Experimental Analysis of Boring Tool vibrations with Passive Damping using FFT Analyzer

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Abstract— **Boring is one of the machining operations, which is most widely used in industry. In the case whenever depth of the hole to be bored is more compared to diameter of hole, there is need of slender boring tool. For slender boring tools the ratio of length to diameter is higher due to which while machining tool may deflect. At the time of boring, forces are exerted at free end which finally results in vibration. As vibrations are always undesirable so it has adverse effects on surface finish and tool life. So to reduce vibrations there are various techniques which can be mainly categorized as active and passive damping. In this experimentation passive damping is used to analyze behavior of boring tool under vibration. So experimentation is done with and without passive damping. FFT analyzer is used to carry out frequency domain analysis. The operating parameters such as Depth of cut in mm (0.3, 0.5 and 0.7), Spindle speed in RPM (300,500,700) and Feed Rate in mm/min (80,100,120) are varied. On the other hand, passive damper characteristics are varied by using damping particles of different sizes. The results are collected in the form of vibration acceleration and surface roughness, comparison is made among boring tool without passive damper and tool with passive damper. Analysis results show that, passive damping reduces vibration and enhances the surface finish.**

Index Terms— **Passive damping, Boring Tool, FFT Analyzer, Vibration, Surface Roughness.**

I. INTRODUCTION

Machines are composed of various links and their assembly which are having relative motion, so vibrations are inherent.

Any motion that repeats itself after an interval of time is called vibration. Whenever system is left to vibrate after an initial disturbance, it is called as free vibration and whenever it is subjected to an external force, it is known as forced vibration. The maximum displacement of vibrating body from its equilibrium position is called the vibration amplitude. Vibration amplitude represents the severity of the problem. 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. Frequency of vibration is the indication of source of problem.

Many times vibrations in machining may be desirable (for e.g. in case of shaker machine) but most of the times it is undesirable due to its adverse effect on quality parameters of job. Machining vibrations mainly depends on various parameters such as speed, feed rate, depth of cut etc. so it is desirable to minimize or control vibrations. Thus whenever it is not possible always to act on parameter which directly causes vibrations, there are two options available i.e. one can go for vibration isolation or vibration damping.

This paper focuses boring process, as boring is one of the machining processes which include enlarging the drilled hole. In the boring operation a single point or multi-point cutting tool is held with holding fixture called as boring bar. It is fitted in tool post against the rotating work piece. Boring is thus also called as internal turning. The tool holding fixture is fixed at one end and free at other end. Cutting forces exerted on tool at its free end. So, it acts as cantilever or Euler Bernoulli beam. So as the depth of hole to be bored increases, length of bar also increases resulting in lowering stiffness and thus resulting in more vibrations. Thus if rigidity of cantilevered boring bar is not sufficient; it would directly affects the dimensional accuracy, tool wear rate and surface finish. Such effect becomes prominent when the length to diameter ratio of boring bar exceeds 4:1.

II. LITERATURE REVIEW

In this paper passive damping (Particle impact damping i.e.PID) technique used, it is a method to increase damping by inserting particles in an enclosure attached to a vibrating structure. The particles absorb kinetic energy of the structure and convert it into heat through inelastic collisions between the particles and the enclosure. Additional energy dissipation may also occur due to frictional losses and inelastic particle-to-particle collisions amongst the particles.

The unique aspect of PID is that high damping is achieved by converting kinetic energy of the structure to heat. In conventional methods of damping the elastic strain energy stored in the structure is converted to heat.

S. Devaraj et al., (2014) proposed fine particle impact damping method in boring operation for surface quality enrichment of the work piece. Damping to suppress the vibrations was provided by embedding fine particles within small hole of a vibrating structure. Authors performed experimental investigation for the surface roughness measurement of work pieces using Copper, Aluminum, Zinc and Silicon particles at different densities. The results obtained proved that the usage of silicon and zinc particles showed less damping capability when compared to the damping capabilities of the boring tool using Copper and Aluminum particles and thus it revealed that the surface finish value of the work piece can be improved using particle impact damping

Pranali Khatake et al., (2013) introduced a vibration attenuation technique for boring bar through the implementation of passive damper. Researchers used damping particles within the boring bar and experimental investigation was undertaken to observe the surface finish of specimen using different overhang lengths of boring bar during operation. The results proved that the chatter of the tool is suppressed at a larger amount which means the self excited vibrations of the boring tool are reduced.

Zhehe Yao et al., (2011) worked on chatter suppression by parametric excitation. In this study, the effect of parametric excitation on a van der Pol–Duffing oscillator with a time delay feedback was studied using the averaging method. It involves the validation of the effect of parametric excitation on chatter suppression through the cutting experiments using Magneto-Rheological (MR) fluid-controlled boring bar. The effect of parametric excitation on the self-excited vibration system was studied regardless of the generation mechanisms of the self-excited vibration. The regenerative effect is the most common effect that generates chatter in the machining processes. Therefore, researcher studied the regenerative effect for the stability analysis of the cutting vibration system. Parametric excitation effects on chatter suppression were investigated by experimental validation and theoretical analysis. The cutting experiments using magneto-rheological fluid controlled boring bar showed remarkable effects on chatter suppression.

M. Senthil kumar et al., (2011) worked on particle damping technique for the control of vibrations in boring bar. He investigated the efficiency of particle damping in vibration attenuation of boring bar using damping particles like copper and lead. In this regard, Boring bar is drilled to have a longitudinal hole in which damping particles were embedded. Experimental investigations were carried out to find out the settling time of boring bar for different particles by giving an impact pulse by an impact hammer to the bar held as a cantilever beam. Damping performances of these particles having various sizes were observed and compared .Natural frequencies of the solid boring bar acting as a beam were compared with those of the drilled boring bar

Henrik Akesson et al., (2009) concentrated on studying the various clamping conditions of boring tool. Authors worked on the effect of different clamping properties on the dynamic properties of clamped boring bars and discussed about Euler Bernoulli modeling of clamped boring bar with emphasis on the modeling of the clamping conditions. Experimental investigation results show variation in dynamic characteristics of boring bar as per the changes in the clamping positions of boring bar is investigated experimentally. Standard and modified boring bars are considered. The influence of standard coupling housings with different number of clamping screws, different clamping screw diameters, different screw tightening torques, on Eigen frequency values and its mode shapes orientation in cutting speed, cutting depth plane was calculated.

Zhiwei Xu et al., (2009) investigated a structure in which damping particles were embedded in the horizontal hole drilled in the vibrating structure. Authors concentrated on the study of shear of the boring bar and its effects on the damping capability of the structure and also presented an analytical model to analyze the effect of particle damping on vibration behavior of boring bar. I It includes the different volumetric ratios of particles and also different types of particles and their various sizes to observe the damping effect of each and to suggest a good damping material for better vibration reduction. The passive damping using damping particles is proved to be effective. Although it is non-linear, it can give a strong energy dissipation rate

Deqing Mei et al., (2009) proposed an MR fluid-controlled chatter suppressing boring Bar. Authors established a dynamic model of an MR fluid-controlled boring bar based on an Euler–Bernoulli beam model. FEM analysis was applied for designing the magnetic field and analyzed the regions of operating stability using the dynamic beam model also concluded that it can be used to suppress the chatter by adjusting the damping and natural frequency of the system. Experimental results regarding the vibrations at the structure's tip in different spindle speeds validated the model and demonstrated chatter suppression in a boring process and reduced the chatter

B.Moetakef-Imani et al., (2009) presented the dynamic simulation of boring process and also presented a model for simulation. Author studied the causes of vibration and vibration behavior of boring bar for certain cutting conditions and revealed that boring bar is easily subjected to vibrations because of its large slenderness ratio. Author used B-spline parametric curves to simulate different tool geometries with a single approach. Euler-Bernoulli Beam theory was used for boring bar modeling and stated that the structure comprising of lathe machine, boring tool and the work-piece undergo excessive vibrations under certain conditions

C. V. Biju, (2009) focused on investigation into the effect of passive damping technique using damping particles on surface topography when boring operation is being processed. For this purpose author used a particle damping method called the novel method, for vibration control during boring process and modeled the boring bars without cavity and with cavity and analyzed using Ansys. Spherical steel particles were used as damping particles in a cavity near machining end of the designed boring bar. Damping characteristics of the boring bar were evaluated for varying sizes and volumetric ratios of damping particles using impact and shaker tests and results were included. Results of experimentation in terms of surface roughness and chatter marks were analyzed and the results showed an improvement of bore quality with particle impact damping as compared with a boring bar without particle impact damping (PID). Shaker tests revealed that 3.17 mm sized steel damping particles with 50% volume fraction reduce the amplitude response of boring bar. Author showed that the transfer of momentum from the vibratory system to the damping particles and the energy dissipation caused by collision between the particles and cavity reduce the self-excited vibration of boring bar thereby improving the stability of boring operation.

Steven E. Olson et al., (2003) established an analytical particle damping model. It involves an analytical evaluation of the particle damper and utilized the particle dynamics method based on the kinematics of particle damping, involving shear friction between the particles and contacting areas and the dissipation of energy in the form of heat of the particle material. Interaction forces between the individual particles and the cavity walls are calculated based on force–displacement relations. Application of the model has been demonstrated by simulating laboratory testing of a cantilevered beam

Friend and Kinra, (2000) conducted a study of particle impact damping in the context of free decay of a cantilever beam in the vertical plane. In their study, particle impact damping (PID) was measured for a cantilever beam with the enclosure attached to its free end. Lead powder was used throughout the study and also studied the effects of vibration amplitude and particle fill ratio (or clearance) on damping. PID was observed to be highly nonlinear, i.e. amplitude dependent. A very high value of maximum specific damping capacity (50%) was achieved in the experiment. An elementary analytical model was also constructed to capture the essential physics of particle impact damping. A satisfactory agreement between the theory and experiment was observed. This work is a continuation of the work by Friend and Kinra. The primary objective of this work is to expand the previous experiments in order to collect PID characteristics of various particle materials and particle sizes. Using the same method and experimental procedures developed by Friend and Kinra, experiments are conducted for lead spheres, steel spheres, glass spheres, sand, steel dust, lead dust, and tungsten carbide pellets. The particle diameter varies from about 0.2 mm to 3 mm. Tests are conducted for different vibration amplitudes, clearances, and number of particles.

Hollkamp and Gordon, (1998) tested a cantilever beam with eight holes along its length which are filled with particles with variation of particle materials sizes and packing ratio. Experimentation reveals that particle material and shape had little influence compared with packing ratio and excitation amplitude. Also an important observation was made that damping increased with amplitude up to a maximum and then decreased if amplitude increased further.

Saluena et al., (1998) used the discrete element method to model three phases or regimes of damping that is solid, liquid and gas. Results showed that solid regime occurs when the particles move together with no relative motion between particles. The fluid regime is characterized by formation of convection pattern and gas is by unpredictable motion of individual particles. Maximum damping occurs at fluidization point which is less in liquid regime and increases in the gas regime.

Papalou and Masri, (1996, 1998) carried out a wide range of experimentation with PD under vertically and horizontally vibrating systems with random excitation. Along with this they have also studied the effect of mass ratio, particle size, container box dimensions, excitation levels, direction of excitation and proposed design procedures based on equivalent single particle damper. From experimentation results obtained showed that there was an optimum length/width aspect ratio and void space inside container. Also it was found that optimally designed single particle damper is more efficient than multiparticle damper of equal mass

Panossian, (1991, 1992) conducted a study of non-obstructive particle damping in the modal analysis of structures at a higher frequency range of 300 Hz to 5,000 Hz. This method consists of drilling small diameter cavities at appropriate locations in a structure and partially or fully filling the holes with particles of different materials and sizes (steel shot, tungsten powder, nickel powder, etc.). Significant decrease in structural vibrations was observed even when the holes were completely filled with particles and subjected to a pressure as high as 240 atmospheres.

III. PROBLEM STATEMENT

To study the behavior of vibration characteristics of particle impact damping under dynamic boring operation.

To determine the optimum combination of various parameters considered during boring process using taguchi methodology.

To do regression analysis, so as to predict optimum combination of various parameters considered during boring operation**.**

It was observed from literature review, until now analysis of vibration characteristics of dynamic boring tool with passive (particle impact) damping has not been done

IV. EXPERIMENTAL PROCEDURE

In order to analyze it, is necessary to follow a scientific approach to carry out experimentation so that relation among each important parameters which affects responses (i.e. surface finish and vibration) can be studied.Taguchi technique provides required scientific approach to carry out experimentation with not only minimum number of trials but also yields reliable results.

Taguchi uses a special design of orthogonal array. The results are then transformed into a signal – to – noise (S/N) ratio to measure the quality characteristics deviating from the desired values. Usually, there are three types of quality characteristics in the analysis of the S/N ratio,

The – smaller – better

The Signal-To-Noise ratio for the – smaller – better,

S/N = -10 *log (mean square of the response)

$$= -10 \log_{10} \frac{\Sigma y_i^2}{n}$$

The – higher – better,

The Signal-To-Noise ratio for the-higher-better is:

S/N = -10*log (mean square of the inverse of the response)

$$= -10\log_{10} \frac{1}{n} * \Sigma \frac{1}{y_i^2}$$

Where n= number of measurements in trial/row, in this case n=1, 2…, 9 and Yi is the ith measured value in a run/row. i =1, 2…, 27.

The – nominal – better
The signal-to-noise ratio for-nominal-better is:

S/N = 10 * log (the square of the mean divided by the variance)

$$= 10\log_{10}\frac{\bar{y}^2}{s^2}$$

The S/N ratio for each level of process parameter is compared based on the S/N analysis. Irrespective of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. Finally, a confirmation experiment can be conducted to verify the optimal process parameters obtained.
To carry out experimentation as per taguchi methodology, it is necessary to consider the parameters which have significant contribution to responses and their level of variation which is tabulated as follows:

Sr. No.	Input Parameters	Unit	Level		
			Low	Medium	High
1	Depth of cut	mm	0.3	0.5	0.7
2	Speed	RPM	300	500	700
3	Feed Rate	mm/minute	80	100	120
4	Damping particle size	mm	3.1750	3.9688	4.7625
5	Volumetric packing ratio	Percentage (%)	60	80	100

Table 1: Input parameters and their levels of variation

Here, volumetric Packing Ratio

$$\frac{\text{Volume of number of particles filled in tool cavity}}{\text{Total volume of cavity generated inside the tool}}$$

Experimental setup consists of, boring tool, FFT analyzer, Damping particles, work piece and CNC machine.

1) Boring tool S16Q SCLCR 09T3 is taken, to carry out boring operation.

Figure1. S16Q SCLCR 09T3 boring tool

Tool specification:
Tool holder length: 180mm
Outer diameter of tool holder: 16mm.
Manufacturer: Widmax

2) The FFT analyzer: It is used as a data acquisition device, wherein it receives signals from the accelerometer, amplifies it, reduces noise and then transmits the signals to the Lab View software, where the acceleration signals can be manipulated and plotted. This electronic device converts the input signal with time or an independent variable into frequency spectrum and display in graphical form. Such analyzer receives analog voltage signal from amplitude through the filler for computations. The analyzer signal in numerical form can be used to find mode shapes and natural frequency**.**

Figure 2.FFT analyzer

Specifications of the FFT analyzer are as follows,
It is a SKF Micro log® GX Series,
Data Collector/Analyzer
It Supports the GX Series Micro log System CMXA 75,
Firmware Version 4.01.

Sensor (Accelerometer):
Deltatron accelerometer combines high sensitivity, low and small physical dimensions making them ideally suited for model analysis. Easily fitted to different test objects using a selection of mounting clips. It measures the rate of change of velocity per time period.

Figure 3. Accelerometer

3) CNC Lathe machine:

Figure 4. CNC Lathe machine

Manufacturer: HYTECH

As per experimental procedure, first trial is conducted as per taguchi array L18 without use of passive damping and responses measured in terms of vibrations and surface finish. Then before conducting second trial tool is modified by drilling hole along the shank length and then as per variation of various parameters values trial is conducted.
As we have considered five parameters varying through three levels so the taguchi test matrix for it is as follows,

Run	A	B	C	D	E	X
1	1	1	1	1	1	X1
2	1	2	2	2	2	X2
3	1	3	3	3	3	X3
4	2	1	1	2	2	X4
5	2	2	2	3	3	X5
6	2	3	3	1	1	X6
7	3	1	2	1	3	X7
8	3	2	3	2	1	X8
9	3	3	1	3	2	X9
10	1	1	3	3	2	X10
11	1	2	1	1	3	X11
12	1	3	2	2	1	X12
13	2	1	2	3	1	X13
14	2	2	3	1	2	X14
15	2	3	1	2	3	X15
16	3	1	3	2	3	X16
17	3	2	1	3	1	X17
18	3	3	2	1	2	X18

Table 2: Test matrix for L18 orthogonal array

According to above table first run can be predicted as follows:
A1=Depth of cut = 0.3mm
B1=Speed =300RPM
C1=Feed Rate = 80 mm/min
D1=Damper particle diameter size = 3.1750mm
E1=Volumetric Packing Ratio = 60%.

V. RESULTS AND DISCUSSION

Run	Depth of cut (mm)	Speed (RPM)	Feed rate (mm/min)	Vibration level (m/s2)	Surface Finish (Ra)
1	0.3	300	80	0.0328	7.153
2	0.3	500	100	0.0691	7.587
3	0.3	700	120	0.152	4.997
4	0.5	300	80	0.0879	14.308
5	0.5	500	100	0.174	7.46
6	0.5	700	120	0.314	6.611
7	0.7	300	100	0.0616	6.1177
8	0.7	500	120	0.102	5.98
9	0.7	700	80	0.283	5.18
10	0.3	300	120	0.0382	7.045
11	0.3	500	80	0.0681	6.751
12	0.3	700	100	0.141	5.558
13	0.5	300	100	0.0730	11.039
14	0.5	500	120	0.101	5.851
15	0.5	700	80	0.643	5.674
16	0.7	300	120	0.0669	10.763
17	0.7	500	80	0.158	5.835
18	0.7	700	100	0.192	7.611

Table 3: Results for trials without damping

Second trial is conducted with damper

Run	Depth of cut (mm)	Speed (RPM)	Feed rate (mm/min)	Size of the damper particle(mm)	Volumetric packing ratio (%)	Vibration level (m/s2)	Surface Finish (Ra)
1	0.3	300	80	3.1750	60	0.0172	5.947
2	0.3	500	100	3.9688	80	0.0490	4.315
3	0.3	700	120	4.7625	100	0.1	2.428
4	0.5	300	80	3.9688	80	0.0145	9.816
5	0.5	500	100	4.7625	100	0.0532	4.030
6	0.5	700	120	3.1750	60	0.0258	4.033
7	0.7	300	100	4.7625	60	0.0147	5.218
8	0.7	500	120	3.1750	80	0.0684	5.723
9	0.7	700	80	3.9688	100	0.0312	4.036
10	0.3	300	120	3.9688	100	0.0146	4.047
11	0.3	500	80	4.7625	60	0.0184	5.028
12	0.3	700	100	3.1750	80	0.0201	3.453
13	0.5	300	100	3.1750	100	0.0198	7.762
14	0.5	500	120	3.9688	60	0.0517	5.56
15	0.5	700	80	4.7625	80	0.0336	4.143
16	0.7	300	120	4.7625	80	0.0162	5.389
17	0.7	500	80	3.1750	100	0.0352	5.269
18	0.7	700	100	3.9688	60	0.0715	4.501

Table 4: Results for the trials with damping variation

From results obtained from above trials, it can be said that vibration is reduced and surface finish is improved.

S/N analysis is then carried out for which results obtained as follows,

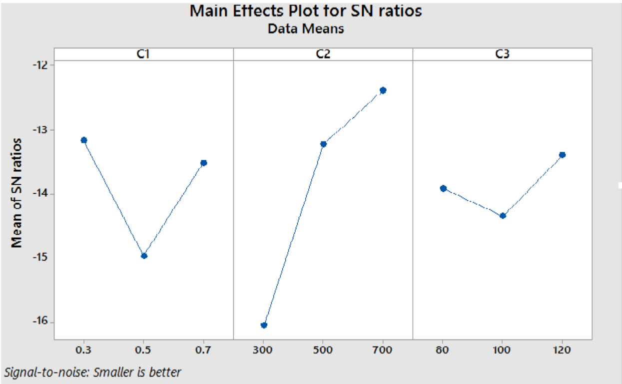

Figure 5. Main effects plot for S/N ratios for first trial

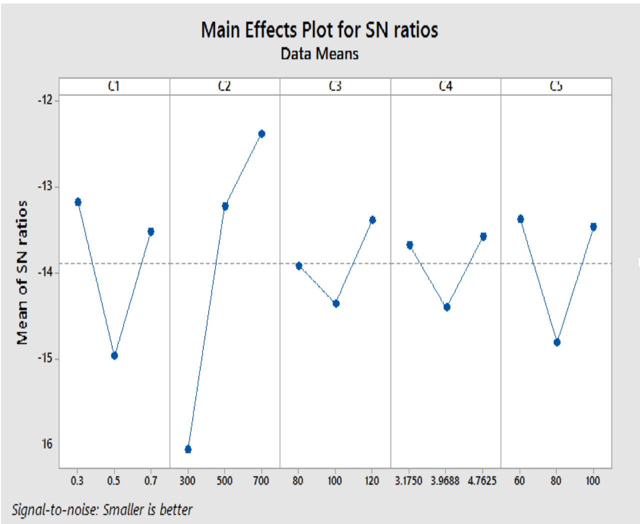

Figure 6. Main effects plot for S/N ratios for second trial

Conclusion: From the above results it can be concluded that,

1) Vibration level reduces by about 45% due to use of passive damping and surface finish enhances by 31%.
2) The optimum combination of parameters obtained using taguchi is A1B3C3D3E1
3) The required regression equation which can predict the level of vibration and surface finish is,

a) Vibration = 0.1961723836+ 0.26328887891(Depth of Cut) -0.0009697204757(Spindle speed) -0.0072267017012(Feed Rate)-0.041648698636(Damper Particle Size) + 0.0093490262281(Volumetric Packing Ratio).

b) Surface finish = -10.45324231 -8.457221342(Depth of Cut) -0.035628730429(Spindle speed) + 0.048880774804(Feed Rate)+1.6350677667(DamperParticleSize)+ 0.60341052390(Volumetric Packing Ratio).

Future Scope:
One can carry out experimentation with different material damping particles to consider the effect of material density.

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