Experimental Analysis of Boring Tool Vibrations Fitted with Passive Dampers

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***Abstract*— Boring operation is most commonly used to enlarging the previously drilled hole. When the hole size is small in diameter and depth is more then the slender boring tool is used. The length to diameter ratio of this boring tool is high and there is always a possibility of boring tool deflection. As the cutting forces are exerted at the free end of the boring tool, the vibration is introduced. The vibration produces the undesirable effects in the form of poor surface finish, reduced tool life etc. To minimize the level of vibration in the boring operation many researchers have used different techniques. This vibration reduction techniques are mainly of active and passive type. From the literature survey it is seen that the passive vibration reduction techniques are becoming more popular due to its inherent advantages.**

In this dissertation work a passive damper is used to investigate the performance of boring tool under vibratory conditions. The experiments for boring operation are carried out using boring tool with and without passive damper. The frequency domain analysis is carried out using FFT analyzer. The machining parameters are varied by changing spindle speed, feed rate and depth of cut. Whereas the passive damper characteristics are altered by using different materials (Viscoelastic and Composite) and damper length (0. 3 and 0.6 times boring tool overhang). The results in the form of vibration acceleration (RMS value) and surface roughness (Ra value) are compared for conventional boring tool and boring tool fitted with passive damper. From the analysis it is observed that the overall vibration decreases due to composite passive damper and also helps to improve the surface finish.

Keywords*— *Boring Tool, Passive Damper, Viscoelastic Material, Composite, FFT Analyzer, Vibration, Surface Roughness.

I. INTRODUCTION

In any machine structure due to dynamic motion the vibration is inherently present. Minimizing the effects of vibration for satisfactory performance of any system is the great task in front of any design engineer. The structure or substructure present in any system which is not firmly supported or a very little chance to support completely is prone to expose to the vibration which will deteriorate its performance. The cantilever type structures are falls under this category. Many researchers are working to develop a support system or damping devices which can alleviate the causes of vibration and helps to improve the performance.

A Machining Basics

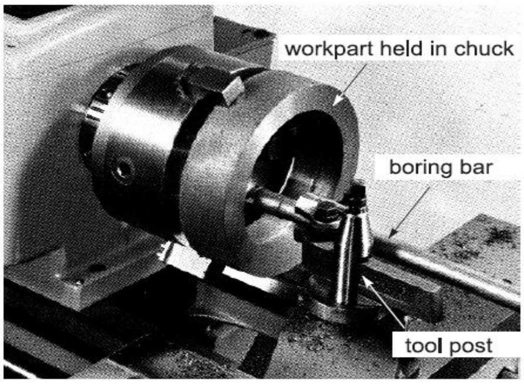
Machining is a general term describing a group of processes that consist of the removal of material and modification of the surfaces of a workpiece after it has been produced by various methods. Thus, machining involves secondary and finishing operations. The very wide variety of shapes produced by machining can be seen clearly in an automobile.

It also should be recognized that some parts may be produced to final shape and at high quantities by forming and shaping processes, such as die casting and powder metallurgy. However, machining may be more economical, provided that the number of parts required is relatively small or the material and shape allow the parts to be machined at high rates and quantities and with high dimensional accuracy. Furthermore, in spite of their advantages, material-removal processes have the following disadvantages:

i) They waste material (although the amount may be relatively small).
ii) The processes generally takes longer than other processes.
iii) They generally require more energy than do forming and shaping operations
iv) They can have adverse effects on the surface quality and properties of the product.

B Boring Operation

Fig. 1 Boring operation on a lathe



Boring is a process of producing circular internal profiles on a hole made by drilling or another process. It uses single point cutting tool called a *boring bar*. In boring, the boring bar can be rotated, or the workpart can be rotated. Machine tools which rotate the boring bar against a stationary workpiece are called *boring machines* (also *boring mills*). Boring can be accomplished on a turning machine with a stationary boring bar positioned in the tool post and rotating workpiece held in the lathe chuck as illustrated in the figure 1.1. In this section, we will consider only boring on boring machines.

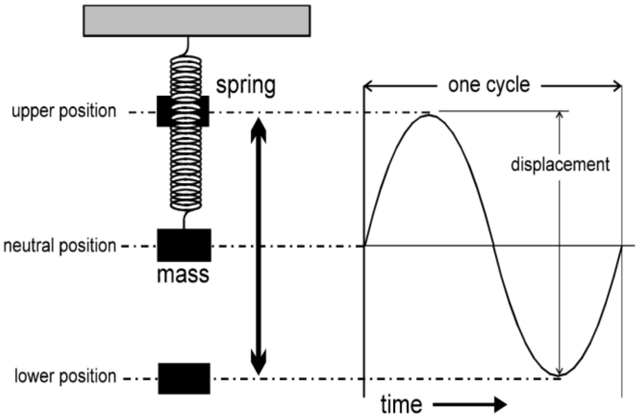
Boring on a lathe is similar to turning. It is performed inside hollow workpieces or in a hole made previously by drilling or other means. Out-of-shape holes can be straightened by boring. The workpiece is held in a chuck or in some other suitable work-holding device. In machining, boring is the process of enlarging a hole that has already been drilled or cast, by means of a single-point cutting tool or of a boring head containing several such tools. The boring operation is also sometimes referred as internal turning operation and which requires due care to attain a desired manufacturing requirements. The dimensions of the workpiece hole generally determine the length and limit of the diameter or cross sectional size of the boring bar. In boring, the long, cantilevered boring bars have inherently low stiffness and become the weakest link in the boring bar-clamping system of the lathe. If the static/dynamic rigidity of these cantilever elements is inadequate, they directly limit the attainable accuracy, due to the easy deflection of the boring bar, even under low magnitude cutting forces, indirectly limit accuracy, the high-frequency micro-vibrations produce noticeable wear in the cutting inserts during each cutting cycle which results in tapered surfaces instead of the required cylindrical ones and limit machining regimes through the generation of self-excited vibrations even at relatively low cutting regimes when the length-to-diameter (L/D) ratio of the boring bar exceeds 4:1.

Boring under conditions with high vibrations in the cutting tool deteriorates the surface finish and may cause tool breakage. Severe noise is also a consequence of the high vibration levels in the boring bar. Active control and passive system are possible solution to the noise and vibration problem in boring operations. In boring operations the boring bar usually have vibration components in both the cutting speed and the cutting depth direction. The introduction of the control force in different angles in between the cutting speed and the cutting depth directions have been investigated. Furthermore, control path estimates produced when the active boring bar was not in contact with the workpiece and during continuous cutting operation are compared. Experimental results indicate that the control force should be introduced in the cutting speed direction. Although the vibrations are controlled in just the cutting speed direction the vibrations in the cutting depth direction are also reduced significantly.

C Vibration Basics

Any motion that repeats itself after an interval of time is called vibration or oscillation. Mechanical systems are prone to vibrate if they can store energy in two different forms, usually potential and kinetic, in a way that energy can flow from one form to the other. Vibration is the process in which this energy exchange takes place. If a system, after an initial disturbance, is left to vibrate on its own, the ensuring vibration is known as free vibration. If a system is subjected to an external force (often, a repeated type of force), the resulting vibration is known as forced vibration. A vibratory system is a dynamic system for which the variables such as the excitations (inputs) and responses (outputs) are time dependent. The maximum displacement of vibrating body from its equilibrium position is called the amplitude of vibration. The time taken to complete one cycle of motion is known as the period of oscillation or time period and the number of cycles per unit time is called the frequency of oscillation or the simply frequency.

Fig.2 A Free Body Diagram of Forced Vibration

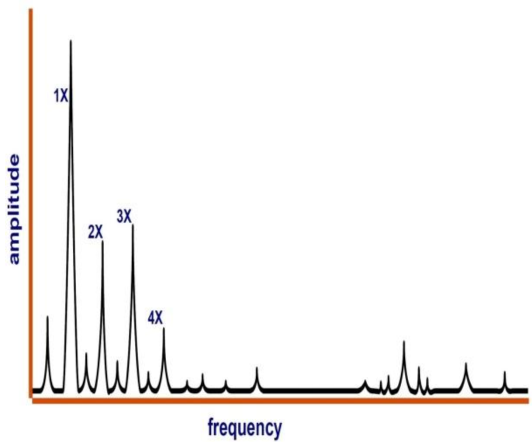


D Vibration in Machining

The designer of any machine or system has usually to deal with vibration. Although there are cases where vibration is a desired effect (vibrating sieves, vibration welding machines, etc.), usually the task of the designer is to minimize, or at least to control, it. When it is not possible to act on what excites vibration or to insulate the relevant element from it, the traditional approach to keep vibration under control is to act on the elastic and inertial characteristics of the system to modify the frequencies at which free vibration takes place (these modifications may include the addition of a further mechanical system operating as a vibration absorber) or to increase the damping properties of the system. Often both actions are required, like when using damped vibration absorbers. Several mechanisms can be used to dissipate energy during vibration. Those traditionally employed are; (i) Dry friction between two surfaces moving in contact with each other; (ii) Internal damping of some materials; (iii) Viscous forces in a fluid. Dry friction is today relied upon only for small quantities of energy, and in very simple machines.

Vibration amplitude indicates the severity of the problem. Vibration frequency indicates the source of the problem.

Fig.3 Graph of Frequency Vs Amplitude



E Measurable Characteristics of Vibration

Velocity is the first derivative of displacement as a function of time, it is the rate of change in displacement (the speed of the vibration).
Acceleration is the second derivative of displacement, it is the rate of change of velocity (the change in speed of the vibration).
Measurements & Units
Displacement(Distance) mils or micrometer, mm
Velocity(Speed-Rate of change of displacement)in/sec or mm/sec
Acceleration(Rate of change of velocity)G's or in/sec^2 or mm/sec^2

TABLE I Relation between Displacement-Velocity-Acceleration

Displacement (D)	$D = \frac{V}{\pi F}$	$D = \frac{GA}{2\pi^2 F^2}$	$D = \frac{2V^2}{GA}$
Velocity (V)	V=πFD	$V = \frac{GA}{2\pi F}$	V=$\sqrt{GDA/2}$
Acceleration (A)	A=$\frac{2\pi^2 F^2 D}{G}$	A=$\frac{2\pi FV}{2\pi}$	$A = \frac{2V^2}{GD}$
Force (F)	F= $\sqrt{GA/2\pi^2 D}$	$F = \frac{V}{\pi D}$	$F = \frac{GA}{2\pi V}$

*G = Gravitational acceleration = 9.80665 m/s^2

F Vibration in the Boring Operation

Today's concern in the manufacturing industry is the vibrations introduced during metal cutting, e.g. turning, milling and boring operations etc. Turning operations, and especially boring operations, are facing severe vibration related problems. To reduce the problem of vibration additional must be taken at the production planning stage and preparation regarding the setting up the machining parameters e.g. speed, feed, depth of cut etc. with respect to workpiece material, in order to obtain a desired shape with given surface finish, material removal rate and geometrical tolerance. Thus, the vibration problem in metal cutting has a considerable influence on important factors such as productivity, production costs, etc. A thorough investigation of the vibrations involved is therefore an important step in resolving this problem.

II. PROBLEM DEFINITION

A boring operation is a metal cutting operation that bores deep, precise holes in the workpiece and use to enlarge existing hole. A tool used to perform the boring operation is called as boring bar and is characterized by great length in comparison to its diameter. The boring bar is clamped at one end to a tool post or a collet and has a insert attached at the free end. The cutting tool is used to perform metal cutting in a bore or cavity of the workpiece. Since a boring bar is usually long and slender, it is tends to vibrate. Deep internal turning (i.e. boring) of a workpiece is a classic example of chatter-prone machining. Performing metal cutting under vibrating conditions will yield unsatisfactory results in terms of the surface finish of a workpiece, toollife and undesirable noise levels. In internal turning operations, the boring bar motion usually consists of force components in both the cutting speed direction and the cutting depth direction (refer chapter 1 for force analysis).

A Influence Of Vibration On Boring Process

The cutting system is well understood as a particular combination of the cutting speed, cutting feed (feed rate), and depth of cut (which are known as process parameters). It is well known that the listed parameters of the cutting system affect the tool life and subsequently the quality of product.

Influence of the cutting feed in a wide range of cutting parameters. The uncut chip thickness or the cutting feed has a direct influence on the quality, productivity, and efficiency of machining. It is believed that the tool life decreases (and, thus, tool wear increases) with increasing cutting feed. Such a conclusion follows from the generally adopted equation for tool life. For example, generalizing the experimental data, Gorczyca [5] proposed the following relation:

$$T = \frac{48.36 \times 10^6}{v^4 f^{1.6} d_w^{0.48}}$$

Where,
$v =$ cutting speedin m/min.
$f =$ feed in mm/revolutions
$d_{w=}$depth of cut in mm
If the cutting speed v and the depth of cut d_w are both constant, then it follows from Eq. that tool life decreases when the cutting feed f is increased.

1) *Influence of the cutting feed under the optimal cutting temperature*

Understanding the influence of the cutting feed under the optimal cutting temperature is important in the selection of the optimal cutting system because the optimal combination of cutting speeds and feeds should be used in the practice of metal cutting.

2) *Influence of the depth of cut*

When the depth of cut increases and the uncut chip thickness is kept the same, the specific contact stresses at the tool–chip interfaces, the chip compression ratio (defined as the radio of the chip and the uncut chip thicknesses), and the average contact temperature remain unchanged. Therefore, an increase in the depth of cut should not change the tool wear rate if the machining is carried out at the optimum cutting regime.

3) *Influence of Tool length*

Using short tool length always provide good surface roughness no matter what cutting parameter level or type of boring bar are used; only slight improvement on surface roughness can be achieved by properly controlling cutting speed, feed rate or tool nose radius. Using long tool length may set excessive vibrations, noise that could be efficiently controlled by use of damped boring bar.

III. DESIGN AND DEVELOPMENT OF PASSIVE DAMPER

In this chapter the design and development of passive damper for cantilever type structure (specifically boring bar) is presented. Presently the concept of passive damping is in the preliminary stage and many researchers are working to develop the passive damper or improve the existing one. The utility of the passive damper is now well establish and development of one of such becomes the important task. The schematic arrangement of mechanical system with damping element is shown below.

A Active Control

The objective of active vibration control is to reduce the vibration of a mechanical system by automatic modification of the system's structural response. The principle of active control of vibration in machining is to analyze in real time the signal emitted during machining, recognize instability (chatter) and compensate for it. For this purpose different techniques can be used. One way is to predict the arising of chatter and consequently change the cutting parameters before the full instability occurs. Another approach for active control is to compensate in real time for the dynamic forces that arise during the cutting process. This method consists a tool design with piezoelectric actuators and force sensors with inter changeable tool head. An active control system for boring bars using accelerometers on the tool for providing the controller with both reference and error signal. The signals are processed and sent eventually to the actuators located in the tool clamp, which compensates by providing dynamic forces to the boring bar. The apparent advantage of the active vibration control approach is the perfect adaptability to the changes in the cutting conditions; all the above mentioned techniques are based on online adaptation to the ongoing process to ensure stability.

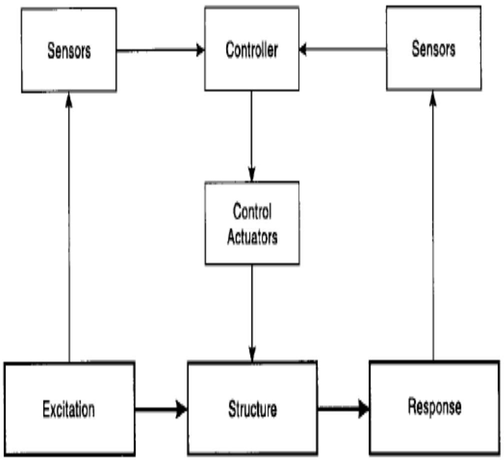
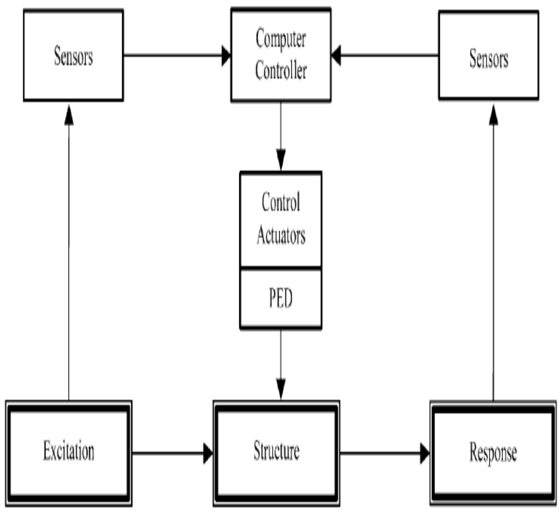


Fig. 4 Structure with Active Control System

Active control System consists sensors to detect the vibration, an electronic controller to process the signal from the sensors and actuators to interfere with the mechanical response of the system. From the actuators a secondary oscillatory response is generated in order to cancel the original response of the system causing cutting instability. Such active control systems need cables for data transfer and energy supply that can interfere with the machining process. Active control systems have been proved to be efficient in laboratory environment but its industrial application has not been welcomed by the end-users due to the complexity of the hardware. The drawback of this approach is the required computation resources and hardware: the system has to process the acquired signal for chatter recognition in real time, and the amount of data can be large. In addition to this, the presence of cables between the control system and the tools could compromise the machining operation.

B Semi Active Control

Fig.5 Structure with Semi-Active Control System

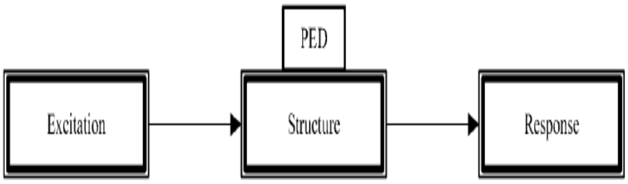


Semi active control systems are a class of active control systems for which is the external energy requirements are smaller amounts than those of typical active control. A battery power, for instance, is sufficient to make them operative. Semi-Active cannot add or remove energy to the structural system, but can control in real time parameters of the structure such as spring stiffness or coefficient of viscous damping. The stability is guaranteed, in the sense that no instability can occur, because semi-active devices utilize the motion of the structure to develop the control forces. Semi-active damping devices with specific control laws have yielded reductions in displacement and structural force, while simultaneously reducing the total base-shear transmitted to the foundation from both structural column and damping forces. Various types of semi-active damping devices have recently been developed in the civil engineering field for controlling structures. The variable oil damper or MR damper, which can control its damping coefficient, are typical examples, and some devices have recently been installed in actual buildings.

C Passive Control

The principle of vibration passive control is to convert the mechanical energy into some other forms, for instance heat. A common way to achieve passive damping is by using viscoelastic (VE) materials to dissipate the energy that causes vibration. The use VE composite materials for damping purposes is quite common, this technique has been used in other fields of application, such as automotive, aeronautics, spacecraft, structural etc. VE composite materials are used for damping enhancement generically in three different ways: as free-layer dampers (FLD), as constrained-layer dampers (CLD) and in tuned viscoelastic dampers (TVD)

Fig.6 Structure with Passive Energy Dissipation (PED)



The basic principle of TVD technique is to add amass residing on a spring and a viscous damper at the point of maximum displacement. This additional single degree of freedom (SDOF) system must have the natural frequency close to that of the boring bar in order to transfer the vibrational energy to the TVD. If the damper is properly designed it will dissipate the mechanical energy. The absorber is tuned by changing the stiffness of the additional system.TVD technique is already successfully used in several successful commercial products. When implementing such a solution it is of vital importance for the design to properly locate the pre-stressed VE composite layers in the structure to optimally exploit the property of VE material to give largest deformation in shear.

D Viscoelastic Material

Viscoelasticity may be defined as material response that exhibits characteristics of both a viscous fluid and an elastic solid. An elastic material such as a spring retracts to its original position when stretched and released, whereas a viscous fluid such as putty retains its extended shape when pulled. A viscoelastic material (VEM) combines these two properties—it returns to its original shape after being stressed, but does it slowly enough to oppose the next cycle of vibration. The degree to which a material behaves either viscously or elastically depends mainly on temperature and rate of loading(frequency). Many polymeric materials (plastics, rubbers, acrylics, silicones, vinyls, adhesives, urathanes, and epoxies, etc.) having long -chain molecules exhibit viscoelastic behavior. The dynamic properties (shear modulus, extensional modulus, etc.) of linear viscoelastic materials can be represented by the complex modulus approach. The introduction of complex modulus brings about a lot of convenience in studying the material properties of viscoelastic materials. The material properties of viscoelastic materials depend significantly on environmental conditions such as environmental temperature, vibration frequency, pre-load, dynamic load, environmental humidity and so on. Therefore, a good understanding of such effects, both separately and collectively, on the variation of the damping properties is necessary in order to tailor these materials for specific applications.

Passive damping using viscoelastic materials is used widely in both commercial and aerospace applications. Viscoelastic materials whose long chain molecules cause them to convert mechanical energy into heat when they are deformed. Perhaps the most important advantage of VEMs is their high loss factor and low storage modules. The loss of factor is measure of energy dissipation capacity of the material, and the storage modulus is a measure of the stiffness of material. The storage modulus(shear modulus) is important in determining how much energy gets into the viscoelastic, and loss factor determines how much energy is dissipated. both the shear modulus and loss factor of VEMs are temperature and pressure dependent, though temperature has a great effect on damping performance.

TABLE: 2 List of common viscoelastic polymeric materials
(Jones, "Handbook of Viscoelastic Damping," 2001)

Sr. No.	**Viscoelastic materials**
1	Acrylic Rubber
2	Butadiene Rubber (BR)
3	Butyl Rubber
4	Butyl 60 A(98%=Isobutylene &
5	Chloroprene
6	Chlorinated Polyethylenes
7	Ethylene-Propylene-Diene
8	Fluorosilicone Rubber
9	Fluorocarbon Rubber
10	Nitrile Rubber
11	Natural Rubber
12	Polyethylene
13	Polystyrene
14	Polyvinyl Chloride (PVC)
15	Polymethyl Methacrylate (PMMA)
16	Polybutadiene
17	Polypropylene
18	Polyisobutylene (PIB)
19	Polyurethane
20	Polyvinyl Acetate (PVA)
21	Polyisoprene
22	Styrene-Butadiene (SBR)
23	Silicone Rubber
24	Silicon 50 A Rubber
25	Urethane Rubber
26	Vinyls
27	Epoxies (Carbon fiber Epoxies)
28	Thermoplastics
29	Polytetra Fluorethylene(PTFE)
30	Adhesives

E Comparison between Active, Semi-Active and Passive Damping Systems

The passive control System does not need complicated hardware and the end-user does not need to introduce new handling routines. Advantages of using passive damping system such as low cost, Predictable response, robustness, low complexity and ease to implementation ensures use of passive control system rather than active system in machining especially boring operations. Passive systems also have some key advantages over fully active or semi-active systems. A passive system does not require any sensing, computing or actuation mechanisms and can thus be relatively inexpensive to manufacture and implement. Passive systems developed and currently used for energy absorption.

F Development Of Passive Damper For Boring Bar (Cantilever System)

Fig.7 Damped Boring Bar Tool with Aluminium and PTFE Material

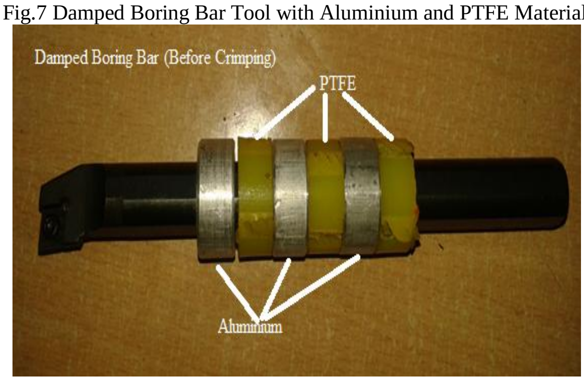


Fig.8 Damped Boring Bar Tool with PTFE Material

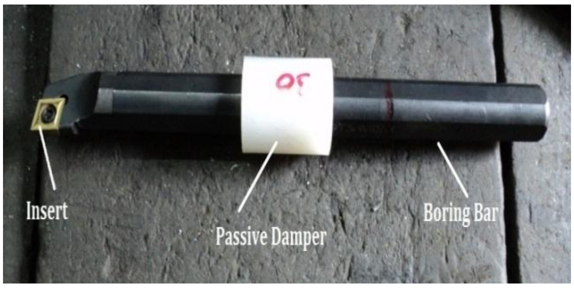


Fig.9 Damped Boring Bar (After Crimping)

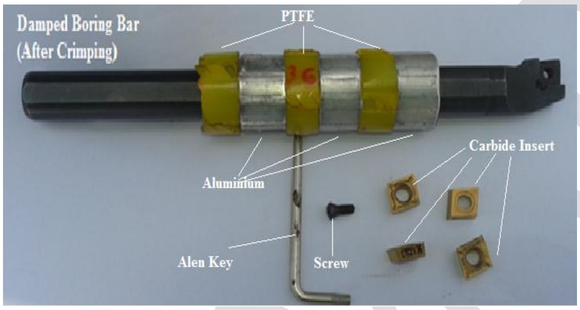
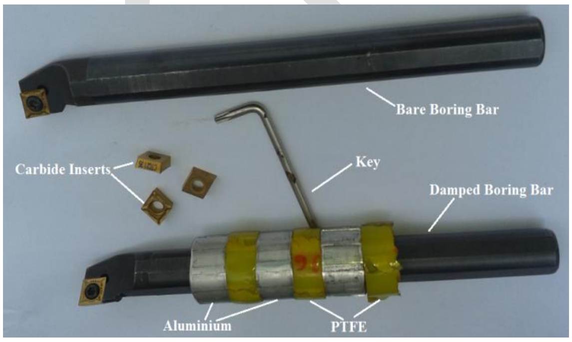


Fig.10 Conventional Boring Bar and Passive Damper with Composite Material



A specific size 3 rings each (Do=21 mm, Di=16 mm, L=12.5) are manufactured on lathe machine with PTFE and Aluminium materials. Two Passive dampers (one is Aluminium & PTFE and second is PTFE Materials) are developed. Damping materials are placed on specific distance(50 mm from tip) from one end crimped with crimping machine Final developed passive damper is as shown in figure(7, 8, 9 & 10)

IV. EXPERIMENTATIONS

For conducting any successful experiment, there is a requirement of rigorous planning and background study of the subject. From the understanding of basics of manufacturing and literature review of past and present research, a problem is clearly defined. From the problem definition it is observed that, vibration created due to large overhang and smaller cross-section of the boring bar. The level of vibration is significantly increased and surface finish obtained after machining is poor. The today's industry requirement is to achieve good surface finish to meet the customers' quality requirements. It is planned to use a passive technique of vibration isolation so that much cost will not be involved.

Following sections of the chapter will explain the procedure of planning and conduction of experiments.

A. Outline Of Experimental Procedure

Experiments are carried out by researchers or engineers in all fields of study to compare the effects of several conditions or to discover something new. If an experiment is to be performed most efficiently, then a scientific approach to planning it must be considered. The statistical design of experiments is the process of planning experiments so that appropriate data will be collected, the minimum number of experiments will be performed to acquire the necessary technical information, and suitable statistical methods will be used to analyze the collected data.

The statistical approach to experimental design is necessary if we wish to draw meaningful conclusions from the data. Thus, there are two aspects to any experimental design: the design of the experiment and the statistical analysis of the collected data. They are closely related, since the method of statistical analysis depends on the design employed.

B. The Role of Experimental Design

1. Improving the performance of a manufacturing process. The optimal values of process variables can be economically determined by application of experimental designs.
2. The development of new processes. The application of experimental design methods early in process development can result in reduced development time, reduced variability about target requirements and enhanced process yields.
3. Screening important factors. Fractional factorial designs using orthogonal arrays are often used in order to screen important factors that impact product performance. This will help to enhance the efficiency of research activities.
4. Engineering design activities such as evaluation of material alterations, comparison of basic design configurations, and selections, comparison of basic

design configurations, and selection of design parameters so that the product is robust to a wide variety of field conditions.

5. Empirical model building to find out the functional relationship between the performance variable and the influence variables (factors or design/process parameters.)

C. Classification of Experimental Designs

1. Factorial design
2. Fractional factorial design

This is a design for investigating a fraction of all possible treatment combinations which are formed from the factors under investigation. Once again, the order in which the treatment combinations are chosen is completely random. Designs using tables of orthogonal arrays, Plackett-Burman designs, Latin square designs (when we assign factors to the rows and columns of a Latin square) and Graeco-Latin square designs are fractional factorial designs. This type of design is used when the cost of experiment is high and the experiment is time-consuming.

3. Randomized complete block design, split-plot design and nested design.
4. Incomplete block design
5. Response surface design and mixture design.

Following section of this chapter discuss about the experimental setup and tools used for conducting the experiments.

D. The Taguchi System Of Quality Engineering

Dr. Genichi Taguchi has introduced more cost effective engineering methodology namely robust design to deliver high quality products at low cost through research and development. It can greatly improve an organization's ability to meet market windows, keep development and manufacturing costs as low as possible. Robust design uses any ideas from statistical experiment design and adds a new dimension to it by explicitly addressing two major concerns faced by all products and process designers:

- How to reduce economically the variation of a product's function in the customer's environment?
- How to ensure that decisions found optimum during laboratory experiments will prove to be valid and reliable in manufacturing and customer environments?

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community

The major steps of implementing the Taguchi method are: (1) to identify the factors/interactions, (2) to identify the levels of each factor, (3) to select an appropriate orthogonal array (OA), (4) to assign the factors/interactions to columns of the OA, (5) to conduct the experiments, (6) to analyse the data and determine the optimal levels, and (7) to conduct the confirmation experiment.

Signal-To-Noise Ratio

In the field of communication engineering a quantity called the signal-to-noise (SN) ratio has been used as the quality characteristic of choice. Taguchi, whose background is communication and electronic engineering, introduced this same concept into the design of experiments. Two of the applications in which the concept of SN ratio is useful are the improvement of quality via variability reduction and the improvement of measurement. The control factors that may contribute to reduced variation and improved quality can be identified by the amount of variation present and by the shift of mean response when there are repetitive data. The SN ratio transforms several repetitions into one value which reflects the amount of variation present and the mean response. There are several SN ratios available depending on the type of characteristic: continuous or discrete; nominal-is-best, smaller-the-better or larger-the-better. In this section we will only discuss the case when the characteristic is continuous. The discrete case will be explained later.

1) Nominal is Best Characteristics

2) Smaller the Better Characteristics

3) Larger the Better Characteristics

There are cases where The-Larger-The-Better is applicable to characteristics such as the strength of materials and fuel efficiency. In these cases, there are no predetermined target values, and the larger the value of the characteristic, the better it is.

The corresponding SN ratio of Larger-the-Better is;

$$SN = -10\ 1og\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

Note that the target value of 1/y is 0 in the larger-the-better characteristic. The SN equations are based on the loss function when there is a set of n characteristics. If we employ the loss- function approach for the nominal-is-best case, we can derive the following SN equation:

$$SN = -10\ 1og\left(\frac{1}{n}\sum_{i=1}^{n}\left(y_i - m\right)^2\right)$$

This form of equation may be more desirable for three reasons. First, where y_i can take a negative or positive value, it is possible for S_m to be less than V, so that equation cannot be used. Second, as y increases, SN increases. However, if y is greater than the target value m, the bigger y becomes the worse. Hence, where y is bigger than m, SN does not reflect desirable situations. Third, the SN values are not based on the concept of the loss function, and are not consistent with the loss function.

E. Orthogonal Arrays

Many designed experiments use matrices called orthogonal arrays for determining which combinations of factor levels to use for each experimental run and for analyzing the data. In the past, orthogonal arrays were known as 'magic squares'. Perhaps the effectiveness of orthogonal arrays in experimental design is magic. What is an orthogonal array?

An orthogonal array is a fractional factorial matrix which assures a balanced comparison of levels of any factor or interaction of factors. It is a matrix of numbers arranged in rows and columns where each row represents the level of the factors in each run, and each column represents a specific factor that can be changed from each run. The array is called orthogonal because all columns can be evaluated independently of one another.

There are 18 orthogonal array tables in the catalogue of Taguchi, these being denoted by $L_N(s^k)$ or just by L_N. Here, $L_N(s^k)$ is a matrix with dimension N× k, s distinct elements and the property that every pair of columns contains all possible s^2 ordered pairs of elements with the same frequency. In particular, N is the number of rows and k the number of columns in the orthogonal array. Elements of an orthogonal array can be numbers, symbols or letters.

F. Workpiece

EN9 is used as workpiece material for conducting the experiments.

Fig.11 Unfinished work-pieces

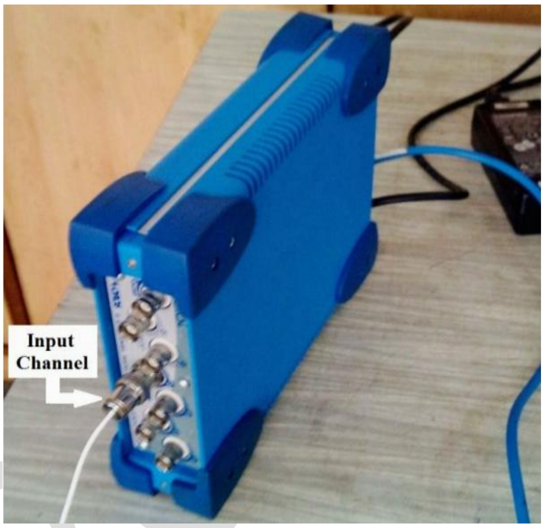
Fig.12 Unfinished work-pieces

Fig.13 Semi-finished (made true) work-pieces

G. FFT Analyzer

The accelerometer is attached to the vibration meter of make OROS. The vibration meter, OR34-2, 4 channels, shown in Fig.5.4 displays the displacement and acceleration at the free end of the boring tool in the required format.

Fig.14 Plate



The instrument is intended to general acoustic and vibration measurements, environmental monitoring, occupational health and safety monitoring. OR34 provides significant number of results like RMS, PEAK in case of vibration measurements. Results can be viewed in real time or can be saved for further analysis using NV Gate application provided with the instrument. Features of OR34 – 2, 4 channels compact analyzer include

- AC/DC power supply
- Real-time bandwidth 40 kHz
- 2 external triggers/tachometers inputs

H. Accelerometer

Dytran make 3056 B2 D accelerometer is used to measure displacement near the free end of the boring tool.

Fig.15 Dytran 3056 B2 D accelerometer

The Model 3056 B2 shown in Fig. 4.5 is a magnetic mount accelerometer. Accelerometer is attached to the boring tool at a distance of 40mm from tool tip. Features of Dytran 3056 B2 D accelerometer are;

- Weight, 10 grams
- Material, base, cap & connector titanium
- Operating range, -55 to +120°C
- Frequency range, 1 to 10,000 Hz
- Sensitivity, 100mV/g

I. Surface Roughness Tester

MITUTOYO SJ 201-P (Specifications)

Fig. MITUTOYO SJ 201-P Surface Roughness Tester

Drive Unit

- Drive Speed - Measuring: 0.25 mm/s and Returning: 0.8 mm/s
- Evaluation Length - 12.5 mm
- Mass - 190 gm

Detector Provided

- Detecting Method - Differential Inductance
- Measuring Range - 350 µm (-200 µm to + 150 µm)
- Material of Stylus - Diamond
- Radius of Skid Curvature -40 mm
- Mass - 18 gm
- Stylus Tip Radius - 5 µm
- Measuring Force - 4 Mn

TABLE 4: L_{16} Orthogonal Array

Sr. No.	Parameter		Level	
			Low (1)	High(2)
1	Spindle Speed - N (rpm)	A	100	200
2	Feed Rate - f (mm/rev)	B	0.02	0.04
3	Depth of Cut – t (mm)	C	1	2
4	Boring Bar Overhang – L (mm)	D	100	120
5	Damper Material	E	Composite	PTFE
6	Damper Length - l (mm)	F	0.3 × L	0.6 × L

TABLE 5: Test Matrix

Run No.	Factors					
	A	B	C	D	E	F
1	1	1	1	1	1	1
2	1	1	1	2	1	2
3	1	1	2	1	2	1
4	1	1	2	2	2	2
5	1	2	1	1	2	2
6	1	2	1	2	2	1
7	1	2	2	1	1	2
8	1	2	2	2	1	1
9	2	1	1	1	2	2
10	2	1	1	2	2	1
11	2	1	2	1	1	2
12	2	1	2	2	1	1
13	2	2	1	1	1	1
14	2	2	1	2	1	2
15	2	2	2	1	2	1
16	2	2	2	2	2	2

Run No. 1 as given in Table of Orthogonal Array states that;
A1 = Spindle Speed = 100 rpm
B1 = Feed Rate = 0.02 mm/rev
C1 = Depth of Cut = 1 mm
D1 = Boring Bar Overhang = 100 mm
E1 = Damper Material = PTFE
F1 = Damper Length = 0.3 × Boring Bar Overhang, i.e. 30 mm

Similarly one can identify the remaining 15 runs.

V. RESULTS ANALYSIS AND DISUSSION

TABLE 6: Result Table for L_{16} Orthogonal Array

Run No.	Factors						Vibration Response (m/sec^2)	
	A	B	C	D	E	F		
1	1	1	1	1	1	1	7.183 × 10-4	7.103 × 10-4
2	1	1	1	2	1	2	1.687 × 10-3	1.628 × 10-3
3	1	1	2	1	2	1	2.32 × 10-3	2.37 × 10-3
4	1	1	2	2	2	2	1.87 × 10-3	1.78 × 10-3
5	1	2	1	1	2	2	9.22 × 10-4	9.45 × 10-4
6	1	2	1	2	2	1	4.547 × 10-3	4.03 × 10-3
7	1	2	2	1	1	2	2.183 × 10-4	2.024 × 10-4
8	1	2	2	2	1	1	1.647 × 10-3	1.62 × 10-3
9	2	1	1	1	2	2	9.98 × 10-4	9.68 × 10-4
10	2	1	1	2	2	1	4.687 × 10-3	4.786 × 10-3
11	2	1	2	1	1	2	2.283 × 10-4	2.176 × 10-4
12	2	1	2	2	1	1	1.867 × 10-3	1.768 × 10-3
13	2	2	1	1	1	1	6.243 × 10-4	6.34 × 10-4
14	2	2	1	2	1	2	1.68 × 10-3	1.67 × 10-3
15	2	2	2	1	2	1	1.67 × 10-3	1.68 × 10-3
16	2	2	2	2	2	2	2.07 × 10-3	2.11 × 10-3

Fig.17 Main Effects Plot for SN Ratios

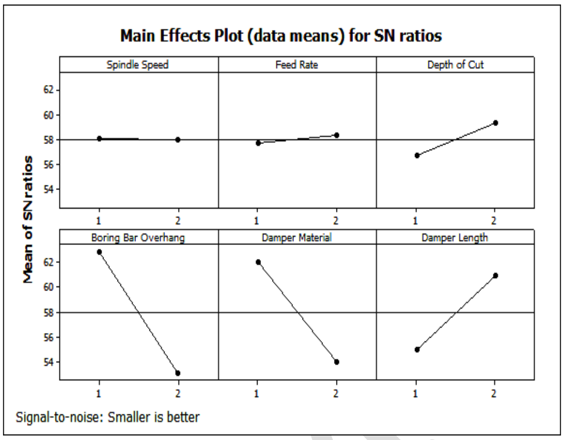


Fig.18: Main Effects Plot for SN Ratios

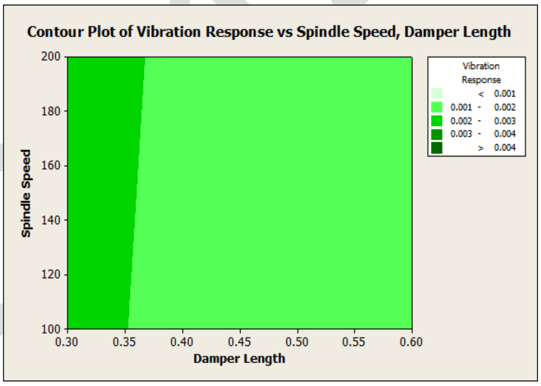


Fig.19 Contour Plot of Vibration Response VS Feed Rate, Damper Length

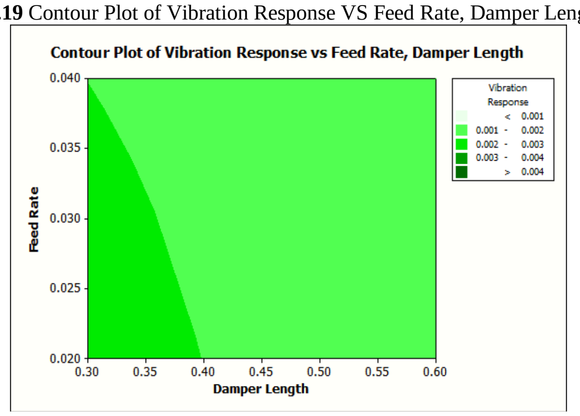


Fig.20 Contour Plot of Vibration Response VS Depth of Cut, Damper Length

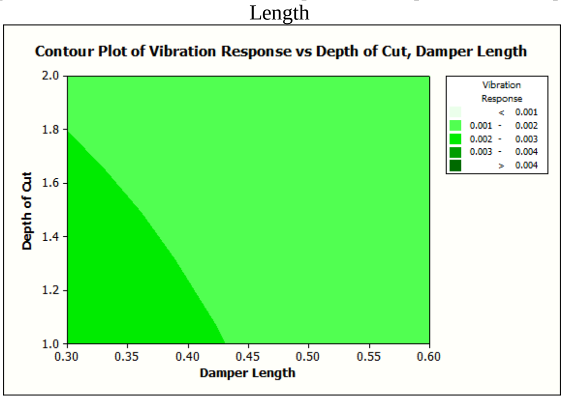


Fig.21 Contour Plot of Vibration Response Vs Boring Bar Overhang, Damper Length

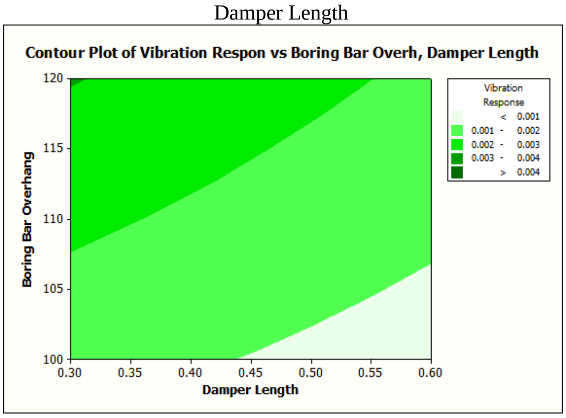


Fig.22 Contour Plot of Vibration Response VS Damper material, Damper Length

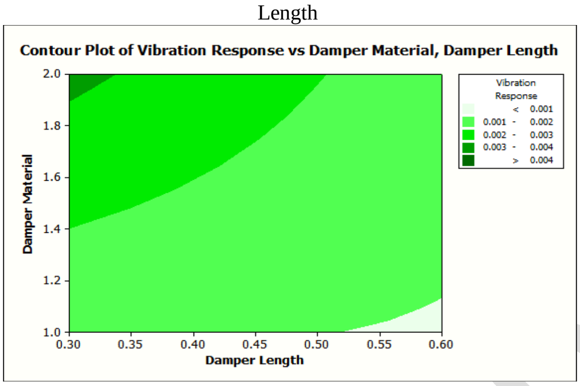


Fig.23 Contour Plot of Vibration Response VS Spindle Speed, Damper Material

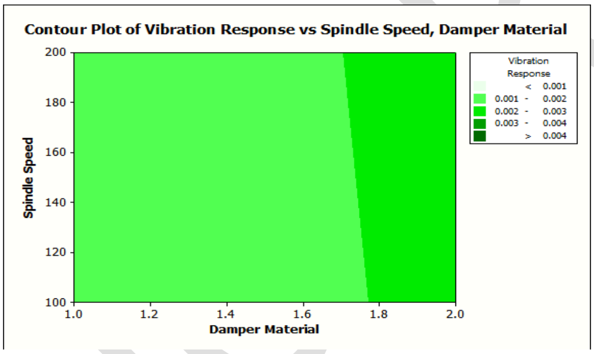


Fig.24 Contour Plot of Vibration Response VS Feed rate, Damper Material

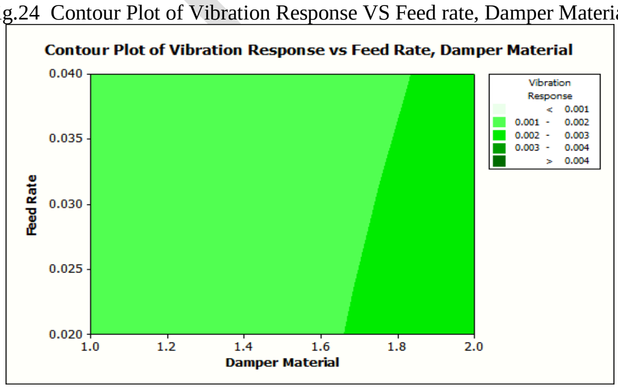


Fig.25 Contour Plot of Vibration Response VS Depth of Cut, Damper Material

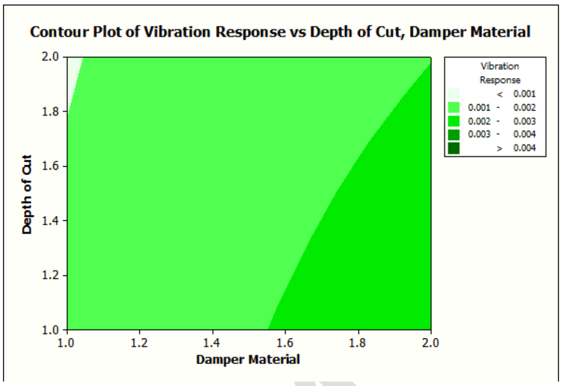


Fig.26 Contour Plot of Vibration Response VS Boring Bar Overhang, Damper Material

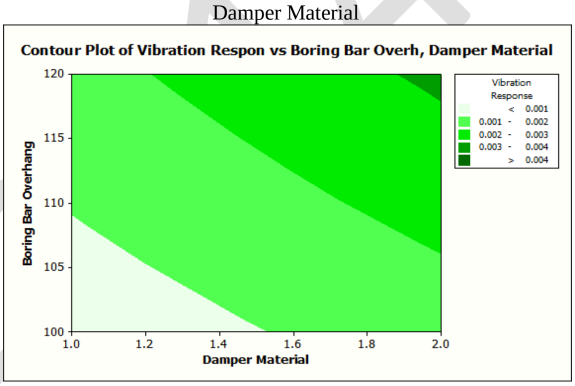


Fig.27 Contour Plot of Vibration Response VS Spindle speed, Boring Bar Overhang

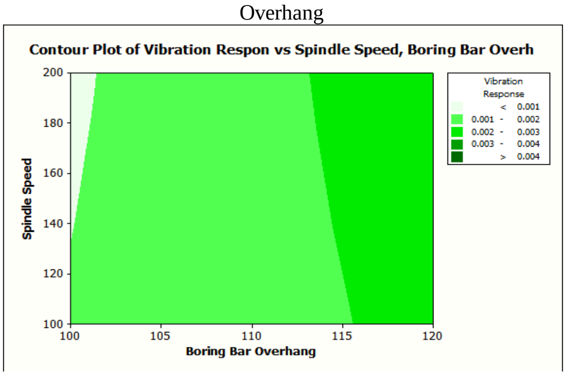


Fig.28 Contour Plot of Vibration Response VS Depth of Cut, Boring Bar Overhang

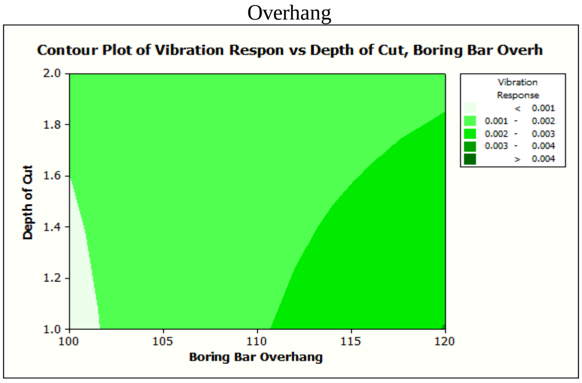


TABLE 7 Comparison of vibration response

Run No.	Vibration Response (m/sec^2)		
	With Passive Damper		Without Passive Damper
1	7.183×10^{-4}	7.103×10^{-4}	4.103×10^{-3}
2	1.687×10^{-3}	1.628×10^{-3}	3.628×10^{-2}
3	2.32×10^{-3}	2.37×10^{-3}	4.37×10^{-2}
4	1.87×10^{-3}	1.78×10^{-3}	3.78×10^{-2}
5	9.22×10^{-4}	9.45×10^{-4}	5.45×10^{-3}
6	4.547×10^{-3}	4.03×10^{-3}	2.03×10^{-2}
7	2.183×10^{-4}	2.024×10^{-4}	3.024×10^{-3}
8	1.647×10^{-3}	1.62×10^{-3}	1.65×10^{-2}
9	9.98×10^{-4}	9.68×10^{-4}	5.68×10^{-3}
10	4.687×10^{-3}	4.786×10^{-3}	2.786×10^{-2}
11	2.283×10^{-4}	2.176×10^{-4}	1.176×10^{-3}
12	1.867×10^{-3}	1.768×10^{-3}	1.72×10^{-2}
13	6.243×10^{-4}	6.34×10^{-4}	3.34×10^{-3}
14	1.68×10^{-3}	1.67×10^{-3}	1.07×10^{-2}
15	1.67×10^{-3}	1.68×10^{-3}	1.18×10^{-2}
16	2.07×10^{-3}	2.11×10^{-3}	1.11×10^{-2}

Fig.29 Comparison of vibration response

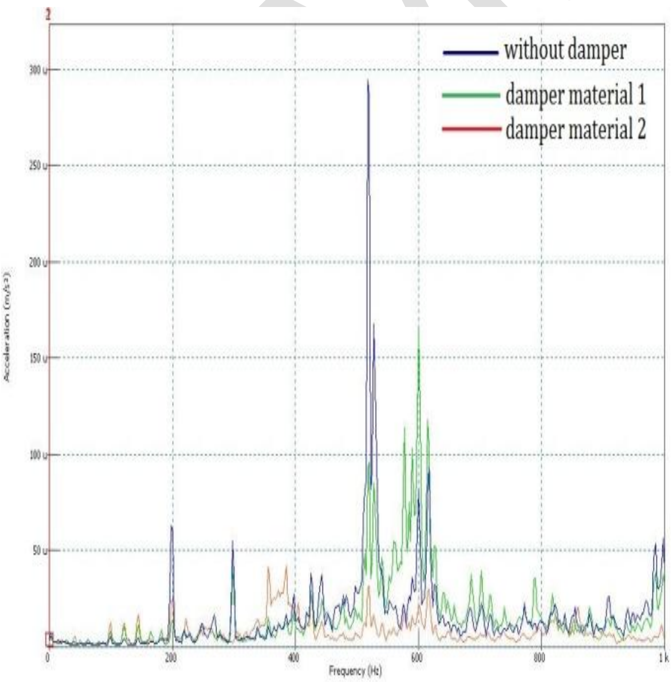


TABLE 8 Comparison of Surface Roughness

Run No.	Surface Roughness Ra (µm)		
	With Passive Damper		Without Passive Damper
1	3.32	3.23	6.08
2	4.23	4.32	8.34
3	4.89	4.87	9.91
4	4.22	4.20	8.88
5	3.11	3.01	5.89
6	5.01	5.10	10.04
7	2.23	2.20	4.78
8	4.78	4.87	9.87
9	2.87	2.77	5.54
10	5.21	5.19	11.34
11	2.34	2.24	4.79
12	4.87	4.67	9.32
13	2.98	3.01	5.89
14	3.92	3.82	7.89
15	4.02	4.12	8.65
16	3.87	3.85	7.45

VI. CONCLUSIONS AND SCOPE FOR FUTURE WORK

Following conclusions were made from the results analysis carried out in the previous chapter;

I. The level of vibration decreases by 40 % due to installation of passive damper on boring tool.
II. Due to reduction of boring tool vibration the surface finish enhances by 48%.
III. The optimized combination of process parameters of passive damper is, $A_2B_2C_2D_1E_1F_2$
IV. The generalized linear regression equation will predict the level of vibration under different operating conditions is;

Acceleration = - 0.00001 –(0.000013 Spindle Speed) –(0.000125 Feed Rate) – (0.000497 Depth of Cut) + (0.00154 Boring Bar Overhang) + (0.00130 Damper Material)–(0.00105 Damper Length)Where
The reliability of the equation is also good as the R^2 value is 86.5%

V. From the contour plots it is observed that irrespective of higher values of machining processe parameters such as spindle speed, feed rate depth of cut the passive damper made of composite material reducethe level of vibration by approximately 25 % as compared to PTFE.

Scope For Future Work

One can carry out Finite Element Analysis of the passive damper to see stress distribution and deformation. There is also a scope to try the different geometries and material for the passive damper to see the effectiveness of the damper.

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