Experimental analysis of vibration control in boring operation using passive damper

E.Mohan [1], U.Natarajan [2], L.Mamundi Azaath[3]

[1&3]Assistant Professor, Department of Mechanical Engineering,
Mount Zion College of Engineering and Technology, Pudukkottai, Tamilnadu, India
[2]Assoicate Professor, Department of Mechanical Engineering,
Alagappa Chettiar Government College of Engineering and Technology, Karaikudi, Tamil Nadu, India.

---***---

Abstract - *Chatter is an unavoidable phenomenon during the machining process. Boring bars possess the cantilever shape and due to this, it is subjected to chatter. The undesirable effect of chatter increase in temperature which will leads to surplus tool wear. To beat these troubles, in this investigation, Nylon and Teflon damper is inserted onto the boring bar according to the overhang of the boring bar and also adequate clearance is provided in order to reduce the cutting temperature, displacement and tool wear. A conventional all-geared lathe is equipped with vibrometer, infrared thermometer and surface roughness tester, and is used to measure the displacement temperature and surface roughness of the components. The influence of input parameters such as cutting speed, depth of cut and feed rate are investigated. The response of the output parameters is recorded by the measuring the surface roughness of components, displacement and temperature of the cutting tool. The main objective of this paper is to introduce the vibration damping techniques in boring tool using passive damper. The optimum conditions to obtain better damping effects for chatter reduction is identified. The newly designed damped tool has been compared with conventional tool. It results shows it is much better than the conventional tool by means of enhance the damping competence; minimize the loss in static stiffness through execution of passive damper.*

Key Words: **boring operations, chatter, vibration control, passive damper.**

1. INTRODUCTION

In boring operation, the cantilevered shaped tool is used to enlarge the existing drilled hole and this boring bar is less rigid than the tool used for external turning operation. It is necessary to use the large length to diameter ratio tool for deep hole machining deep hole. While increase the overhang length of the boring bar its results the deflection in the boring and produced the vibration between a tool and a work piece. Vibration reduces the work piece surface quality and life of the tool. There are several ways to eliminate the vibration produced during the machining operations such as Active damping method, passive damping method or semi active damping method for the stability of that boring bar. The objective of the vibration reduction is to improve the dynamic stiffness of the machine tool structure, to increase the material removal rate and life of the tool tip.

1.1 Chatter Vibration

Chatter vibrations are there in nearly all cutting operations and they are major problem in achieving required productivity. Regenerative chatter is the most harmful to any process as it creates excessive vibration between the tool and the workpiece, resulting in a poor surface finish, high noise and tool wear which in turn reduce the machine tool life, reliability and safety of the machining operation [1]. Chatter is a self-excited vibration that can arise during the machining operations and become a general limitation to productivity and part quality. For this reason, it has been a vital topic in the industries and academic concentration in the manufacturing sector for several years. A great deal of research has been conceded out since the late 1960s to crack the vibration related problems. Researchers have studied how to detect, identify, avoid, prevent, reduce, control, or suppress the vibrations by many approaches. The state of research on the vibration problem and classifies the active method developed to make sure steady cutting conditions [2].

Vibration is a repetitive, periodic, or oscillatory reaction of a mechanical system and its possessions are very general in our daily life. Suppression or elimination of terrible vibrations and creation of desired forms and levels of superior vibration are general goals of vibration engineering. One of the passive vibration control methods are used to control the vibrations which is random in nature. Passive vibration damping methods are results in very high damping effects. Easy design and simple maintenance free constructional features have attracted many of the researchers to develop an efficient methodology for studying its performance [5].

1.2 Turning Processes

In turning processes, mainly three types of vibrations could occur: free, forced and self-excited. Among these three vibrations free vibration is transient and less important. Forced vibrations occur with the function of periodic cutting forces acting on the cutting tool. Self-excited vibrations effect from an interface between the cutting forces and cutting-edge displacements. The amplitude of self-excited vibrations increases rapidly up to a few amplitudes which are limited by the nonlinearity of the cutting process. The frequency of self-excited vibrations is close to and superior to the natural frequency of the cantilever tool. Chatter or self-excited vibration is the most important type of vibration in machining operations. Regeneration and mode coupling are the main categories leading to chatter [3].

The boring tool was modelled as a cantilever Euler–Bernoulli beam and only its first mode of vibration was considered for vibration analysis. The stability of the two-degree-of-freedom model was analysed constructing the stability diagram, dependent on the bar characteristics and on the absorber parameters (mass, stiffness, damping, and position). Two analytical approaches for tuning the absorber parameters were compared. The selection criterion consisted on the maximization of the minimum values of the stability-lobes diagram. Subsequent analysis performed in this work, allowed formulating of new analytical expressions for the tuning frequency improving the behaviour of the system against chatter [4].

2. REGENERATIVE CHATTER IN MACHINING PROCESS

2.1 Regenerative chatter

The regenerative chatter is considered to be one of the most vital causes of volatility in the metal cutting process. The regenerative effect is caused by the superposition of consecutive cuts, where the tool removes a wavy surface produced in the previous pass. Phase shift between older and latest cuts may cause the tool to excite at a chatter frequency (ωc) that is close to dominant structural natural frequency (ωn). Due to the overhang length of a boring bar, the vibrant stiffness is limited and liable to chatter. The maintenance of a constant cutting speed and a depth-of-cut are needed to suppress chatter, which may be achieved by changing the dynamics of tool tip [6]. Chatter is added detrimental to machining due to its instability than forced vibrations. Chatter free critical depth of cut of a machine is inversely proportional to the pessimistic real part of frequency response function at the tool–workpiece interface. Instead of targeting suppression of magnitude, the negative real part of frequency response function of the machine is reduced by designing single and multiple damper systems [13]. Vibration absorbers have been widely used to suppress undesirable vibrations in machining operations, with an exacting distinction on avoiding chatter. However, it is familiar that for vibration absorbers to function successfully their stiffness and damping must be exactly tuned based upon the natural frequency of the vibrating structure. For general vibration problems, suitable tuning strategies were developed. However, the special nature of the chatter stability problem means that this classical tuning methodology is no longer optimal [14].

2.2 Machining parameters

Machining parameters, including the spindle speed, feed rate, and cutting depth, were chosen as numerical factors [7]. A distinction in phase occurs among the tool tip displacements on the radial direction and on the cutting one. The feed motion direction and the cutting one are almost in phase. The values of the long and small ellipse axes show that these sizes are rising with the feed rate value. A weak growth of the long and small axes ratio is obtained when the feed rate value decreases. The axis that goes through the stiffness centre and the tool tip represents the maximum stiffness direction. The self-excited vibrations appearance is strongly influenced by the system stiffness values, their ratio, and their direction [9].

The velocity response obtained from the mathematical model for the main mass and impact mass clearly indicates that the damping of the system depends on the number of effective impacts and not on the total number of impacts. Optimum parameters are determined for design of impact damper based on the mathematical model [10]. Machining is an intricate process in which many variables can affect the desired results. Among them, surface roughness is a widely used index of a machined product quality and, in most cases, is a technical requirement for mechanical products since, together with dimensional precision; it affects the functional behaviour of the parts during their useful life, especially when they have to be in contact with other materials [11].

3. CONTROL OF MACHINING VIBRATION

Vibration control techniques are classified as two main categories as active and passive. Active control techniques required sensor systems to sense the vibration, an electronic controller system to process the signal from the sensors and actuators to interfere with the mechanical response of the system. The passive control technique does not need complicated hardware and the end-user does not need to introduce new handling routines. Implementations of passive damping in tooling equipment are already available on the market.

3.1. Active Control

The objective of active vibration control is to reduce the vibration of a mechanical system by automatic modification of the systems structural response. The principle of active control of vibration in machining is to analyse in real time the signal emitted during machining, recognize instability and compensate for it. The detectable benefit of the active vibration control approach is the perfect adaptability to the changes in the cutting conditions; the disadvantage 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 [8].

3.2. Passive Damper

The boring bar is held in the tool post at one end and the remaining part is called as overhang length. Some length of the boring bar from insert tip is known as cutting region which not be damped purposefully to enable the proper machining. Thus, the remaining length in between the cutting region length and that held in tool post needs to be damped to eliminate the unwanted vibration due to slenderness of the boring tool. In this investigation Nylon and Teflon materials are selected for the progress of passive vibration damper. These materials are manmade synthetic polymers that are generally used in the polymer industry. Nylon material is made a polyamide and Teflon material is a fluoro polymer. Both of them possess a high molecular weight and they are thermoplastics. The Teflon is chemically less reactive material with a high electric conductivity, and a very low coefficient of friction. Nylon is a silky material and it is an alternative for both metals and non-metals.

4. FABRICATION OF BORING BAR DAMPER

Fig-1 Model of damped boring tool bar

The new damped boring tool is designed using solid works modelling software.

Fig-2 Boring bar with Nylon and Teflon damper

Table 1. Properties of tool and damper materials

Parts	Material	Density	Young's modulus	Poison's ratio
Tool holder	EN31	7.84×10^{-6} kg/mm^3	2.84×10^5 N/mm^2	0.3
Tool insert	Cemented carbide, 6% co	14.95×10^{-6} kg/mm^3	6.25×10^5 N/mm^2	0.22
Damper 1	Teflon	2.2×10^{-6} kg/mm^3	4×10^2-5.52×10^2 N/mm^2	0.46
Damper - 2	Nylon	1.13×10^{-6} kg/ mm^3	3.7×10^3 N/mm^2	0.39

5. EXPERIMENTAL WORK

In this research 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 Vibration meter. The machining parameters are varied by changing spindle speed, feed rate and depth of cut.

Fig-2 Experimental setup of the passive damper

The boring operations were carried out on a lathe machine. The work piece was mounted in a chuck. The machining parameters like feed, speed, depth of cut etc., were used based on the manufacturer's recommendations. Passive damper is introduced in between the insert and tool holder. The length of passive damper on boring bar and overhang length was changed. The vibration meter and the deflections were measured in terms of acceleration by accelerometer during the machining operation and readings are tabulated in the table3.

5.1 Methodology

Design of Experiment (DOE) approach is chosen to investigate the effect of varying controllable parameters. Numbers of experiments to be carried out are decided with the help of Taguchi Method with MINITAB-15 software. It is assuming that inherent vibration, tool wear and length to diameter ratio (L/D) are constant during the all experimentation but cutting speed, depth of cut and feed rate are varied at different levels as per DOE. The present work shows the influence of cutting parameters on the transverse tool vibration during machining. Here, optimization of cutting parameters and tool parameters on turning is done by Taguchi Method, Regression Analysis and ANOVA. The number of level considered for each factor in DOE is as shown in Table 2[15].

Table 2. Cutting parameters and their level

	Variables	Level 1	Level 2	Level 3
A	Spindle Speed (rpm)	116	76	48
B	Feed rate (mm/rev)	0.15	0.20	0.25
C	Depth of cut (mm)	0.3	0.6	0.9

5.2 Surface Roughness Measurement

Fig- 3 Surface roughness measurement using surf-tester

Vibrations are produced by cyclic variation in the dynamic components of the cutting forces. Usually these vibrational motions start as small amplitude vibration responsible for the serrations on the finished surface and chip thickness irregularities. Under some conditions, the cutting process

Fig-4 Vibration and temperature measurement

Table 3. Acceleration value with and without damper

Speed (rpm)	Feed rate (mm)	Depth of cut (mm)	Accel. without damper	Accel. with Nylon damper	Accel. with Teflon damper
116	0.15	0.3	2.5	0.3	0.3
	0.20	0.6	3.0	0.9	0.2
	0.25	0.9	3.2	0.4	0.3
76	0.15	0.3	3.6	0.3	0.5
	0.20	0.6	3.9	0.7	0.4
	0.25	0.9	2.7	0.8	0.3
48	0.15	0.3	3.2	0.9	0.4
	0.20	0.6	2.1	0.5	0.3
	0.25	0.9	2.8	0.6	0.2

Table 4. Surface roughness value with and without damper

Speed (rpm)	Feed rate (mm)	Depth of cut (mm)	Ra Without damper	Ra With Nylon damper	Ra With Teflon damper
116	0.15	0.3	7.15	4.81	2.37
	0.20	0.6	6.42	3.82	2.95
	0.25	0.9	5.76	2.87	3.53
76	0.15	0.3	7.07	4.12	3.37
	0.20	0.6	6.39	3.18	4.0
	0.25	0.9	5.88	4.17	1.49
48	0.15	0.3	7.02	3.48	4.38
	0.20	0.6	6.62	4.54	1.88
	0.25	0.9	5.94	3.50	2.50

Table 5. Cutting temperature value with and without damper

Speed (rpm)	Feed rate (mm)	Depth of cut (mm)	Temp. without damper	Temp. with Nylon damper	Temp. with Teflon damper
116	0.15	0.3	52.0	43.80	43.40
	0.20	0.6	49.1	43.60	43.50
	0.25	0.9	46.8	44.37	43.60
76	0.15	0.3	50.1	43.80	43.70
	0.20	0.6	47.8	44.50	43.70
	0.25	0.9	46.8	44.70	43.0
48	0.15	0.3	49.3	44.50	43.90
	0.20	0.6	48.1	44.30	43.30
	0.25	0.9	45.8	45.20	43.20

where: Accel. - Acceleration, Ra- Roughness value

may be unstable, and the small amplitude vibration can progress to the large amplitude motion that affects the machined surfaces continuously. This wave formed surface roughness is measured by surface test and the surface roughness values of the workpiece with and without passive damper are listed in Table 5 [16].

6. REGRESSION ANALYSIS

6. 1 Taguchi Design for vibration analysis

Taguchi Orthogonal Array Design

L9(3^3)
Factors : 3
Runs : 9
Columns of L9 (3^4) Array

6.2 Ra value -versus speed, depth of cut, feed

The relationship between the factors and the performance measures were modelled by regression model. The regression equations obtained were as follows.
The roughness (Ra) model is given below equations: -

6.2.1 Model Summary (without damper)

S	R-sq	R-sq(adj)	R-sq(pred)
0.0428211	99.60%	99.36%	98.48%

6.2.2 Regression Equation (without damper)

Ra = 8.1043 - 0.001182 speed - 2.0341 depth of cut - 1.584 feed

6.2.3 Model Summary (Nylon damper)

S	R-sq	R-sq(adj)	R-sq(pred)
0.0270306	99.89%	99.82%	99.63%

6.2.4 Regression Equation (Nylon damper)

Ra = 7.1206 - 0.000079 speed - 1.0393 depth of cut - 13.293 feed

6.2.5 Model Summary (Teflon damper)

S	R-sq	R-sq(adj)	R-sq(pred)
0.0209674	99.97%	99.95%	99.89%

6.2.6 Regression Equation (Teflon damper)

Ra = -0.3387 + 0.000360 speed - 1.4400 depth of cut + 20.581 feed

The Temperature model is given below equations: -

6.3 Temperature -versus speed, depth of cut, feed

6.3.1 Model Summary (without damper)

S	R-sq	R-sq(adj)	R-sq(pred)
0.172620	99.49%	99.19%	97.86%

6.3.2 Regression Equation (without damper)

Ra = 52.517 + 0.02361 speed - 6.649 depth of cut - 9.88 feed

6.3.3 Model Summary (Nylon damper)

S	R-sq	R-sq(adj)	R-sq(pred)
0.273894	81.66%	70.65%	25.57%

6.3.4 Regression Equation (Nylon damper)

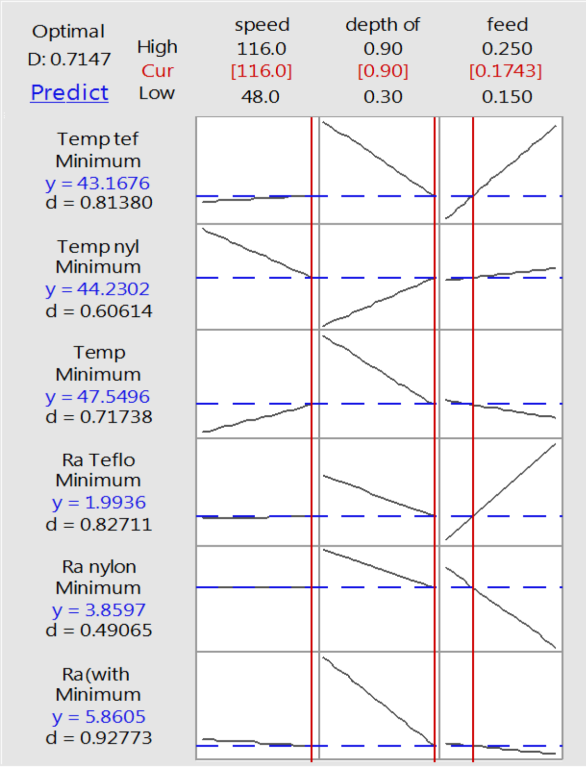
Ra = 44.070- 0.01086 speed + 1.208 depth of cut + 1.91 feed

6.3.5 Model Summary (Teflon damper)

S	R-sq	R-sq(adj)	R-sq(pred)
0.0611657	97.06%	95.29%	87.89%

6.3.6 Regression Equation (Teflon damper)

Ra = 42.837 + 0.000514 speed - 0.6667 depth of cut + 5.000 feed



The predicted values are compared with the corresponding experimental values. The ANOVA results show all the values of the response factors, surface roughness and cutting force components. Also, keen improvements are there in surface finish and vibration suppression with passive damper. Additionally, this study shows that the feed rate, depth of cut and feed rate have significant statistical influences on the surface roughness. The best surface roughness was achieved at the speed=116rpm, depth of cut=0.30mm, feed=0.17mm.

3. CONCLUSIONS

The passive damping technique has vast potential in the reduction of deflection. In this research work is proposed to reduce the deflection of the boring bar in the boring operation. The results prove that the passive damping technique has vast potential in the reduction of deflection. Passive dampers are also relatively cheaper than other commercially available damper. It can therefore also be concluded that the passive damping has a good effect in improving surface finish in boring operation. Based on experimental results, the observations which were made in this research work are concluded and summarized. The Teflon passive damper equipped with the boring tool exhibited lower values of the surface roughness, vibration, feed, overhang length, cutting temperature, and tool wear. Teflon reduces 75% of vibration and 60% increased surface finish then conventional tool. Nylon reduces 65%of vibration and 50%increased surface finish then conventional tool.

ACKNOWLEDGEMENT

The authors would like to express thanks to all the staff of Mount Zion College of Engineering & Technology, Pudukkottai, Tamilnadu, India to carry out this investigation as successful.

REFERENCES

1. M. Siddhpura, R.Paurobally "A review of chatter vibration research in turning" International Journal of Machine Tools & Manufacture 61 (2012) 27–47.
2. Guillem Quintana, Joaquim Ciurana "Chatter in machining processes: A review" International Journal of Machine Tools & Manufacture 51 (2011) 363–376.
3. J.Saffury, E.Altus "Optimized chatter resistance of viscoelastic turning bars" Journal of Sound and Vibration 324 (2009) 26–39.
4. M.H. Migue lez, L.Rubio "Improvement of chatter stability in boring operations with passive vibration absorbers" International Journal of Mechanical Sciences 52 (2010) 1376–1384.
5. R.Vinayaravi, D.Kumaresan "Experimental investigation and theoretical modeling of an impact damper" Journal of Sound and Vibration 332 (2013) 1324–1334.
6. Y. Alammari, M. Sanati, "Investigation of boring bar dynamics for chatter suppression" Procedia Manufacturing, Volume 1, 2015, Pages 768–778.
7. Chih-Cherng Chen, Ko-Ta Chiang "Analyzing the design of vibration reduction with the rubber-layered laminates in the precision turning with a diamond cutting" International Journal of Advanced Manufacturing Technology (2011) 57:101–116.
8. Lorenzo Daghini, Andreas "Design, Implementation and analysis of composite material dampers for turning operations" International Journal of Mechanical and Mechatronics Engineering, Vol:3, No:5, 2009.
9. Claudiu F. Bisu · Philippe Darnis "Displacements analysis of self-excited vibrations in turning" International Journal of Advanced Manufacturing Technology (2009) 44:1–16.
10. R. Vinayaravi, D. Kumaresan "Experimental investigation and theoretical modelling of an impact damper" Journal of Sound and Vibration 332(2013)1324-1334.
11. D. R. Salgado, F. J. Alonso "In-process surface roughness prediction system using cutting vibrations

in turning" International Journal of Advanced Manufacturing Technology (2009) 43:40–51.

12. L. Rubio, J.A.Loya "Optimization of passive vibration absorbers to reduce chatter in boring" Mechanical Systems and Signal Processing (2013).

13. Y. Yang, J.Munoa, Optimization of multiple tuned mass dampers to suppress machine tool chatter" International Journal of Machine Tools & Manufacture 50 (2010) 834–842.

14. Neil D. Sims "Vibration absorbers for chatter suppression: A new analytical tuning methodology", Journal of Sound and Vibration 301 (2007) 592–607.

15. N. B. Chaudhari, R. N. Yerrawar "Experimental investigation of transverse machine tool vibration using passive damping" Journal of Vibration Analysis, Measurement, and Control (2016) Vol. 4 No. 2 pp. 69-84.

16. T. Alwarsamy, P. Thangavel, "Reduction of machining vibration by use of rubber layered laminates between tool holder and insert", Machining Science and Technology, 11:135–143.