VIBRATION ATTENUATION IN LATHE TOOL USING PARTICLE IMPACT DAMPING

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Abstract: In machining operation, the quality of surface finish is very important factor for many machined pieces. Thus to assure better surface finish, optimize the cutting parameter is very important. The main objective of this paper is to suppress the vibration in lathe tool by using different damping particles in tool post. The principle of particle impact damping is the removal of vibratory energy through losses in the form of thermal energy that occur during the impact of particles with each other and with walls. The selected damping particles like stainless steel (S.S), Mild steel (M.S), Copper(Cu), are experimented with various cutting parameters. The cutting tool vibrations are mostly influenced by cutting parameters like depth of cut, cutting speed and feed rate. In this study, lathe tool vibrations are suppressed by with and without damping particle in tool post. In this experiment vibrations are measured indirectly by using lathe tool dynamometer and surface roughness. To increase buoyancy level, Taguchi L9 experiment was conducted to find out the optimized parameter and variances from closer value. Analysis result of the experiment shows that particle impact damping(PID) have effectively improve the surface finish and decrease the tool vibration.

KEYWORDS: Damping particles, Taguchi L9, Lathe tool dynamometer, PID, Surface Roughness.

1 INTRODUCTION

The vibration is the important factor plays significant role in every machining processes. Nowadays, the manufacturing and tool engineers are focusing to reduce the amplitude of vibration to increase the surface finish, accuracy of workpiece. The major aim of all researcher are trying to produce material with less wear rate, high accuracy and high production rate with good dimensional accuracy. The major two types of vibrations are forced and self-excited vibration, the forced vibration are caused by forces that exist in the machine like improper design of gear, misalignment and some unbalanced machine tool components etc. Self-excited vibrations are majorly occurred due to structure of tool, chip removal interaction which affect the cutting zone and small hard spots etc. The hard sports create some fluctuation(impart shocks) between tool and workpiece during machining processes [1]. Meanwhile, the cutting tool vibration are majorly caused due to the cutting parameters like cutting forces, depth of cut, and feed rate.

1.1 Vibration control in machine tool

The vibration in machine tool can be controlled by reducing the sources and intensity of vibration. The major two factors to control vibration are static stiffness and damping for the modes of vibration which has conceal relationship between the tool and workpiece. The static stiffness especially prevent the material from deformation due to cutting forces and the damping is another technique used 7to reduce the amplitude of vibration [2].

1.2 Vibration Damping

Vibration damping is a technique to reduces the amplitude of vibration to a greater extent or to reduce the intensity of vibration.

I. Types of vibration damping: -Active and passive damping techniques are common methods of attenuating the exciting vibration in a structure. Active damping techniques are not applicable under all circumstances due to power requirements, cost, environment, etc. Under such circumstances, passive damping techniques are a best alternative. Various forms of passive damping exist, including viscous damping, viscoelastic damping, friction damping, and impact damping.
II. Particle impact damping: - Particle damping is the use of particles moving freely in a cavity to produce damping effect. The particles like shots or viscoelastic materials are tightly packed in a cavity, during the operation the vibration in the system are exhausted as heat to the environment.
III. Working principle: - During the machining process the particles collide with each other and convert the mechanical energy into thermal energy. Due to this the vibration generated inside the system are get exhausted as heat energy.

Factors considered for selection of damping material: - A good damping material need to "bounce back" or return energy to the system (shots) as much as possible [1]. In addition, the material should withstand at high temperature environment (polymers like sorbothane).

1.3 Vibration sensing methods

To measure the vibration there are two types of methods available: -

Table 1. Vibration sensing methods[3]

Direct method	Indirect method
Vibrometer	Cutting forces
Accelerometer	Surface roughness
Transducer	Temperature

The researchers are mostly utilizing the indirect method for past few decades to detect the vibration. However, the enormous development of new computer powered device are helping to overcome the traditional difficulties [3].

I. Direct method: - By this method primarily the sensors (touch sensors, power sensors, vibration sensors, temperature sensors, force sensors, vision sensors, flow sensors, acoustic emission sensor) collect the data from the system. After that the results are analyzed by software like regression analysis, neural network etc.

II. Indirect method: - In this method the results are depend upon the proportionality of results of direct method. For instances, in particle damping the mechanical energy was converted into thermal energy, so by measuring the temperature of the damping system we can determine the damping ratio.

Vibrational frequency(Hz) 1/α Temperature (℃)

2. LITERATURE SURVEY

B.P.Kolhe, S.P.Rahane, and D.S.Galhe [1] have studied about the effects of cutting tool vibration during operations on CNC machine. In this study it clearly explain about the sources for vibration i.e vibration due to in homogeneities in the Work piece and vibration due to cross-sectional variation of removed material. In this experiment the tool holder is supported with and without damping pad by using different damping materials. The results are fetched by FFT analyzer through data acquisition unit. To increase the buoyancy and reliability of the experiments taguchi and ANOVA method was implemented and equations are formulated. From the result of the experiment it shows that the cutting tool vibration is greatly influenced by the cutting parameters like depth of cut, feed rate and cutting speed.

Y.Altintas and M.R. Khoshdarregi [2] combined vibration avoidance and contouring error compensation were experimentally demonstrated to improve the damping and contouring accuracy on a two-axis table. Apart from that due to high speed, high acceleration contour machining operation it laid the way for contouring errors. These vibration are raised due to the structural modes of the machine tool. The major cause for contouring error is both due to limited bandwidth of the servo drives as we as vibration. This experiment can also be extended to five axis machine with both linear and rotary drives.

S. S. Abuthakeer, P.V. Mohanram and G. Mohan Kumar [3] have studied about the cutting tool vibration and its effect over dimensional precision, life of cutting tool etc. In this experiment the damping pad made of neoprene was used as a tool holder in CNC machine and experiment were conducted with and without damping pad. To increase the buoyancy and reliability of results full factorial was used. In addition to that, multilayer perception neural network model has been constructed with feed forward back-propagation algorithm used by gathered data. From the modal analysis the signals peaks exhibit response in a particular natural frequency range 3400 Hz without any damping pad and it shifted to 2150 Hz with neoprene damping pad.

B.P.Kolhe, S.P.Rahane, and D.S.Galhe [4] have investigated the quality of surface finish for many turned workpieces. In this experiment it focus mainly on optimize the cutting parameters using two performances measures, machine tool vibration and work piece surface roughness. To increase the accuracy of experiments, Taguchi L9 experimental design method has used in this experiment. Under this condition various experiment were conducted also corresponding cutting tool vibration and surface roughness were measured. Experimental result are validate with analysis of variance (ANOVA) and regression analysis to identify the influences of the different cutting parameter on the vibration of cutting tool.

Ahmed SyedAdnan and SathyanSubbiah [5] have studied the applying of vibration along the cutting edge and perpendicular to the cutting velocity. That applied vibratory motion is expected to provide a small sawing action that will enhance the ductile fracture occurring ahead of the cutting tool as the chip separates from the bulk work material. Due to this sawing action the surface finish get increased. To validate the result the cutting forces, chip thickness and surfaces finish are measured and compared with similar cutting condition without application of vibration. From the result it shows that chip thickness is also reduced and surface finish is improved upon application of vibration.

T.A.Jadhav and Syed Meraj Ali [6] investigated about the effects of particle impact damping in boring tool. In this experiment the lead and steel shots are taken as damping materials and operation were carried out in CNC machine. In this present study particle impact damping is used to suppress the vibrations of a boring tool in which a longitudinal hole is drilled and partially filled with metal particles. Finally the effect of input parameters like tool overhang length, spindle speed, particle material and packing ratio on acceleration amplitude of the boring tool is studied. An attempt has been made to develop an elementary mathematical model which predicts the effect of system and damping parameters on vibration level of the tool tip by using dimensional analysis approach along with multiple regression method.

Yasunori Wakasawa, Masatoshi Hashimoto, and Etsuo Marui [7] conducted experimental investigation on damping characteristics of structures packed with balls. For this experiment square pipe, accelerometer, FFT analyzer, digital oscillorecorder were used to predict the results. From the result it shows that the packing arrangements, packing ratio and repulsion coefficient plays important role in damping. In addition to that the effects of impulse magnitude, square pipe dimensions, ball size and excitation directions on damping characteristics are investigated. Conclusion of this study shows that using smaller size balls and less gap between ball and surface of wall would have high damping capacity.

Al-Habaibeh A. and Gindy N [8] examined that vibration cause severe effect on surface finish and tool life. The main intension of this paper is to develop automated condition monitoring system for machine tools and machining opeartions. The new approach termed ASPS(automated sensory and signal processing selection system) is used to monitor the machining operations. The system utilizes OAs method to reduce the experimental time and good evaluation of the designed monitoring system. The proposed system are compared with the pattern recognition capability of a back propagation neural networks and a fuzzy logic classifier.

Armando ItaloSette Antonialli, Anselmo Eduardo Diniz, Robson Pederiva [9] have studied the vibration analysis of cutting force in titanium alloy milling. The main aim of this paper to examine the effect of tool entering angle on tool vibration and prediction of tool life in titanium alloy milling operation. In this experiment the vibrations are amplified and radial component of the cutting forces in each experiment is examined. From the result it shows that higher entering angle cause higher frequencies and it leads to cutting edge breakage that attenuate the tool life. Meanwhile, the lower entering angle resulted in normal wear. To conclude that lower vibration will prevent cutting edge breakage caused by fatigue.

Marcus A. Louroza, Ney Roitman, Carlos Magluta [10] have investigated the possibility of using the coulomb damping, it majorly aims to concentrate the vibrations of structures submitted to human loading. A computational-theoretical model was developed with two degree of freedom. This project was executed in cantilever beam in order to calibrate easily. And also it clearly mentioned that the system is applicable to some situations and design area need to be carefully examine. From the result it shows that the system requires higher damping factor but it is not reached in actual practice. When this parameter is not satisfied an efficiency drop is evaluated.

3. OBJECTIVES

The main focus of this project is to eliminate the lathe tool vibration and reduce the surface roughness during machining process. Initially, particle impact damping technique is implemented to reduce the surface roughness and increase the dimensional accuracy of workpiece. The reduction in vibration will increase the lathe tool life. The reduction in vibration are detected and validated using lathe tool dynamometer and surface roughness tester respectively[3].

4. EXPERIMENTATION

The metal shot size chosen for this project is 2mm, 3mm, and 4mm in all three type of material, so to fill the shots the tool post is drilled by vertical drilling machine using standard 6.8mm drill pit shown in fig 1.

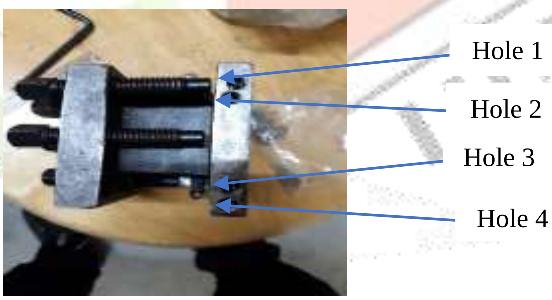

Fig. 1 Shots filled in drilled tool post

To increase the damping efficiency the tool post is drilled to the full length of 90mm at bottom side. After the drilling operation the separated shots are filled in the drilled holes of tool post[7]. The shots are filled to the entire longitudinal length of tool post (90 mm) and then the turning operation is carried out and the readings are noted from the lathe tool dynamometer.

4.1 Variable depth of cut test

In this machining process the depth of cut was varied as 0.8mm, 1mm, 1.2mm and keeping the speed constant as 4570rpm. The tool (H.S.S) is fixed inside the tool holder of dynamometer sensor and the three connections are connected to the digital display unit as shown in fig 2. The display unit shows the results of feed forces(Ff), thrust forces(Ft), and cutting forces(Fc) that are indicated as PU1, PU2, and PU3 respectively. For this investigation the cutting forces is taken as major result. As mentioned before the filling of metal shots are distinguished as three process and for each process the same material with different ball size are used. For instances, the stainless steel shot(S.S) is initially experimented with 2mm shot, then replaced with 3mm and 4 mm shots. Likewise the experiment is done with mild-steel(M.S) and copper(Cu) shots.

Initially the experiment is done with small depth of cut 0.8mm with replacement of stainless steel shot, mild-steel shot and copper shot in different sizes. After that the same experiment is performed with depth of cut of 1mm and 1.2mm. During the experimentation the cutting forces(Fc) is measured for every turning operation and the results are noted down. The entire experimentation is carried using variable parameter as shown in table 3.

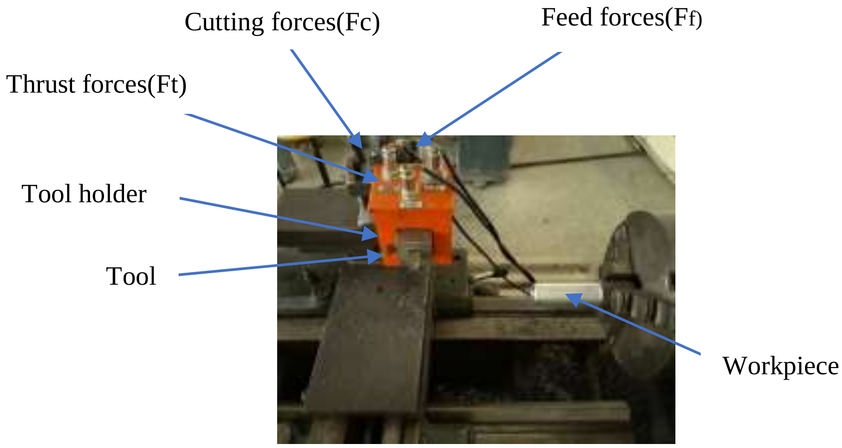

Fig. 2 Experimental setup

Table. 2 Collection of data (variable depth of cut test)

DEPTH OF CUT (mm)	CUTTING FORCE(Kgf)										SPEED (rpm)
	WITH DAMPING									WITHOUT DAMPING	
	STAINLESS STEEL (DIA IN mm)			MILD STEEL (DIA IN mm)			COPPER (DIA IN mm)				
	2	3	4	2	3	4	2	3	4		
0.8	0.20	0.60	0.42	0.36	0.38	0.23	0.47	0.79	0.81	0.44	4570
1	0.32	0.83	0.5	0.39	0.28	0.39	0.68	0.39	0.59	0.45	4570
1.2	0.65	0.63	0.64	0.29	0.27	0.37	0.45	0.58	0.72	0.53	4570

Table. 3 Cutting parameters

PARAMETERS	VARIABLE DEPTH OF CUT TEST	VARIABLE SPEED TEST
Cutting speed(rpm)	4570	3284, 4570, 5734
Depth of cut(mm)	0.8, 1, 1.2	1

4.2 Variable speed test

In this experiment the depth of cut is maintained as 1mm and the speed is varied as 3284, 4570, and 5734rpm as shown in fig 3. Like the depth of cut test here also the shots like stainless steel, mild-steel and copper are replaced with different sizes(2mm, 3mm, 4mm) for each experiment. Initially the belt is fixed in the pulley 1 to maintain the speed of 3284rpm and to conduct various speed test the belt is changed to pulley 2 and pulley 3 having capacity of 4570rpm and 5734rpm respectively.

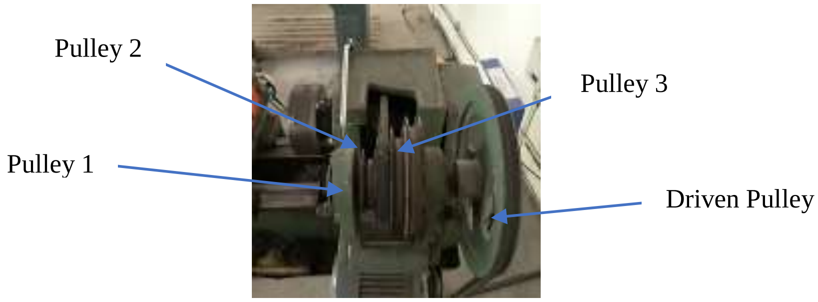

Fig. 3 Varying speed using pulleys

Table. 4 Collection of data (Variable speed test)

SPEED (rpm)	CUTTING FORCE(Kgf)										DEPTH OF CUT (mm)
	WITH DAMPING									WITHOUT DAMPING	
	STAINLESS STEEL (DIA IN mm)			MILD STEEL (DIA IN mm)			COPPER (DIA IN mm)				
	2	3	4	2	3	4	2	3	4		
3284	0.21	0.27	0.91	0.86	0.57	0.46	0.99	0.97	1.12	0.89	1
4570	0.32	0.83	0.51	0.39	0.28	0.39	0.68	0.39	0.59	0.45	1
5734	0.25	1.19	0.39	0.62	0.18	0.31	0.37	0.60	0.68	0.56	1

5. COMPARSION OF RESULT

5.1 Variable depth of cut test

From the result the shot diameter of 2mm predicted to have good damping efficiency. This particular experiment is conducted with shots of 2mm diameter. In this variable depth of cut test the S.S shot have the low cutting forces for depth of cut 0.8mm. In this case the smaller value is better, so by comparing all other results stainless steel shot is better as shown in fig 4. However, by increasing the depth of cut the cutting forces is reduced mostly by mild-steel shots. In depth of cut 1mm the M.S and S.S shot are in same value and have only smaller deviation. But in 1.2 depth of cut the M.S is only the shot having low cutting forces in the shot size of 2mm. By taking the copper in account, it always shows higher cutting forces value in all depth of cut. In overall the copper is completely not suitable for damping technique in this particular experiment. Finally, the graph illustrate that S.S shot have lower cutting forces in smaller depth of cut , but in increasing of depth of cut M.S shots is better. Finally in comparison of all shot material in different sizes with variable depth of cut it shows that shot diameter of 2mm is best. Along with the shot diameter the optimized depth of cut also predicted as 1mm in average. So by using shot diameter of 2mm in mild-steel for depth of cut 1mm is feasible.

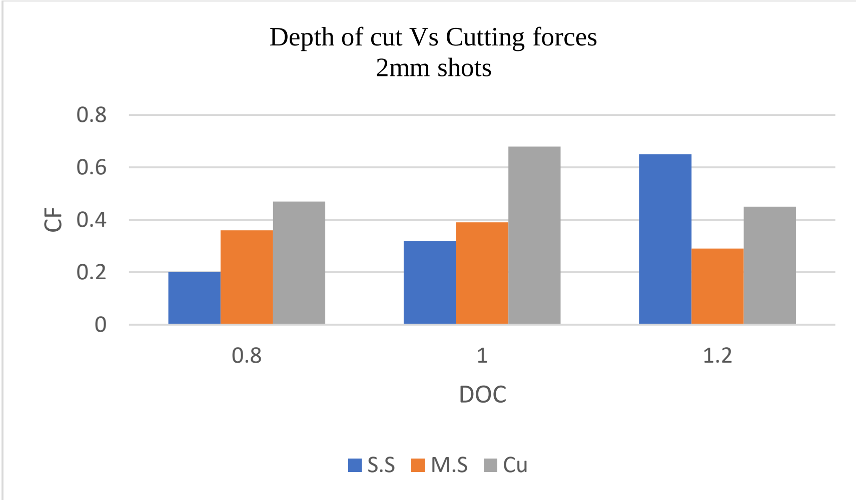

Fig. 4 Depth of cut Vs Cutting Forces (2mm shots)

5.2 Variable speed test

In this test all values are compared and best results are fetched, that the shot diameter of 2mm is very efficient by comparing the cutting forces value. Finally, all the graphs show that using mild-steel shot in diameter of 2mm in depth of cut 1mm is very efficient. Effectively to increase the damping effect the speed of 4570 is very feasible.

6. ANALYSIS OF RESULT

In both experiment variable depth of cut test and variable speed test the effective damping capacity was found. And also the effective machining parameter also determined.

I. RESULT OF DEPTH OF CUT TEST:

Finally, in comparison of all shot material in different sizes with variable depth of cut it shows that shot diameter of 2mm is best. Along with the shot diameter the optimized depth of cut also predicted as 1mm in average. So by using shot diameter of 2mm in mild-steel for depth of cut 1mm is feasible.

II. RESULT OF VARIABLE SPEED TEST:

At last from the graph it shows that using mild-steel shot in diameter of 2mm in depth of cut 1mm is very efficient. Effectively to increase the damping effect the speed of 4570 is very feasible.

In the both cases the best result is found out but to validate and increase the buoyancy level the results are analysed in MINITAB 2017 software. The Minitab software helps to find out the most influences factor in this experiment.

6.1 Variable depth of cut test

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[3]. 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)

$= -10log_{10}\frac{\sum yi^2}{n}$

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)

$= -10log_{10}\frac{1}{n} * \sum\frac{1}{yi^2}$

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)

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

The S/N ratio for each response is computed differently based on the category of the performance characteristics and hence regardless of the category the larger S/N ratio corresponds to a better performance characteristic. For the given input parameter of mild-steel shot diameter, depth of cut and output factor as cutting forces the graph is plotted. In this graph signal to noise smaller is better given, so it shows the least and large value of experiment. In this graph it shows that using mild-steel shot of diameter 2mm and depth of cut of 1mm is better. In previous the comparison of result the approximate result is same as the Taguchi result.

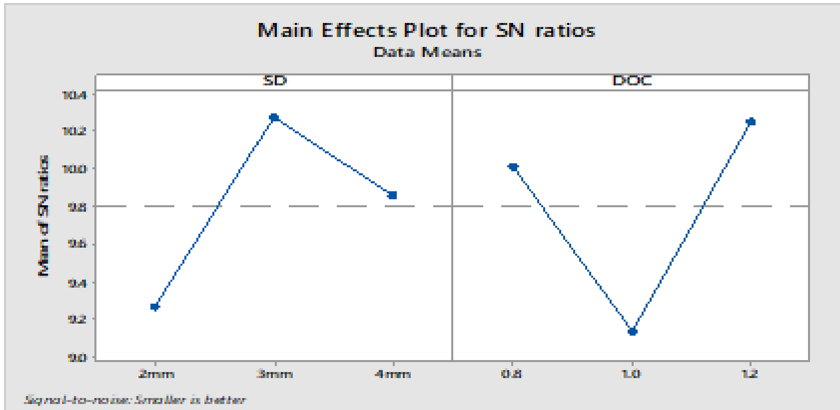

Fig. 5 SN Ratio graph

To check the variances level the residual plot is normal probability plot, versus fits, histogram and versus order graphs are used. The normal probability plot of the residuals to verify the assumption that the residuals are normally distributed. The normal probability plot of the residuals should approximately follow a straight line. In major the probability graph is take in account and it shows that the points are have only smaller deviation from the standard line. In both versus fits and versus order graph the deviation level of experiment is very low when compare to variable speed test.

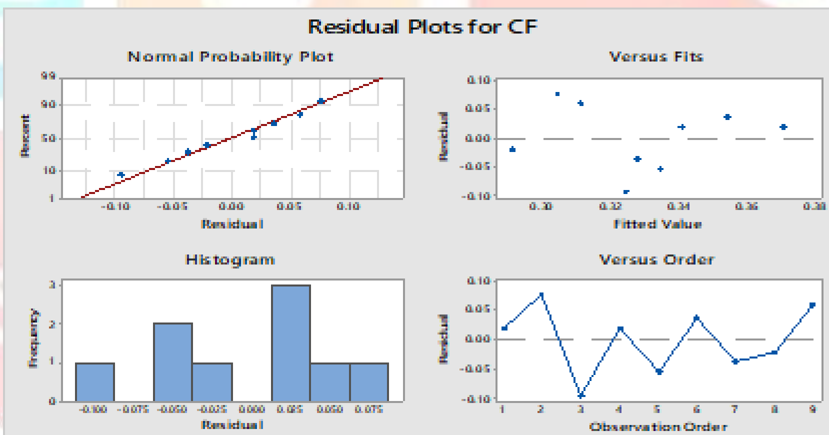

Fig. 6 Residual plot for CF

6.2 Variable speed test

The variable speed test is same as the previous design of experiment and in this experiment the speed and depth of cut is defined as input parameters and the cutting forces as output parameter. In this experiment also the signal to noise ratio smaller value is better, so the graph plot the small value to correlation with cutting forces. In this graph it shows that mild-steel shot diameter of 2mm with speed of 3284rpm is the best parameter for damping. In the previous comparison of SN ratio shows that using 2mm shot is feasible.

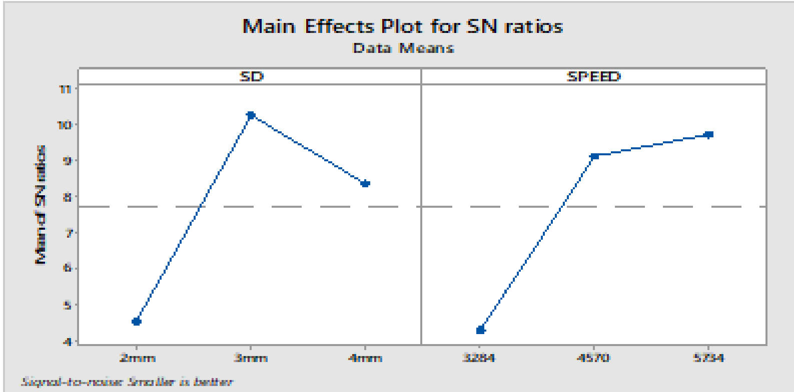

Fig. 7 SN Ratio graph

To again check the variances of this test the residual plot is plotted using normal probability plot, versus fits, histogram and versus order.

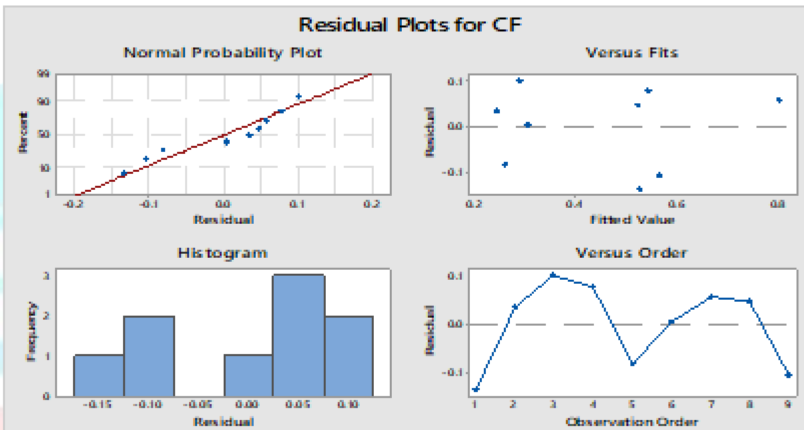

Fig. 8 Residual plot for variable speed test

In the first normal probability graph it shows higher deviation then variable depth of cut test. And in comparison of all other plots like versus fits, versus order the values get scattered to a greater extent. Finally the comparison of graph clearly illustrate that using mild-steel shot 2mm in diameter with depth of cut of 1mm in a speed of 3284 is feasible. But in comparison of both depth of cut and variable speed test the most influences factor is depth of cut. This factor is already mentioned in Taguchi L9 design as rank 1 and the variances of residual plot also shows that the varying depth of cut have more influences on damping effect rather than varying the cutting speed.

7. VALIDATION OF RESULT

From the Taguchi L9 design it was found that mild steel shot of diameter 2 mm was more efficient. To validate the result surface roughness of the workpiece was measured and compared with and without damping operation. The MITUTOYO SJ-210 SERIES is used to measure the surface roughness of workpiece. The all workpiece are measured at standard length of 20mm by using surface roughness probe. In the results Ra, Rz, Rq values are collected but Ra value was taken as major value. Since the comparison of surface roughness value shows that the tool post without damping have surface roughness value of Ra=0.14µin. However, in with damping of tool post the surface roughness value was measured as Ra=0.12µin for variable depth of cut test and for variable speed test the surface roughness value is Ra=0.13µin, So in overall the surface roughness value was very low for damping with variable depth of cut test. As in all previous comparison of graph it shows that using mild-steel shot diameter of 2mm in a depth of cut of 1mm was best. So now in the surface roughness result also shows that the tool post with damping of variable depth of cut test was better and it is a most influencing parameter of this experimentation.

Table. 5 Comparison of result

Without damping	Ra=0.14µin
With damping variable DOC test	Ra=0.12 µi
With damping variable SPEED test	Ra=0.13 µin

8. CONCLUSION

From above experiments it shows that the damping material have controled the lathe machine tool vibration . The cutting tool vibrations are mainly influenced by cutting parameters like cutting speed, depth of cut. In this work, the cutting tool vibrations are controlled using various damping material like Steel shot, Mild steel shot, Copper shot. Experiments were conducted in a lathe where the tool post was supported with and without damping materials. Finally after anaysing of results from experiments it shows that mild-steel of shot diameter 2mm with a depth of cut of 1mm is best optimize parameter to increase the damping effect, where the improvement is 13.3% as compared to the regular setup.

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