ISSN 2395-1621

Analysis of a Boring Bar Using Polymer Based Composite as a Passive Damper

#1C.R.Kulgod, #2T.A.Jadhav

[1]crkulgod13.scoe@gmail.com

[2]tajadhav11@gmail.com

#12Mechanical Engineering Department, Sinhgad College of Engineering, Vadgaon (Bk), Pune, India

ABSTRACT

In metal cutting the vibration problem remains to be one of the most hazardous and it hampers the production as well as finishing of the product. Thus, there is a need to suppress the vibrations of the boring tool by means of various techniques. In recent years, use of composite layers emerges as one of the popular passive damping technique. In this work, in order to analyze the vibration suppression of boring bar, a composite layer has been applied. The effect of various cutting parameters on tool vibrations has been analyzed by applying composite layer in different orientations. The 45° fibre orientation gives maximum damping. Hence, the result of said has been verified with FEM analysis. This paper focuses on the collection and analysis of the data generated by dry boring of mild steel samples on a lathe machine. The full factorial design was used to analyze the effect of speeds, feeds, depths of cut, and tool lengths on tool vibrations. This analysis explored the impact of every cutting parameter on tool stiffness and damping.

Keywords— **Composite boring bar, Cutting parameters, Damping, Design of experiment, Dry boring, Vibration**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

Boring is a commonly used operation in enlarging holes such as engine cylinder holes. When boring bars are slender and long, the operation is constrained by excessive static deflections or self-excited chatter vibrations. Both are detrimental to the accuracy and surface finish of the hole, as well as causing accelerated wear and chipping of the tool. The boring process subjects the boring tool to vibrations and cutting in deep workpiece cavities is likely to result in high vibration levels. The results of such vibration levels generally result in reduced tool life, poor surface finishing and disturbing sound. Internal turning frequently requires a long and slender boring bar in order to machine inside a cavity, and the vibrations generally become highly correlated with one of the fundamental bending modes of the boring bar. Different methods can be applied to reduce the vibrations, the implementation of the most efficient and stable methods require in-depth knowledge concerning the dynamic properties of the tooling system. Furthermore, the interface between the boring bar and the clamping house has a significant influence on the dynamic properties of the clamped boring bar. This seminar report focuses on the properties of a boring bar that arise under different clamping conditions of the boring bar and are introduced by a clamping house commonly used in the manufacturing industry. The dynamic properties of a boring bar for different cases of the boundary condition of the boring bar are presented partly analytically [1].

Conventional techniques of the vibrational suppression which could be applied in this application, i.e. incorporation of passive vibrational absorber into the boring bar or utilizing an active boring bar, require detail knowledge of the spatial dynamic properties of the regular boring bar and boring bar with composite layer on it. The natural frequencies and mode shapes of both can be estimated using different approaches, like experimental modal analysis, analytical modelling, e.g. the Euler-Bernoulli model, and numerical modelling for instance using finite element analysis. The finite element analysis gives a possibility not only to develop an accurate model of the desired system to obtain its spatial dynamic properties, but also to use this model later for the design of active tool holders. The research is focused on the development of a composite boring bar with different layers of composites on it and further analysing it for various conditions [2].

In a boring operation, the boring bar is subjected to dynamic excitation, due to the material deformation process during a cutting operation. This will introduce a time-varying deflection of the boring bar. If the frequency of the excitation coincides with one of the natural frequencies of the boring bar, a condition of resonance is encountered. Under such circumstances the vibrations are at a maximum, thus the calculation of the natural frequencies is of major importance in the study of vibrations. There are two major types of vibrations in the boring bar caused by the forces from the cutting process, bending vibrations and torsional vibrations. The force is applied at the cutting tool and the force originates from the chip deformation process during a cutting operation. In order to model the structural dynamic properties of a boring bar, a simple model might be the Euler-Bernoulli beam. Most realistic structural systems are characterized by the ability to support transverse shear as well as having internal stiffness [5].

II. COMPOSITE MATERIAL – CARBON FIBRE

Carbon fibres are a sort of superior fibre available for engineering application. It’s additionally known as graphite fibre or carbon graphite, carbon fibre consists of terribly thin strands of the element carbon. Carbon fibres have high durability and are terribly sturdy for their size. In fact, carbon fibre could be the strongest material. Carbon fibres have high elastic modulus and fatigue strength than those of glass fibres. Considering service life, studies suggests that carbon fibre-reinforced polymers have a lot of potential than aramid and glass fibres. They are extremely chemically resistant and have heat tolerance with low thermal expansion and corrosion resistance.

Each fibre is 5-10 microns in diameter. To grant a sense of however little, that's, one metric linear unit (um) is zero.000039 inches. One strand of spider net silk is sometimes between 3-8 microns. Carbon fibres are doubly as stiff as steel and 5 times as sturdy as steel, (per unit of weight). The most necessary factors determining the physical properties of carbon fibre are the degree of carbon content, (typically over 92 percent by weight) and orientation of the bedded carbon planes [3].

Carbon fibre-reinforced composite materials are used to build aircraft and space vehicle elements, racer bodies, golf club shafts, bicycle frames, fishing rods, automobile springs, sailing boat masts, and plenty of alternative components wherever lightweight weight and high strength are required. Carbon fibre’s high strength, light weight and resistance to corrosion build it a perfect reinforcing material.

Inertia of carbon fibre epoxy composite is regarding 1/10 of the product of steel or metal used for the moving components of machine structures. Specific stiffness of high modulus carbon fibre epoxy is regarding ten times over those of typical metals like steel, aluminium, etc.

Composites can be used in machine tool structures because of its good damping properties that bring down the consequences of the vibrations. Passive damping is wide employed in engineering applications, as well as bridges, numerous mounts, machine components such as rotating shafts, component vibration isolation, novel spring designs which help to achieve damping without the use of traditional dashpots or shock absorbers, and structural supports.

The drawback of active technique 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. Active damping techniques are not applicable under all circumstances due to power requirements, cost, environment, etc. Under such circumstances, passive damping techniques are a viable alternative [3].

The following table shows how the composite material is better than the conventional material.

TABLE 1
Comparison between Properties of Composite and Conventional Material

Condition	Composite Material	Conventional Material
Load-strain relationship	**More**	**Less**
Fatigue Notch sensitivity	**Low**	**High**
Transverse properties	**Weak**	**Strong**
Mechanical properties	**Higher**	**Lower**
Fatigue strength	**Higher**	**Lower**
Sensitivity to corrosion	**Much less**	**High**

III. DESIGN AND CONSTRUCTION OF THE COMPOSITE BORING BAR

The high-speed steel boring bar of diameter 16 mm is used for the boring of mild steel workpiece of 80 mm diameter. Because of dynamic stiffness and natural frequency of high-speed steel, boring with high slenderness ratio is very difficult as it induces vibrations in boring operation. It is difficult to perform a boring operation at low feed rate, low speed and high depth of cut due to poor properties of the boring bar. Therefore, in this project work the boring bar of diameter 19 mm is designed by using carbon fibre as a passive damper. The unidirectional carbon fibre is wrapped to the high-speed steel boring bar to increase the damping with the help of epoxy resin as an adhesive agent. The unidirectional carbon fibre is cut into 10^0 and 45^0 pieces and they are wrapped around the boring bar to get different combinations of the boring bar by using different fibre orientation. The schematic diagram of the boring bar is shown in the figure [4].

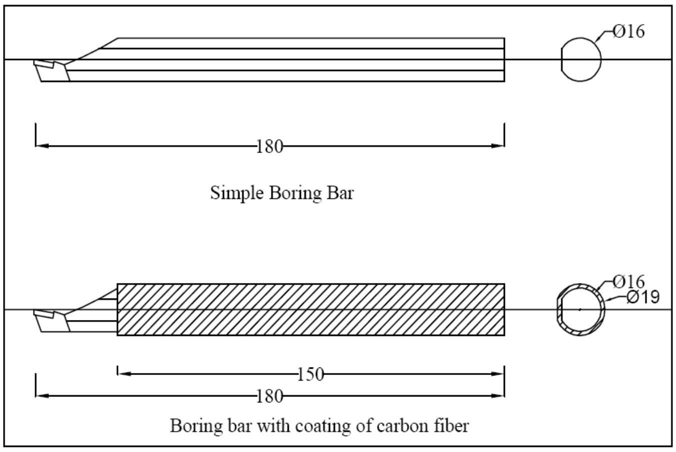

Fig. 1 Schematic diagram of the boring tool with and without coating

Steel is having less stiffness (210 GPa) as compared to the composite material (350 GPa). Hence to improve longitudinal and bending stiffness, coating of carbon fibre with different fibre orientation (10^0, Cross 10^0, 45^0, Cross 45^0) is done on the shank of the boring bar. Adhesive used for coating of a carbon fibre is the epoxy resin. Epoxy resin is not only act as an adhesive but also it improves the stiffness of the structure.

Fig.2 Photograph of standard and carbon fibre coated tool

Once the epoxy resin is applied over the carbon fibre and boring bar, the wrapping has to be done quickly because epoxy resin starts getting thick once it is mixed with a hardener and exposed to air. After wrapping carbon fibre around the shank of the boring bar it is kept aside for 2 days to become hard. The hardening process continuous for 16 days but it will not largely affect the properties of carbon fibre. To put the accelerometer over the boring bar for measuring the data, after hardening of the carbon fibre, small piece of coated material is removed and that metal part is polished to remove the adhesive. The coated boring bars prepared for the experimentation are shown in Fig. 3

Fig. 3 Boring bars prepared for experimentation

IV. EXPERIMENTAL ANALYSIS

A. Experimental Setup

The vibration analysis of the boring tool with and without coating has been carried out on the lathe machine in college workshop. The capacity of the lathe machine is 18.5 KW and a maximum machining diameter of 300 mm. The experiment was performed on a mild steel workpieces having 80 mm inner diameter as an internal boring operation using S16Q SCLCR 09T3 WIDAX boring bar.

The specifications of the boring tool used in the cutting test are given in Table 2.

TABLE 2
Specifications of the boring bar

Tool Used	**(S20S SCLCR 09T3 WIDAX)**
Bar material	**Steel**
Bar length (mm)	**180**
Bar diameter (mm)	**16**
Tool nose radius (mm)	**0.4**

The F.F.T. analyser has been used to obtain the vibration acceleration amplitude and the displacement of the boring bar under different combinations of cutting parameters. An accelerometer has been mounted with the help of adhesive at the tip of the boring bar in order to get efficient results of the tip of the tool under different conditions. The F.F.T. analyser is connected to a laptop by using USB cable in order to get a graphical representation of the output of the experiments. The entire experimental setup has been shown in Fig. 5

Fig. 4 Experimental Setup

B. Experimental Procedure

To increase the damping properties of the boring bar, the tool has been coated with carbon fibre which acts as a passive damper. To understand the effect of carbon fibre with different fibre orientations, four boring bars are prepared namely 10 Tool, Cross 10 Tool, 45 Tool and Cross 45 Tool. To investigate the effect of various cutting parameters, a full factorial experimental design is prepared. By using the combinations of different cutting parameters, 135 experimental readings were successfully taken. These different parameters are speeds, feeds, depths of cut, and overhang tool lengths.

The experiments have been conducted by mounting an accelerometer at the tool tip to measure the maximum tool acceleration and displacement of the tip in the vertical direction. The output parameters were recorded with an F.F.T. analyser. Averaging of the acceleration amplitude and displacement of the tool is done in the frequency domain. The vibration response for the boring bar with and without coating of carbon fibre has been obtained to determine the maximum amount of damping achieved.

Below table shows the cutting parameters used for the experimental analysis which are obtained from the literature.

TABLE 3
Cutting Parameters used for experimentation

Parameters	1	2	3
Spindle speed (rpm)	**280**	**450**	**710**
Feed rate (mm/rev)	**0.05**	**0.1**	**0.016**
Depth of cut (mm)	**0.1**	**0.2**	**0.3**
Overhang length of tool (mm)	**96**	**112**	**128**

V. RESULTS AND DISCUSSION

In order to study the effect of different fibre orientation on the damping of the boring bar, four tools are prepared. First the pilot experiments were performed to investigate the performance of each boring bar. At first by keeping spindle speed and feed rate constant i.e. 710 R.P.M. and 0.05 mm/rev respectively, 9 readings were taken by using combination of overhang tool length (96 mm, 112 mm, 128 mm) and depth of cut (0.1 mm, 0.2 mm, 0.3 mm). From the pilot experiments, it is found that the tool with cross 10-degree coating and cross 45-degree coating gives the better results over the other two tools.

TABLE 4
Percent reduction in acceleration amplitude

		% Reduction in Amplitude			
Overhang Length (mm)	**Depth of Cut (mm)**	**10 Tool**	**Cross 10 Tool**	**45 Tool**	**Cross 45 Tool**
96	**0.1**	**40.18**	**53.49**	**21.22**	**84.42**
	0.2	**57.17**	**67.12**	**0.88**	**67.77**
	0.3	**55.74**	**15.30**	**25.14**	**63.57**
112	**0.1**	**14.90**	**56.50**	**35.80**	**69.28**
	0.2	**31.78**	**39.09**	**28.15**	**67.53**
	0.3	**31.68**	**40.35**	**33.59**	**73.61**
128	**0.1**	**44.61**	**41.72**	**67.49**	**72.268**
	0.2	**44.13**	**48.95**	**53.14**	**56.29**
	0.3	**20.75**	**24.98**	**50.26**	**56.59**

Percent reduction in amplitude of coated boring bar is given in a TABLE 4.

Form table it is clear that the cross 45 tool gives the maximum reduction in amplitude and the range of maximum reduction is in between 65% to 85 %. After that the cross 10 tool reduce the amplitude better than remaining two tools and the percent reduction is in between 40% to 70%. Therefore for further experimentation Cross 10 Tool and Cross 45 Tool are investigated under various conditions.

TABLE 5
Percent reduction in displacement of tool

		% Reduction in Displacement			
Overhang Length (mm)	**Depth of Cut (mm)**	**10 Tool**	**Cross 10 Tool**	**45 Tool**	**Cross 45 Tool**
96	**0.1**	**37.5**	**75**	**12.5**	**75**
	0.2	**50**	**66.67**	**33.33**	**50**
	0.3	**50**	**16.67**	**0**	**16.67**
112	**0.1**	**27.69**	**67.69**	**43.08**	**63.08**
	0.2	**34.43**	**39.34**	**27.87**	**59.02**
	0.3	**39.**	**52.**	**35.**	**68.29**

		02	44	37	
128	0.1	24.39	40.24	51.22	34.15
	0.2	24.71	11.76	35.29	4.71
	0.3	6.59	9.89	48.35	8.79

From pilot experiments it is also found that Cross 10 Tool and Cross 45 Tool also give the better reduction in the displacement. The percent reduction in the displacement is shown in TABLE 6.

Graphical representation of the reduction in amplitude and reduction in displacement gives more clarity about the damping obtained using the passive damper.

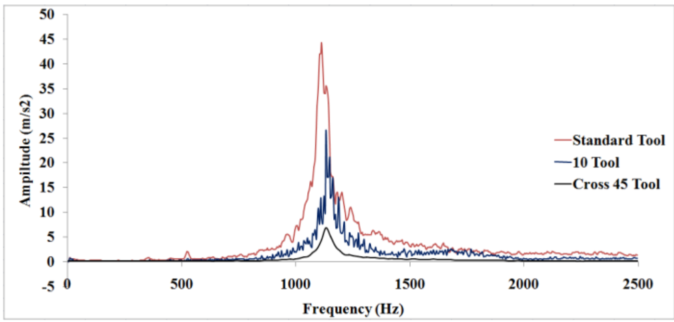

Fig. 6 Frequency vs. Amplitude graph obtained from F.F.T. analyser

It can be seen from Fig. 6 that the maximum reduction in the vibration amplitude has been obtained at Cross 45 Tool. The amplitude of simple tool at a frequency 1113 Hz is 44.3 m/s^2. The amplitude of vibration is decreased when Cross 10 Tool is used and it is 26.5 m/s^2 at 1147 Hz. The value of amplitude further decreases when the Cross 45 Tool is used and it is found to be 6.9 m/s^2 at 1138 Hz. This result shows that the carbon fibre which is acting as a passive damper has a tremendous effect in increasing the tool damping by reducing the vibration acceleration amplitude compared with the simple solid tool.

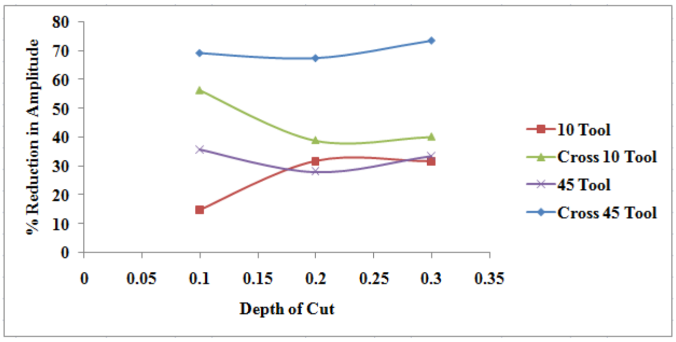

Fig. 7 Percent reductions in the amplitude at 112 mm overhang length

Above figure shows the percentage reduction in the amplitude of the boring bar when the overhang length of the tool is 112 mm. The reduction in the displacement for the Cross 45 Tool is in between 676% to 74% whereas for Cross 10 Tool it is in between 39% to 57%. From figure it is clear that the Cross 45 Tool gives the maximum reduction in the amplitude and the Cross 10 Tool also gives better reduction in the amplitude than the remaining two tools.

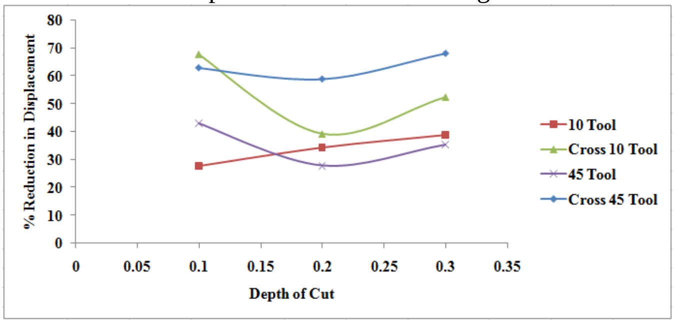

Fig. 8 Percent reductions in the displacement at 112 mm overhang length

Above figure shows the percentage reduction in the displacement of the boring bar when the overhang length of the tool is 112 mm. The reduction in the displacement for the Cross 45 Tool is up to 69% whereas for Cross 10 Tool it is around 53% when the same depth of cut is considered. From figure it is clear that the Cross 45 Tool gives the maximum reduction in the displacement and the Cross 10 Tool also gives better reduction in the displacement than the remaining two tools.

A. Effect of various parameters on boring bar

TABLE 7

Percent reduction in acceleration amplitude

			% Reduction in Amplitude	
Overhang Length (mm)	**Feed (mm/rev)**	**Speed (rpm)**	**Cross 10 Tool**	**Cross 45 Tool**
96	0.05	280	15.91	17.87
		450	4.61	16.09
		710	15.20	12.46
	0.1	280	13.58	7.82
		450	1.58	12.10
		710	11.83	25.04
	0.16	280	9.42	26.27
		450	14.26	35.86
		710	7.33	24.87
112	0.05	280	51.94	65.70
		450	65.53	64.69
		710	38.10	69.37
	0.1	280	21.33	43.58
		450	37.29	49.36
		710	46.02	54.54
	0.16	280	18.46	47.31
		450	14.88	35.83
		710	16.80	55.79
128	0.05	280	26.93	60.93
		450	50.78	57.94
		710	43.50	56.17
	0.1	280	17.82	81.72
		450	26.78	80.29
		710	9.66	73.04

	0.16	**280**	**8.37**	**38.18**
		450	**9.34**	**45.19**
		710	**25.58**	**76.25**

From pilot experiments, it is clear that Cross 10 Tool and Cross 45 Tool gives good damping over the other two tools. Therefore, full factorial design experiments were performed using these two tools and results were compared with the simple tool.

To investigate the effect of different parameters which are feed, spindle speed and overhang length of the tool, by using the design of experiments chart is prepared. TABLE 7 shows the different cutting parameters and obtained results related to them. For each overhang length, three feeds and three speeds are decided according to availability. Thus for each overhang length 9 readings were obtained which covers all the combinations.

From the above table, it is observed that, for a particular overhang length of tool and feed rate, as spindle speed goes on increasing amplitude of vibration decreases. With the increment in the feed rate of the tool, amplitude of the vibration also increases. It is found that more the overhang length more the amplitude of vibration. The Cross 10 Tool and Cross 45 Tool show great reduction in the amplitude of vibration over the simple tool at same operating conditions. The following table shows the percent reduction in the amplitude when damped tool is used.

The following figures show the reduction in the amplitude of the boring bar. The graphical representation gives better understanding of the results. The graphs for amplitude reduction at three different overhang lengths (96 mm, 112 mm, 128 mm) are shown. For each overhang length combinations of three feeds (0.05 mm/rev, 0.1 mm/rev, 0.16 mm/rev) and three spindle speeds (280 rpm, 450 rpm, 710 rpm) were considered.

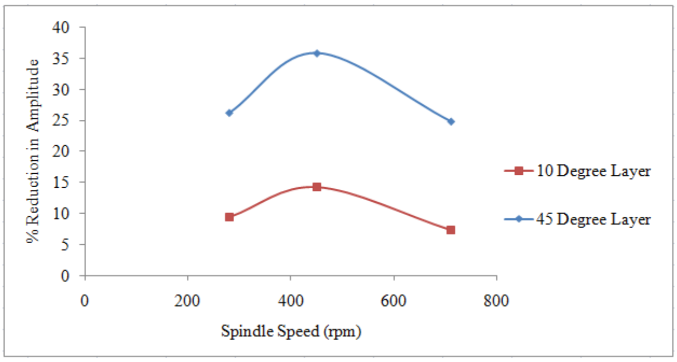

Fig. 8 Percent reductions in the amplitude at 96 mm overhang length

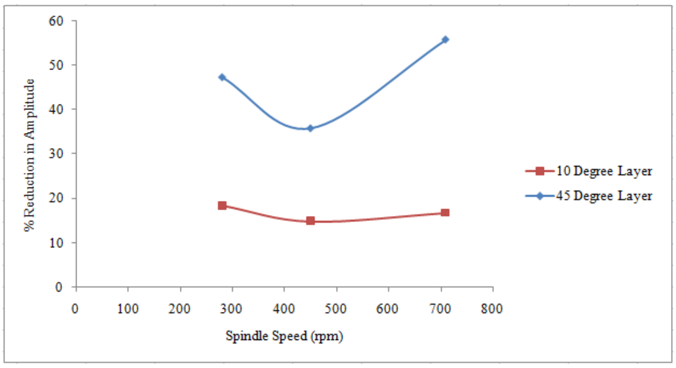

Fig. 9 Percent reductions in the amplitude at 112 mm overhang length

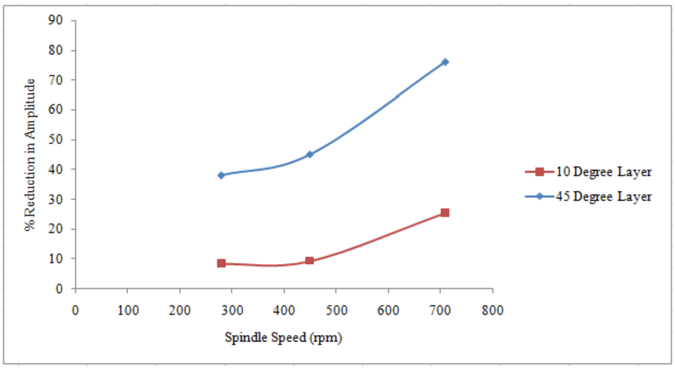

Fig. 10 Percent reductions in the amplitude at 128 mm overhang length

Fig 8, Fig. 9 and Fig. 10 clearly indicates that, Cross 45 Tool gives more reduction in the amplitude than Cross 10 Tool when cutting conditions for both tools were kept constant. The nature of the graph is almost same. The percent reduction for maximum overhang length is up to 80%. For minimum overhang length i.e. 96 mm, the maximum reduction in amplitude is at 450 rpm for both Cross 10 Tool and Cross 45 Tool.

VI. CONCLUSIONS

In order to study the effect of different fibre orientation on the damping of the boring bar, full factorial experimental analysis has been performed. For simple tool and coated tool, readings were taken under the same cutting conditions to check the performance of each tool. In this work it is observed that magnitude of amplitude goes on decreasing as spindle speed is increases. For more depth of cut the magnitude of amplitude is higher. As the feed rate of boring bar increases value of amplitude also increases.

From the experimental analysis it is observed that, the boring bars which are coated with carbon fibre with different fibre orientation gives the damping effect when compared to simple boring bar. The Cross 45 Tool i.e. the tool coated with carbon fibre with 45 degree fibre orientation gives the maximum damping effect over the other tools and the Cross 10 Tool gives the better results over the other tools. At highest overhang length i.e. L/D = 8 acceleration reduction is obtained up to 70% when Cross 45 Tool is used.

REFERENCES

[1] R. Chandra , S.P. Singh , K. Gupta , “Damping studies in fiber-reinforced composites - a review”, Department of Mechanical Engineering, Indian Institute of Technology, Hauz Khas 110016, New Delhi, India.

[2] L. Andren, L. Hakansson, A. Brandt, I. Claesson , “Identification of motion of cutting tool vibration in a continuous boring operation—correlation to structural properties”, Mechanical Systems and Signal Processing 18 (2004) 903–927, Department of Telecommunications and Signal Processing, Blekinge Institute of Technology, 372 25 Ronneby, Sweden.

[3] Dai Gil Lee, Hui Yun Hwang, Jin Kook Kim, “Design and manufacture of a carbon fiber epoxy rotating boring bar”, Mechanical Design Laboratory with Advanced Materials, Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong, Yuseong-gu, Daejeon-shi 305-701, South Korea.

[4] Shuzo Nagano, Takayuki Koizumi, Toru Fujii, Nobutaka Tsujiuchi, Hiroki Ueda & Kobe Steel, “Development of a composite boring bar”, Doshisha University, Tanabe, Kyoto 610-03, Japan.

[5] D. G. Lee, “Manufacturing and Testing of chatter free boring bars”, Korea Institute of Technology - Sponsored by N. P. Suh (I) , M.I.T. Received on January 4, 1988.