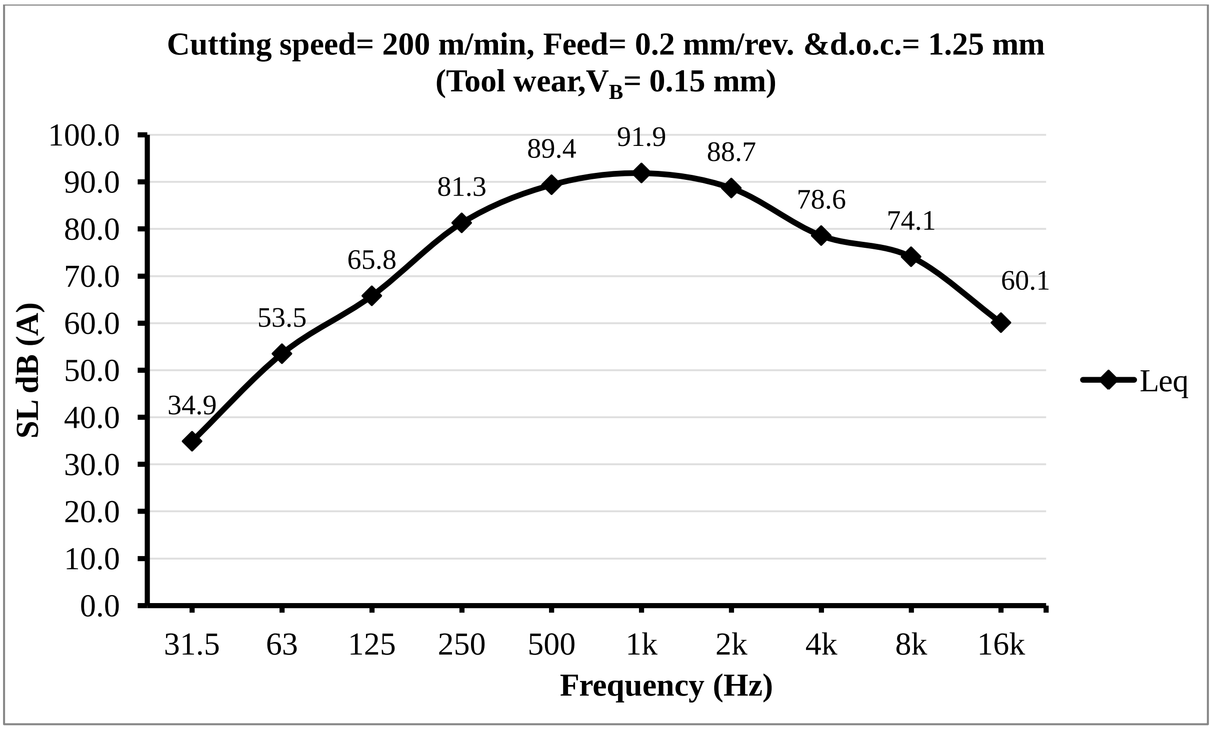


Figure 6.22 Sound Level Vs Frequency

Figure 6.22 shows frequency spectrum of sound when cutting operation is performed with cutting tool having flank wear of 0.15 mm (i.e. VB= 0.15 mm). During cutting operation peak frequency was 1000 Hz and sound level corresponding to this frequency was 91.9 dB(A).

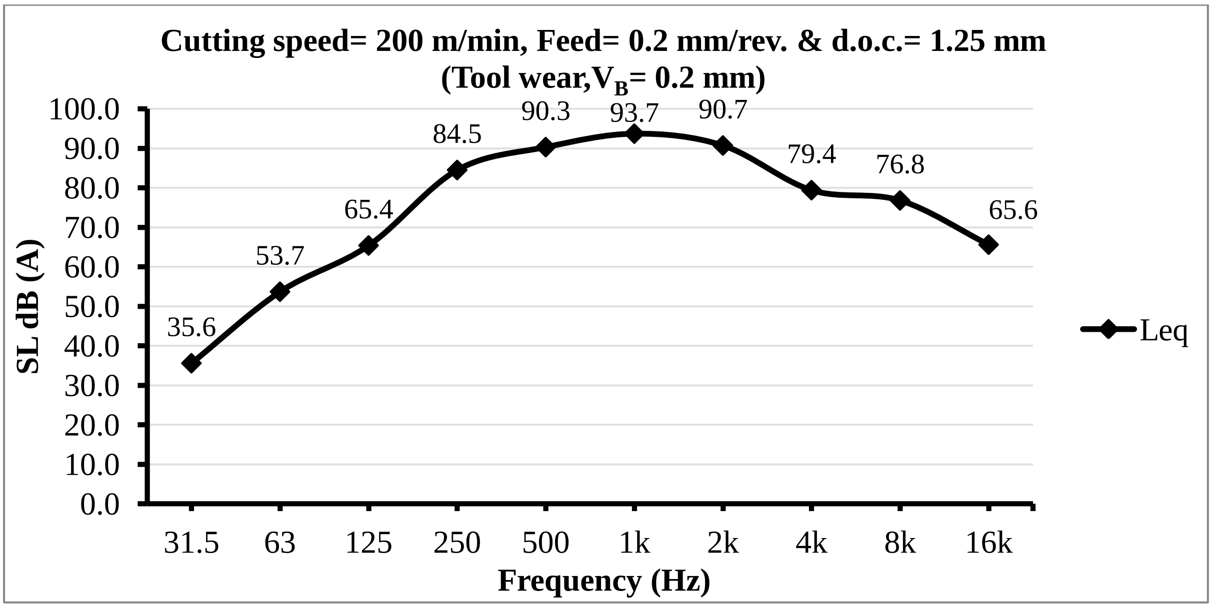


Figure 6.22 Sound Level Vs Frequency

Figure 6.23 shows frequency spectrum of sound when cutting operation is performed with cutting tool having flank wear of 0.2 mm (i.e. VB= 0.2 mm. During cutting operation peak frequency was 1000 Hz and sound corresponding to this frequency was 93.7 dB (A).

From above study is found that during the free run the peak frequency was 500 Hz , as the cutting operation was performed the peak frequency shifted to 1000 Hz. With the progression of tool flank wear from 0 mm to .2 mm the sound level at the peak frequency (i.e. 1000 Hz) increased from 83.1 dB(A) to 93.7 dB(A). Figure 6.24 shows the variation of frequency spectrum with increase in flank tool wear from 0 mm to .2 mm.

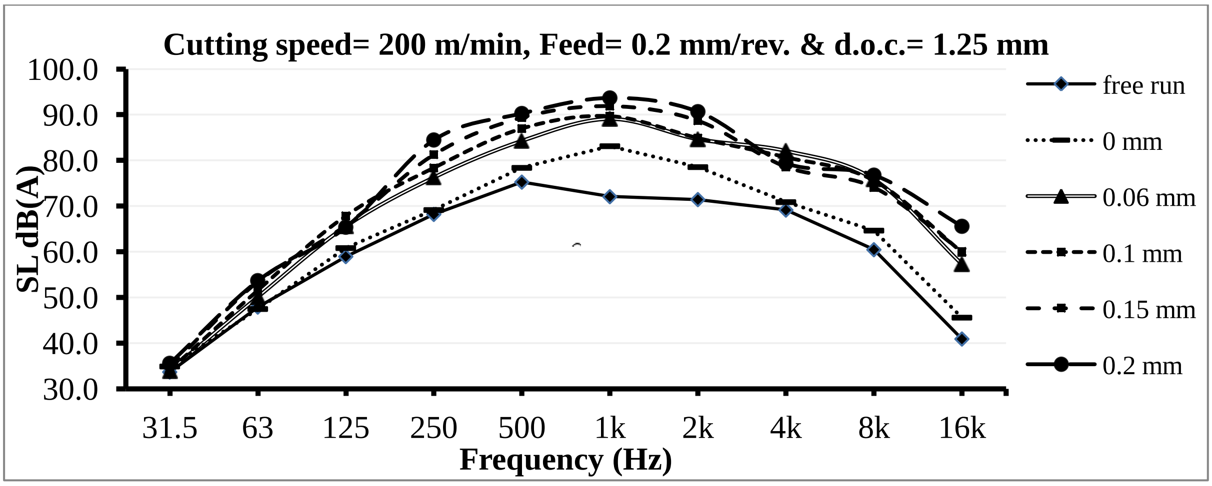


Figure 6.22 Sound Level Vs Frequency

CHAPTER 7

FINDINGS AND CONCLUSION

7.1 FINDINGS

From the analysis of variance it is found that the most affecting parameter on noise was cutting speed and feed having P values 0.012 and 0.013 respectively. Optimal parameters for lower sound level were found to be cutting speed 200 m/min, feed 0.2 mm/rev. and depth of cut 1.25 mm. When the cutting speed varied from 225 m/min to 250 m/min peak frequency shifted from 500 Hz to 1000 Hz. When the cutting operation was performed on optimal condition the peak frequency was 1000 Hz and as the tool flank wear increased from 0 mm to 0.2 mm the sound level at the peak frequency increased from 83.2 dB (A) to 93.7 dB (A).

7.2 CONCLUSION

On the basis of noise measurements recorded and the results generated the following conclusions are drawn from the study:

1. When the cutting speed varied from 175 m/min to 250 m/min the Leq sound level increased from 90.3 dB (A) to 94.9 dB (A) and when feed varied from .05 mm/rev. to 0.2 mm/rev. the Leq noise level decreased from 94.5 dB (A) to 86.7 dB (A) stating that increases in cutting speed increases the L_{eq} sound level and with the increases in feed the L_{eq} sound level decreases.
2. ANOVA was carried out to find out that which factor is most affecting during cutting operation. Analysis stated that the cutting speed and feed were most significant factor which affects the sound level values during cutting operation most.
3. Frequency analysis for 1/1 Octave band was done for different combination of parameters. The results stated that the peak frequency shifted from 500 Hz to 1000 Hz when cutting speed varied from 225 m/min to 250 m/min.
4. Frequency analysis for 1/1 octave band was also done for optimal parameters with the progression of tool wear. The results stated that the peak frequency in sound level was 1000 Hz during cutting operation and the sound level increases gradually from 83.1 dB(A) to 93.7 dB(A) with increase in tool wear from 0 mm to 0.2 mm respectively, shows that the sound level has direct correlation with tool wear. It helps in

determining the online tool wear measurement without affecting the machining process.

7.3 FUTURE SCOPE

The presented work can be extended by working upon different directions. Some of them are listed below:

- It is concluded from results that the maximum Leq sound level is at frequency of 1000 Hz. By using an intensity probe, parts will be found where the maximum sound level occurs at particular frequency.
- With the help of this analysis, it can be extended for other work and tool materials.
- It can be helpful in predicting online tool wear monitoring by measuring high peak frequency during cutting operations.

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APPENDIX-A

Measurement of sound levels at different combination of operating parameters

Exp. no.	Cutting speed (m/min)	Feed (mm/rev.)	Depth of cut (mm)	SL_1 dB(A)	SL_2 dB(A)
1	175	0.05	0.50	94.4	95.0
2	175	0.10	0.75	92.7	92.5
3	175	0.15	1.00	91.7	91.1
4	175	0.20	1.25	83.2	83.5
5	200	0.05	0.75	92.0	91.9
6	200	0.10	0.50	89.5	88.9
7	200	0.15	1.25	82.8	83.0
8	200	0.20	1.00	83.3	83.6
9	225	0.05	1.00	94.4	95.1
10	225	0.10	1.25	92.2	93.1
11	225	0.15	0.50	95.8	95.6
12	225	0.20	0.75	85.4	85.2
13	250	0.05	1.25	96.0	96.4
14	250	0.10	1.00	94.9	94.7
15	250	0.15	0.75	93.7	93.6
16	250	0.20	0.50	94.6	94.6

APPENDIX-B

1/1 octave band frequency spectrum data for different combination of parameters

Exp. No.	Cutting Speed (m/min)	Feed (mm/rev)	D.O.C (mm)	Frequency (Hz)									
				31.5	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**16000**
1	175	0.05	0.5	38.1	47.1	55.9	71.6	80.7	73.4	71.7	69.7	62.8	42.9
2	175	0.1	0.75	37.2	46.7	55.3	76.7	82.4	74.8	73.7	70.0	65.5	46.1
3	175	0.15	1	36.0	47.4	55.6	74.5	80.4	75.1	74.1	70.8	65.8	48.1
4	175	0.2	1.25	34.6	49.0	57.5	75.5	81.3	79.0	77.4	74.7	70.7	53.8
5	200	0.05	0.75	38.0	45.3	55.1	73.5	78.1	73.3	72.0	68.4	67.1	48.8
6	200	0.1	0.5	38.7	46.7	55.1	73.2	76.4	73.7	71.7	67.6	64.3	45.3
7	200	0.15	1.25	36.3	48.5	55.1	69.9	74.4	73.5	72.0	70.1	69.7	52.3
8	200	0.2	1	33.7	46.1	54.5	70.4	75.6	73.1	71.7	71.3	68.1	47.5
9	225	0.05	1	43.3	57.6	63.6	67.6	76.6	74.9	75.8	74.2	68.6	49.3
10	225	0.1	1.25	39.6	49.5	59.4	77.7	85.2	79.4	77.9	74.8	70.3	50.6
11	225	0.15	0.5	36.7	47.0	56.9	73.2	81.3	75.9	75.7	75.1	69.1	49.7
12	225	0.2	0.75	35.9	48.6	57.5	74.6	82.4	79.8	79.5	76.4	70.9	51.3
13	250	0.05	1.25	34.9	48.1	56.9	68.8	73.2	74.5	73.5	72.4	67.0	49.7
14	250	0.1	1	36.4	46.7	56.6	77.2	75.5	83.7	75.2	71.3	68.4	49.9
15	250	0.15	0.75	36.0	46.5	54.7	70.6	78.4	83.9	76.4	73.2	70.1	51.7
16	250	0.2	0.5	37.1	48.6	58.1	73.7	79.4	78.5	74.9	70.5	65.9	48.9

APPENDIX-C

1/1 octave band frequency spectrum data for optimal parameters with tool wear

	Frequency									
Tool wear (VB)	**31.5**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**	**16k**
free run	33.7	47.9	59.0	68.2	75.3	72.1	71.4	69.2	60.5	40.9
0 mm	34.9	47.5	60.8	69.2	78.4	83.1	78.6	70.9	64.7	45.6
0.06 mm	34.0	50.1	65.6	76.3	84.3	89.1	84.7	82.1	75.9	57.3
0.1 mm	34.1	51.6	67.9	78.4	87.0	89.7	84.9	80.7	75.6	59.9
0.15 mm	34.9	53.5	65.8	81.3	89.4	91.9	88.7	78.6	74.1	60.1
0.2 mm	35.6	53.7	65.4	84.5	90.3	93.7	90.7	79.4	76.8	65.6