Static analysis of composite boring bar using FEA

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ABSTRACT

Boring is an internal turning operation in which pre-drilled holes or holes in a cast, etc. are enlarged. The relative motion between the workpiece and tool in cutting direction results deflection in the boring bar and deformation in cutting insert during the boring operation, which produces the poor surface finish. In view of this a static analysis of the composite boring bar has performed and compared with conventional one. Moreover, the modal analysis of conventional and composite boring bars has shown for six modes of vibrations to find out the natural frequencies using ANSYS® 15.0. It has been observed that there are four bending and two torsion modes available in the six modes of vibration. Further, the total deformation, equivalent stress and equivalent strains have been taken from the simulation and compared with the composite and conventional boring bars.

Keywords: Composites, Boring Bar, Natural frequency, Damping Ratio, Deformation.

1. INTRODUCTION

The vibrations generated during machining operations such as turning, milling and boring is one of the major concern in manufacturing industries. Boring is an internal turning operation in which pre-drilled holes or holes in cast, etc. are enlarged. This process is associated with severe vibrations due to long overhang. A long and slender boring bar is more sensitive to the excitation brought in by the deformation of material caused by the machining operation. The boring bar is usually the weakest link in the clamping system of the lathe and motion of boring bar may vary with time. The deformation of the workpiece results in the dynamic motion (vibration). This dynamic motion or vibration influences the results of the boring operation, particularly the surface finish of the workpiece. The vibration also influences the tool life. This operation is used for a better dimensional accuracy of the pre-drilled holes. Hence, additional care should be taken in production planning to minimize these vibrations with assured shape tolerance. Therefore, the vibrations produced in boring operation have

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considerable effect on significant factors such as productivity, production cost, etc. An exhaustive investigation of these induced vibrations results in a significant step towards solving these problems. The relative motion between the workpiece and tool in cutting direction results deformation of the boring bar as well as cutting insert during the boring operation.

Clancy et al. (2002) studied the effect of tool wear in face turning operation by developing an enhanced three-dimensional frequency-domain chatter prediction model. A process damping model has been developed to simulate the interference that occurs between the tool flank and workpiece surface based on the slope change along the tool cutting edge. The same model is validated using cutting conditions with and without wear. The theoretical predictions have good agreement with the experimental data for various cases [1]. Edhi and Tetsutaro (2002) studied the stability of high frequency machining vibration using extended chatter model in fine boring operation. The amplitude ratio of X and Y directional vibration displacements has been predicted for those cutting conditions above the stability borderline. Results of those predictions have been confirmed to agree with the experimental measurements obtained by cutting tests, therefore proving the validity of the basic extended chatter model and the equation for predictions [2]. Cakir and Yahya (2005) performed a static analysis to identify high stress regions and identification of the natural frequency with maximum relative displacement in those regions. Finally, harmonic forcing analyses at those frequencies are carried out [3]. Assefer (2013) studied parametric analysis by generalized finite element analysis using ANSYS. It is observed that taper, opening and its size are the important factors that need to be considered in the design of machine tool column. On the other hand, the size of aperture has an influence on the static and dynamic rigidity of the machine tool column and hence attentions need to be given by the machine tool structural designer [4]. Sam Paul et al. (2014) studied the effect of boring tool holder with and without damper by varying the overhang length on tool vibration using both ANSYS and experimentally. It has been observed that using damper, tool vibrations are reduced and cutting performance is improved effectively from experimentation. Moreover, it has been observed that 100 mm overhang length cutting tool is having less deflection compared to all other values. Further, it has been observed that increase in acceleration of cutting tool with overhang length conditions the cutting tool vibration depends strongly on overhang length [5]. Shrikant et al. (2014) studied the performance of boring tool under vibrations using passive dampers. It has been observed

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that the vibration level decreases by 40 % due to installation of passive damper on boring tool. In addition, the surface finish enhances by 48% due to reduction of boring tool vibration. Further, regression analysis and optimization of process parameter has been performed. It has been observed that irrespective of higher values of machining process parameters the passive damper made of composite material reduce the level of vibration by approximately 25 % as compared to PTFE [6]. Sayeed Ahmed et al. (2014) presented a new methodology to study the damping effect of magnetic rheological fluid during end milling operation. It has been seen that ANSYS can predict the value of deflection very accurately with a variation of 3% to 5% of the actual value in end milling under different machining conditions. The magnetic-rheological damping provides the effective means of chatter resistance. Due to reduction in vibrations, the chatter marks on the machined surface have also reduced. This indicates that by using MR damper it is possible to achieve a good control over tool vibration and uniform quality product [7]. Tushar and Vaibhav et al. (2016) studied the composite boring bar for better performance. It has been observed that the proposed boring bar can be approved for reducing vibration in boring process. Since the frequency of vibration is greatly reduced by applying the modifications without much affecting the strength of the bar, so these modifications can be considered good for boring bar. Though after all these analysis, we can trust this model for use but a practical testing of same is recommended [8]. Kulkarni and Jamgekar (2016) carried out the experiments using passive dampers on the boring tool in boring operation. It has been observed that by using passive damper vibration of boring bar is reduced which result in good surface finish. Further, modal analysis has been performed to find out the natural frequency for various modes. It has been observed that at higher natural frequencies above 1500 Hz boring bar will undergo bending and twisting [9]. Vignesh et al. (2017) performed the modal and harmonic analysis on the boring bar in boring operation using various passive damping materials. It has been observed that the mode shapes and natural frequency of the boring tool has been improved with damping materials. It has been observed that the peak frequency obtained from the modal analysis is same as that of harmonic analysis. Copper damped boring tool shows that there is a significant improvement in its frequency when compared with other damping materials. Hence copper is suggested as a suitable damping material for boring operations [10]. Jeyakumar et al. (2017) studied the modal analysis of boring tool with and without dampers. It is observed that the natural frequency of boring tool has been enhanced with damping materials. From the FEA analysis, it is observed that amplitude of the vibration has been reduced with damping materials. In that analysis PAPAYASTUM damped boring tool amplitude of vibration has been reduced when compared with undammed boring tool and damper ALOEVERA ROOT [11]. Many researchers studied the modal, static and harmonic analysis of the boring bar with and without dampers to minimize the tool vibration. Metal matrix composites are the materials which are having goo mechanical and high damping properties. Hence, in this work we used metal composite as the boring bar material.

In the present work, the static, modal and harmonic analysis of the conventional and composite boring bar has been performed. Further, the total deformation, equivalent stress and equivalent strains from static analysis, natural frequencies from modal analysis and damping ratios from harmonic analysis have been computed from the simulation and results of composite boring bar are compared with the conventional boring bar.

2. MODELLING OF BORING BAR

The standard boring bar of diameter 16mm and length 200 mm is modeled using Solid Works software. The geometry of the boring bar is presented in figure 1. The model of the boring bar is same for both conventional and composite boring bar. The properties of the conventional and composite boring bar used in the static and harmonic analysis in ANSYS are tabulated in Table 1.

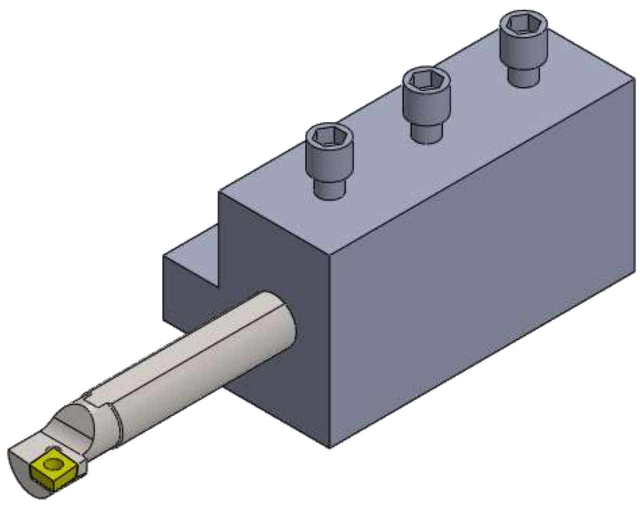

Figure 1. Geometry of the boring bar with insert and tool holder

Table 1. The material properties of conventional and composite boring bars used in ANSYS

Property	Units	Steel	Composite
Density	**g/cc**	7.85	1.8925
Modulus of Elasticity	**GPa**	200	208.5
Poisson's ratio	**No units**	0.33	0.33

3. FINITE ELEMENT ANALYSIS

Boring bar along with insert and screw is modeled and analyzed using ANSYS to determine the static and dynamic characteristics. The material of the boring bar used in the analysis is steel and magnesium based metal matrix composite.

3.1. Static Analysis

The static analysis has been performed using ANSYS software to obtain deflection values at an overhang length of 110 mm for both conventional and composite boring bar. Solid element of type 8 node 185 was used in this study. Considering the boring bar as a cantilever beam, all degree of freedom was fixed for the given overhang length. A point load of 420 N has been applied at the tip of the boring bar in vertical direction. It has been observed that the deflection of conventional boring bar is more compared to composite boring bar at an overhang length of 110mm as shown in figure 2. This is due to the composite materials are having more damping properties. This clarifies that, use of composites as boring bar material can help in attenuation of excessive vibrations and help in better machining operation and longer tool life.

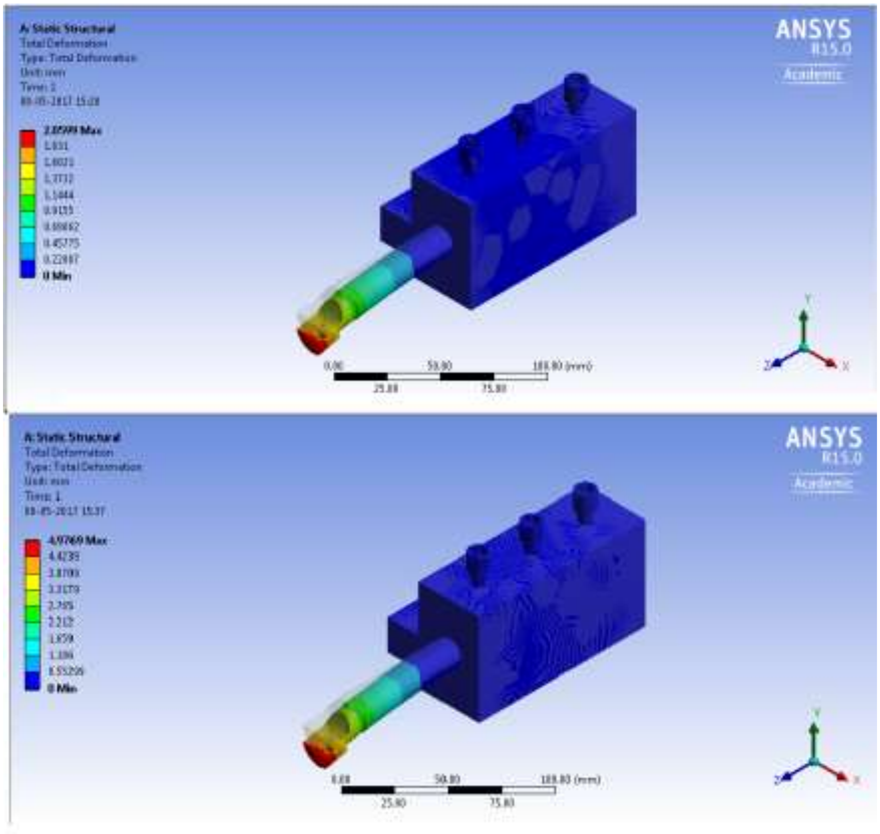

Figure 2. Total deformation of (i) composite boring bar and (ii) Conventional boring bar

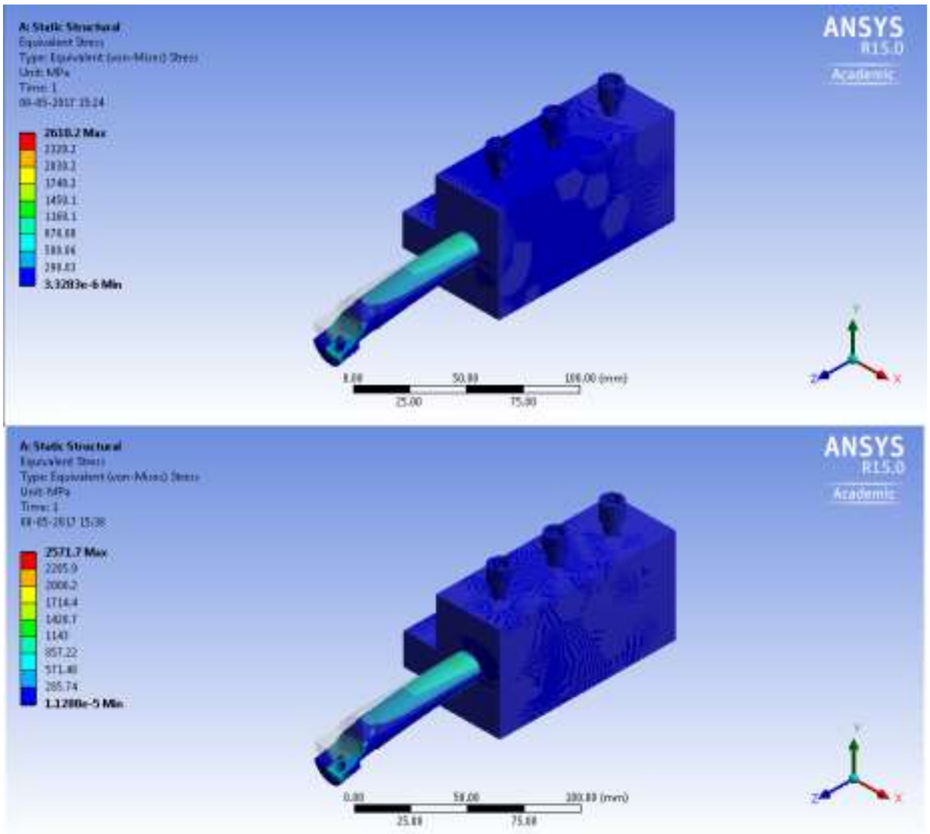

Figure 3. Comparison of Equivalent Stress of (i) composite boring bar and (ii) Conventional boring bar

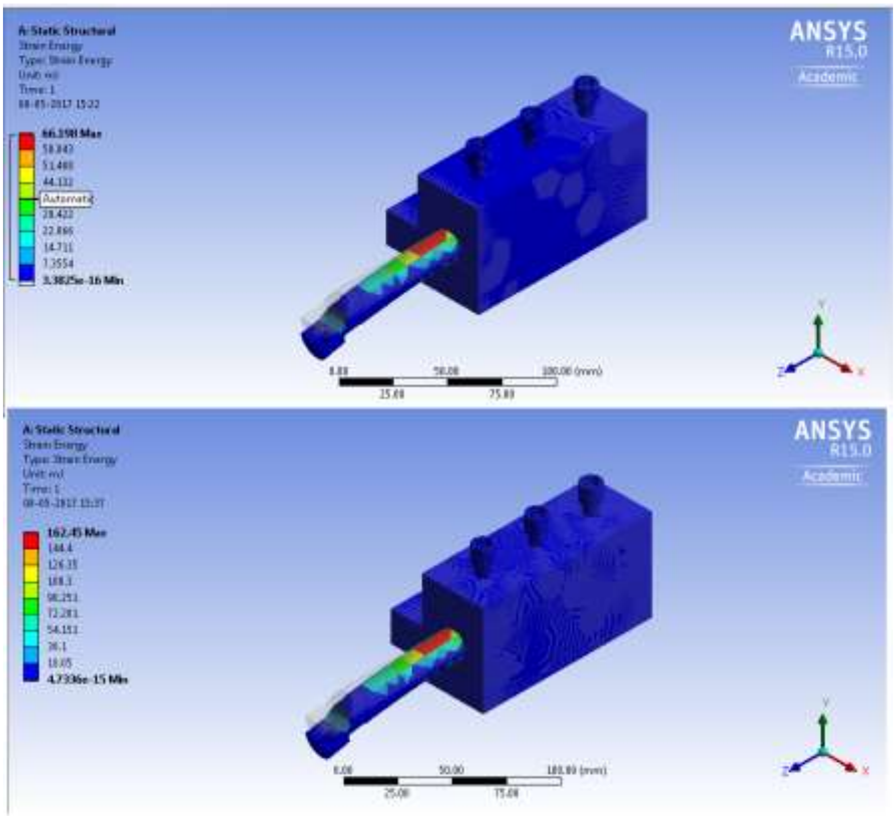

Figure 4. Comparison of Equivalent Strain energy of (i) composite boring bar and (ii) Conventional boring bar

The equivalent stress of the boring bar made of composite is more than the boring bar made up of steel from figure 3. This clearly explains that the composite bar is less prone to failure if we compare the material strength. The total strain energy of the boring bar made of composite is more than the boring bar made up of steel from figure 4. This explains that the composite boring bar can store more strain energy than the conventional boring bar.

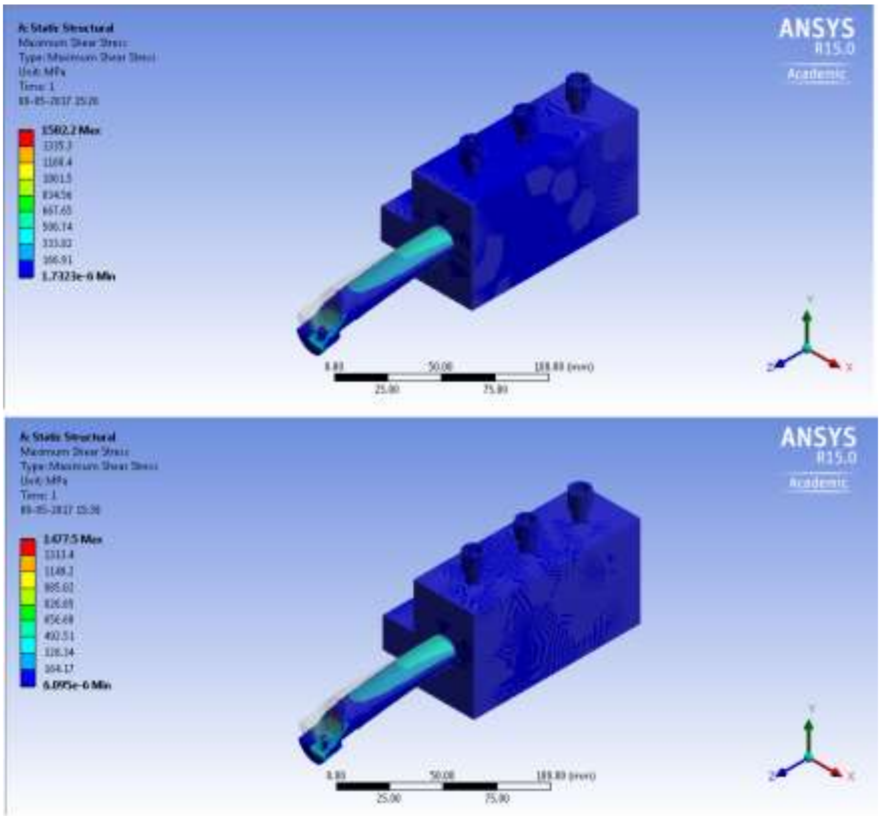

Figure 5. Comparison of Maximum shear stress of (i) composite boring bar and (ii) Conventional boring bar

The maximum shear stress of the boring bar made of composite is more than the boring bar made up of cold rolled steel form figure 5. This can be concluded that the composite boring bar is more resistant to torsion compared to conventional boring bar, which increases the productivity of the tool.

3.2. Modal Analysis

Modal analysis is the field of measuring and analyzing the dynamic response of structures and fluids when excited by an input. This id frequently utilized to abstract the modal parameters of a system, including natural frequencies and mode shapes. This is fundamental response analysis and has therefore gained more attentions. It is performed and the maximum natural frequency obtained at 90 mm overhang is 3555.3 Hz.

Table 2. Results of modal analysis for conventional and composite boring bars

Mode	Time/frequency	
	Conventional boring bar	Composite boring bar
1	225.53	226.92
2	235.82	236.32
3	1390.5	1399.2
4	1451.8	1455.1
5	3541.9	3555.3

3.3. Harmonic Analysis

Harmonic analysis is a branch of mathematics concerned with the representation of functions or signals as the superposition of basic waves, and the study of and generalization of the notions of Fourier series and Fourier transforms. Fourier analysis is used to analyze the periodic function into a sum of simple sinusoidal components. Any sustained cyclic load will produce a sustained cyclic response in a structural system. Harmonic response analysis gives the ability to predict the sustained dynamic behavior of structures, thus enabling to verify whether or not the designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations. Harmonic response analysis is a technique used to determine the steady state response of a linear structure to loads that vary sinusoidally with time

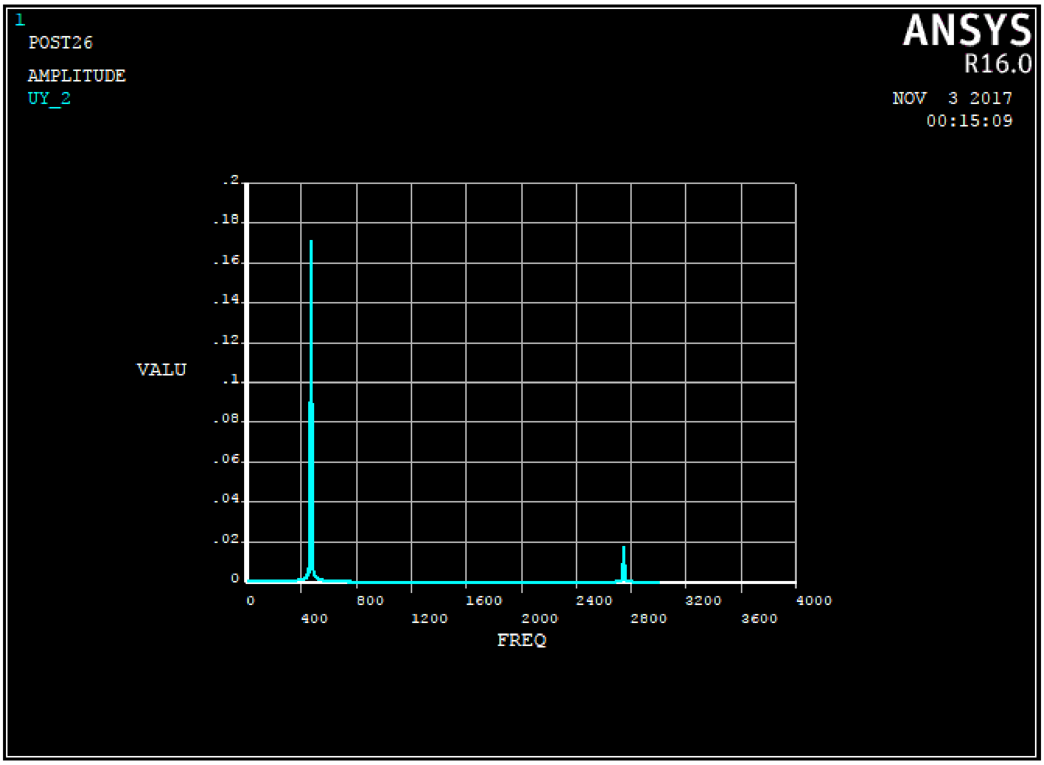

Figure 6. Harmonic analyses at 110 mm overhang length for composite boring bar

In this study, a load of 420N is applied to calculate the damping ratios using the Half-power band width method for both composite and conventional boring bar as explained in Figures 6 and 7. Damping ratio values for conventional and composite boring bars are 0.018 and 0.125 respectively at an overhang length of 110 mm.

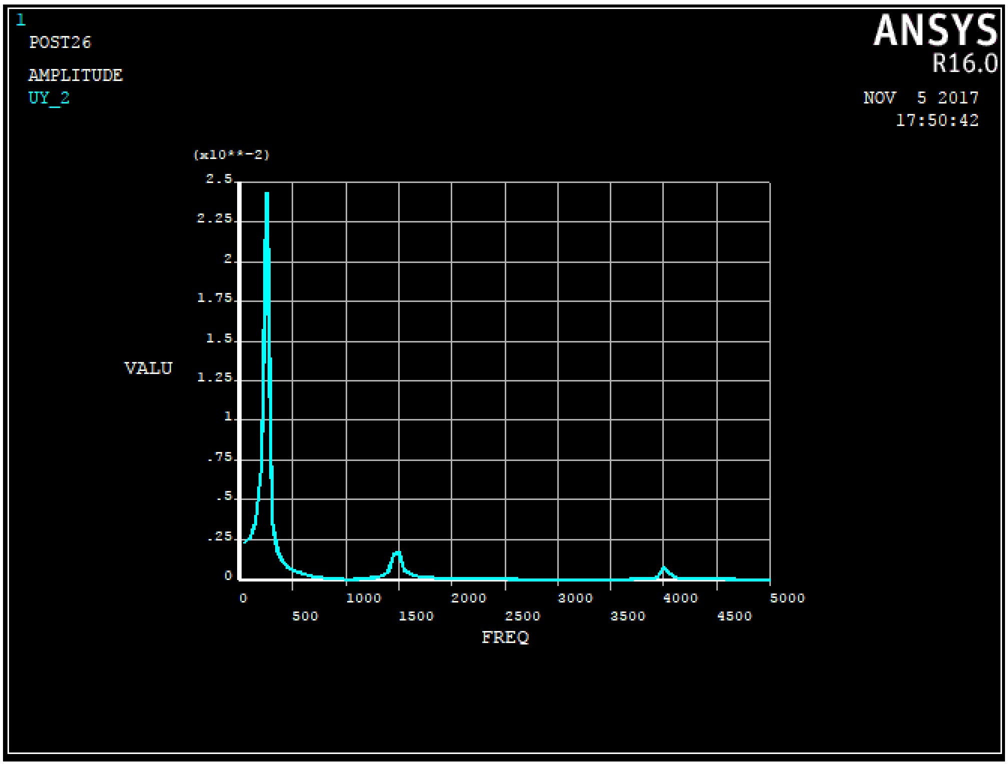

Figure 7. Harmonic analyses at 110 mm overhang length for conventional boring bar

4. CONCLUSION

In the present paper, the static, modal and harmonic analysis of the conventional and composite boring bar has been performed. The modal analysis of conventional and composite boring bars has been shown for six modes of vibrations to find out the natural frequencies using ANSYS® 15.0. It has been observed that there are four bending and two torsion modes available in the six modes of vibration. The four bending modes are first four modes and fifth and sixth modes are torsion mode.

Further, structural analysis has been carried out to find out the total deformation, equivalent stress and equivalent strains. It has been observed that the total deformation for conventional and composite boring bars is more at the tip of the tool. The strain is maximum along the top surface of the boring bar and tip in case of conventional one whereas only at the tip of the composite boring bar. The maximum stress in conventional and composite boring bars is obtained at the periphery near to the tool holder. From static structural analysis, it is noticed that the composite boring bar is more suitable to minimize the vibration which improve the surface finish of the machined part.

From harmonic analysis the sinusoidal as well as frequency response plots are obtained. The natural frequencies obtained from modal analysis are in good agreement with the harmonic analysis. The damping ratios of the conventional and composite boring bar have been calculated using Half-Power band width method from frequency response plot. The values are 0.018 and 0.125 for conventional and composite boring bars respectively at an overhang length of 110 mm. From these analyses it is concluded that composite material for boring bar is most suitable for minimizing the vibration and improve the surface finish and tool life.

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