ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

Magneto Rheological Damper assisted Control of Machine Tool Vibration

[1] Rahul Kishore, [2] Sounak K Choudhury, [3] Kashfull Orra
[1] Department of Mechanical Engineering, Indian Institute of Technology Kanpur, India

Abstract:- **Work in this paper is primarily focused on monitoring and controlling the tool vibration using magneto-rheological damper. Magneto–rheological damper consists of MR fluid whose viscosity and shearing stress can be controlled by changing the magnetic field around it with the help of current passing through the coils wrapped around the fluid container. Study involves the characterization of MR fluid as well as vibration characterization of MR damper. Thus MR damper provides variable stiffness and better damping ability and hence better control over the process. The experimental results show that dynamic response and machining parameters (tool wear, surface roughness and cutting force) of the cutting tool system is improved to a great extent when MR damper was employed. In this paper, transmissibility approach and half power band width method were incorporated to analyse the signal amplitude ratio, the damping ratio and settling time of MR damper. In addition to these dynamic stability of the cutting tool holder was obtained with second mode of vibration using ANSYS. With the help of MR damper the tool vibration was reduced to a great extent which ensures reduction in tool wear, less fluctuation in cutting force, less power consumption and hence better tool life and improved productivity.**

Index Terms— Damping Ratio, Hard Turning, Magneto- Rheological (MR) fluid, MR damper, Transmissibility.

I.INTRODUCTION

Tool vibration in cutting process is primarily due to the fluctuations in cutting force due to the shearing of chip and the presence of frictional force between the tool and workpiece interface. Two major types of vibration experienced by tool are- self excited and forced vibration. Instability in the cutting process is termed as chatter which occurs when the rigidity of the cutting tool and its support is assumed small in one direction and allowing the cutting tool to vibrate in one direction only (Type 1 or Type 2 chatter [1]).Instability in the dynamics of the cutting tool relative to the work material increases the tool wear and causes poor surface finish leading to dimensional inaccuracy in the work material. To understand and control the tool vibration (non-linear responses), theoretical modelling and its analysis pose a great importance. Many research works are still in progress for proper theoretical analysis of tool vibration. Practically, cost involved in eliminating machine vibration is too high. Therefore, industries have to find certain alternative to achieve the same. In view of that, this paper emphasises on introducing an active damper with less operating cost. MR damper consists of piston cylinder (containing MR fluid) arrangement and coils that are wound around the cylinder (described in section 2 and 4). In this electromagnetic damper, with supply of electric current to the coil, eddy current develops inside the piston cylinder arrangement.
According to the Lenz law, this eddy current will create magnetic field of opposite polarity with time varying magnetic field, leading to the formation of chain-like structure of MR particles. The strength of this chain will depend on viscosity and shear stress which are controllable. This will create a reaction force which will try to balance the main cutting force in order to suppress vibration. Even though a lot of research works have been conducted on tool vibration, only a few studies can be found on controlling tool vibration on-line using controllable damper. Therefore, this paper focuses on the design and development of controllable damper which can be easily installed making it competent to diminish tool vibration on-line. Yan et al. [3] have presented a damper structure whose foundation and designs were theoretically calculated. Based on the calculation and some mathematical analysis they have found volume, thickness and width of the MR fluid used within the damper. Guo et al. [4] proposed a model to study the effect of bi-viscous and hysteresis on MR damper. They have studied vibration isolation for predicting amplitude of undesirable effect of vibration in the system. Xiao et.al. [5] have proposed a vibratory cutting model to suppress chatter. From the simulation result which was in agreement with the measured experimental value, they concluded that with the use of vibratory cutting method chattering on the work surface can be minimised. Tarang et al. [6] used a piezoelectric inertia actuator acting as a tuned vibration absorber to suppress chatter in turning operation. Frumusanu et al. [7] presented a stability intelligent control technique for online monitoring of cutting force signal. A dedicated control model was implemented to take the appropriate decisions related to the spindle speed. The chatter onset was successfully avoided by this approach. Al-Regib et al. [8] developed a systematic procedure for optimal selection of spindle speed variation and corresponding frequency of the cutting force signal developed through chattering so that input energy required

can be minimized for obtaining stable cutting in a turning process. Park et al. [9] had extensively reviewed the development of active materials in machining process with a special focus on piezo-electric and magneto-restrictive materials and applications in active suppression of chatter for turning and other cutting processes. Metered et al. [10] had experimentally identified the dynamic behaviour of an MR damper along with the control parameters. From their analysis it was revealed that neural based damper controller can be best for controlling damper, with extended service life and minimal use of sensors. Chen et al. [11] have introduced a computational method to stabilize chattering in turning process. Their computation involved solving characteristic equation as a single bounded variable equation. Thus many researchers [12-15] had tried to suppress the vibration of cutting tool through the modelling by predicting cutting velocity so as to avoid the random fluctuation of cutting force. Main focus in this paper is to design a magneto-rheological damper and install at the bottom of tool holder in hard turning process, ensuring that this arrangement will be highly responsive to the applied force at given cutting parameters. Number of turns of coils required to achieve the possible amount of magnetic field at varying DC power supply through external source was calculated. In addition, characterization of magneto-rheological fluid and damper was studied. Transmissibility approach was adopted to determine damping factor of cutting tool in vibratory motion on machining hardened AISI D2 steel in turning process.

II. DESIGN AND CHARACTERIZATION OF MAGNET-RHEOLOGICAL FLUID DAMPER

Magneto-Rheological fluids are non-suspension and non-colloidal of micron sized magnetisable particles mixed with non-magnetic carried fluid.70% Fe-particle mixed with 30% viscous SAE 40 oil has been used in this paper. In the presence of magnetic field, these micron- sized Fe-particles in SAE 40 oil begin to align along the flux path and form particle chain- like structure which is shown in Fig. 1. This particle chain helps to restrict the fluid movement by increasing the viscosity of the MR fluid. Due to this behaviour of MR fluid, it is used as a medium in the damper to enhance the damping force required to suppress the cutting tool vibration exerted in the turning process. The main advantage of MR fluid is its ability to reversibly change from free-flowing linear viscous liquid to semi-solid with controllable yield strength. This can be achieved by controlling the induced magnetic field by controlling current across the coil. MR fluid was stirred till they were completely mixed. The viscosity of the mixture is a measure of flow characteristic and is an important property. A rheometer (Anton Paar MCR 301 MRD 180 attachment) was used to measure the viscosity and other flow properties (shear stress, shear rate) of the mixture in the presence of magnetic field when subjected to varying temperature. Weight constituent of MR fluid in damper with 40 mm diameter and 25 mm height is found out from

$$\text{Weight of sample} = \frac{V_T \times S_{weight(\%)} \times \rho_{Sample}}{100} \quad (1)$$

In order to understand the rheological behaviour of MR fluid it is very important to do the characterisation of MR fluid. Fig. 2(a) shows variation of the shear stress with respect to shear rate for the MR fluid with the application of current supplied internally to the system. Viscosity of MR fluid with respect to shear rate is shown in Fig. 2(b).It was observed that MR fluid behaviour is quite Non-Newtonian due to the alignment of MR particle in the direction of magnetic flux path created due to the supply of electric current while shear thinning was observed when there was no magnetic field at zero electric current. Further, Fig. 2(b) demonstrates the shear thinning behaviour of MR fluid with increasing shear rate at individual supply of electric field. But with increase in supply of electric field shear thickening was observed. This is because of increase in magnetic field due to increase in electric field that restricts the mobility of Fe-particles between the two poles (N-S) of magnet. Fig. 3 shows the relationship between viscosity and shear rate for MR fluid at varying temperature. It was observed that viscosity remains almost same with increase in shear rate at constant electric current of 1.2A. It is obvious that with increase in temperature MR fluid loses its viscosity and becomes thinner making it in effective in suppressing the tool vibration. Mean yield viscosity for this case was observed to be less than 0.5 kPa.s.

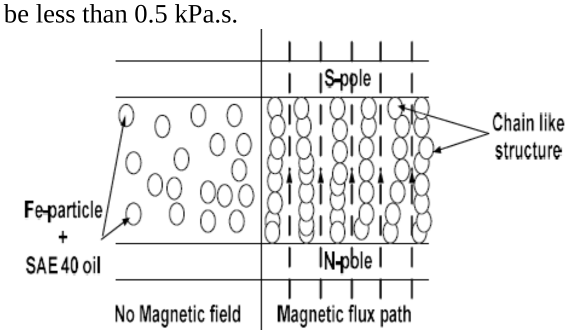


Figure 1: Fe-particle without and with magnetic field path forming chain like structure

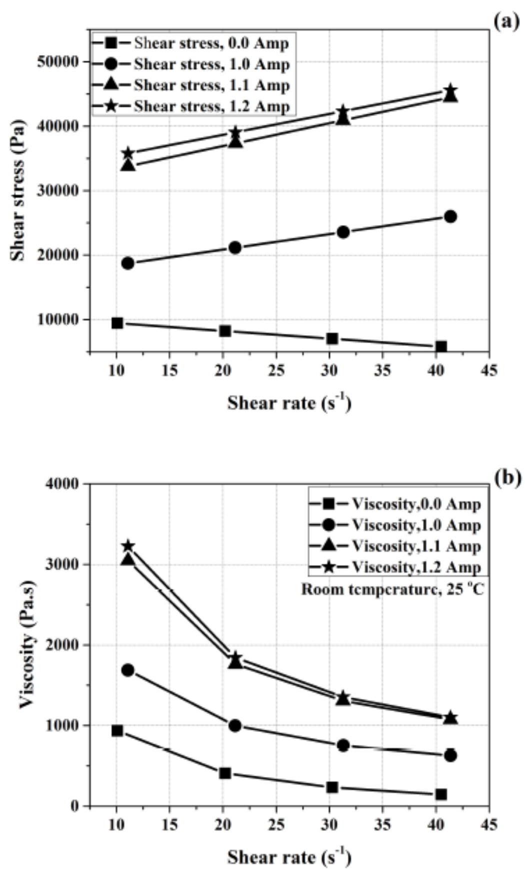


Figure 2: MR fluid with the application of magnetic field at room temperature of 25 0C (a) shear stress as a function of shear rate (b) viscous behaviour with respect to shear rate

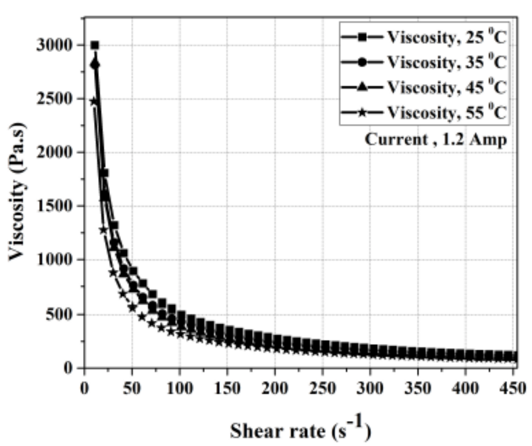


Figure 3: Shear thinning behaviour of MR fluid at varying temperature at constant supply of electric current of 1.2 A

Magneto-rheological damper consists of piston-cylinder arrangement filled with MR fluid and standard Cu wire was used for the windings of the damper, as shown in Fig. 4. The magnetic field generated by supplying electric current determines the physical behaviour of MR damper. Damping can be controlled by controlling the shear stress and viscosity of MR fluid. These rheological properties of MR fluid can be controlled by controlling voltage across the coils. The entire assembly of piston, cylinder, cap, and the cylinder base plate had to be accommodated within this limited space between the cutting tool holder and the bed. From standard wire gauge of Cu, number of windings around the cylinder damper was 1000. As per the Helhmoltz relation, diameter of the wire and number of turns were optimized to generate maximum possible magnetic field considering the breakdown of the insulation of wire.

MR damper was characterised on LDV (Laser Doppler Vibrometer). Fig. 5 shows the relationship between transmissibility to that of natural frequency at varying voltage. The acceleration transmissibility in both the cases (with and without damper) was compared. In general, transmissibility is the ratio of dynamic output to the dynamic input [2],i.e, the amount of vibration suppressed to stabilise the cutting tool by the damping force. Overall, transmissibility indicates the effectiveness of the MR fluid damper. From Fig. 5 it was observed that transmissibility reduces and moves towards the lower frequency level and the transmissibility for each case (i.e. at 20V, 30V, 40V and 50V) is less than unity which indicates that the system behaves as underdamped. This is possible due to the alignment of MR particle in the direction of magnetic flux path The intensity of the magnetic field increases due to increase in voltage by external DC power supply. The maximum transmissibility was found to be 0.2527 at corresponding frequency of 844 Hz. Transmissibility at 20V, 30V, 40V and 50V are 0.1307, 0.1048, 0.0805 and 0.058 respectively and corresponding peak frequency are 805 Hz, 797 Hz, 781 Hz and 769 Hz respectively. In order to have proper understanding of variation of magnetic field within the system, Ansoft Maxwell software was used. Fig. 6 shows variation of magnetic field across the piston when current was supplied across the coils. The aim of this analysis was to visualise the magnetic field across the piston when current is supplied to the coils, to analyse flux in the coil and to analyse damping force when piston is moving. Fig. 6(a) shows the variation of magnetic flux in the coil with respect to time. When electric current was supplied across the coil magnetic field was induced within the MR fluid cylinder damper following the relationship between the voltage and induced flux within the coil, i.e., φ = f(V,N), where V is the voltage applied across the coil, N is the number of turns and φ is the magnetic flux linkage. Fig. 6(b) shows the variation of damping force with respect to time. Here time stamp was taken to be 1sec because of the fact that the response of MR fluid is in nanoseconds. As soon as the magnetic field was induced, the MR particles tried to align themselves in the direction of magnetic field very rapidly. This rapid movement of MR particles created a sudden increase in damping force and suppressed the cutting tool vibration but after a certain time, they try to stabilize and hence force exerted on the piston by MR particles tends to remain constant.

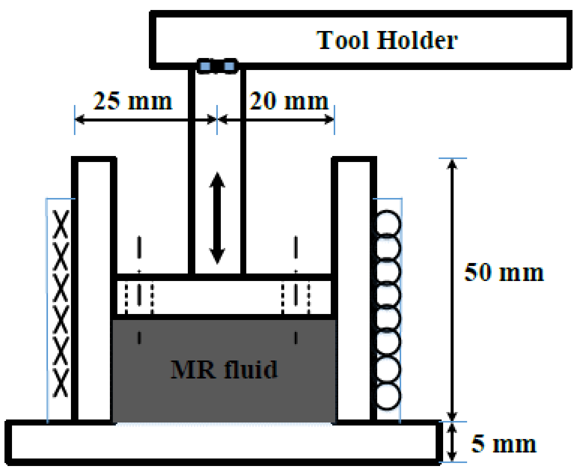


Figure 4: Model of electro-magneto rheological damper attached to the cutting tool holder in turning process

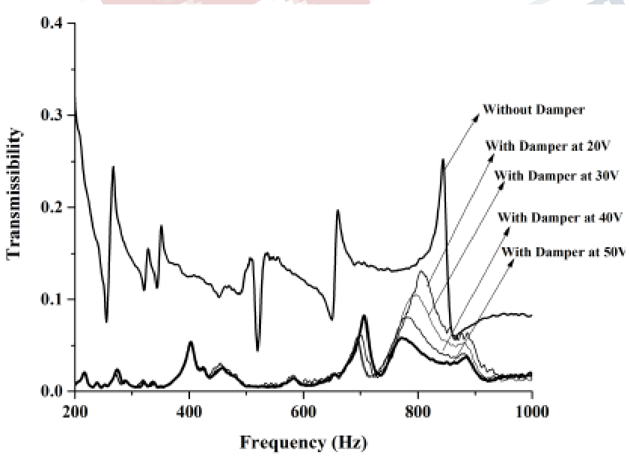


Figure 5: Acceleration transmissibility curve with natural frequency at varying voltage supply

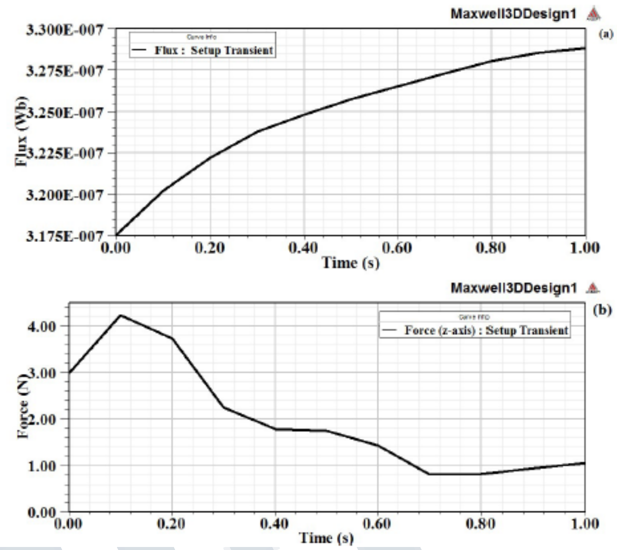


Figure 6: Magnetic field analysis across MR damper: (a) variation of magnetic flux linkage in the coil with respect to time (b) damping force with respect to time

III. EXPERIMENTATION

Experiments were carried out on a CNC automatic lathe machine of Fanuc controller (Oi mate-TD). Machine tool was fitted with KISTLER 9257BA, piezoelectric dynamometer. During machining, real time tool vibration, both with and without damper, was analysed. In order to energise the MR fluid, the current was supplied through external DC power supply. Material used for the damper was SS 410 steel. Lab View program was used for the frequency analysis of cutting tool in z-direction and cutting forces in x, y, and z directions. The main aim was to suppress vibrations along the direction of cutting force, assuming that other end of the cutting tool holder was rigid. Tool wear was monitored at regular interval of length of machining using digital USB type microscope (Dino-lite 2.0) with maximum magnification of 230X. Experiments were conducted at constant feed and depth of cut, but at varying cutting speeds. The machining was performed on AISI D2 steel with work material hardness of 52±2 HRC. AISI D2 steel, with the composition of C=1.7%, Cr=12%, Si-Mn each 0.3%, W=0.5%, V=0.1%, Mo=0.6%has high percentage of carbon-chromium alloy, making the steel durable, corrosion resistance and of high strength. This material has found applications in blanking, forming, drawing dies and other machine parts. Work material of 65-75 mm diameter and 300 mm length was chosen for machining up to 3 min. A diamond-shaped ceramic insert of CNGA 120408 T02025 PT 600M series with mega-

IFERP
connecting engineers... developing research
ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

coating of Al_2O_3+TiC was used as the tool and the tool holder used was of PCLNR 25×25 M12. Machining parameters used for analysis were as follows: cutting speed V= 70 m/min, 110 m/min and 150 m/min; cutting feed f = 0.1 mm/rev; depth of cut d = 0.5 mm and voltage V = 20V (0.62A), 30V (0.84A), 40V (1.0A), 50V (1.11A). Experimental set up is shown in Fig. 7.

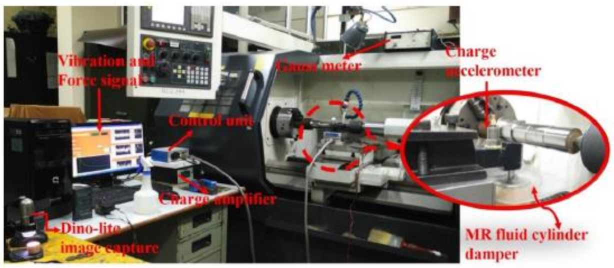


Figure 7: Experimental set up

IV. RESULTS AND DISCUSSION

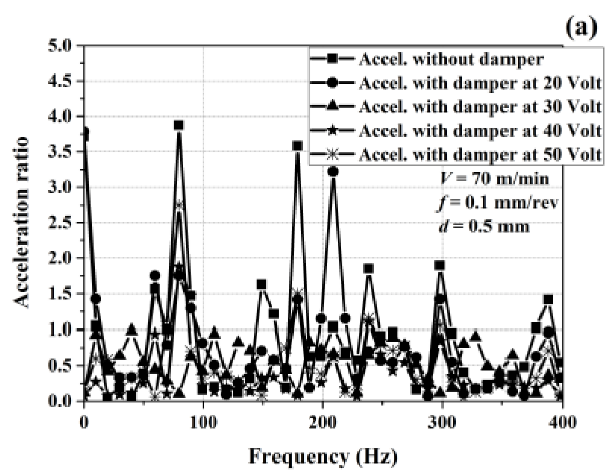
MR damper was attached to the tool holder as shown in Fig. 7. The vibration of the cutting tool was measured and the effect of cutting parameters and the supply voltage on the tool vibration was investigated. Experimental results are shown in Fig. 8– 12. Fig 8 shows that with the damper, the acceleration ratio decreased over the selected range of frequency which confirms that the MR damper is effective in suppressing the vibration during machining. According to the Newton's laws of motion, for the single degree of freedom system given in the present paper (MR damper arrangement to tool holder), the governing equation can be defined as follows:

$$m\frac{d^2x}{dt^2}+(c-b)\frac{dx}{dt}+kx=\frac{dF(t)}{dt} \qquad (2)$$

Where m is mass of the cutting tool holder, c, bare damping constants, k is stiffness constant and F(t) is the external cutting force in z-direction. Fig. 8(b) shows the vibration response (in terms of acceleration ratio) of the tool with and without MR damper at a cutting speed of 110 m/min. It was observed that the vibration of tool decreases when damper was placed beneath the tool. It was observed that the application of electric field to the MR fluid leads to decrease in acceleration ratio for a certain range of frequency. This can be primarily due to the alignment of MR particles in a particular direction when the electric field is applied. The rheological properties (viscosity and shear stress) of MR fluid is dependent on applied voltage. The highest damping force can be observed at 50V. Thus at cutting speed of 110 m/min best damping can be observed at 50V. The damping ratio from the experiment was calculated using well known half power band width method [16], defined as

$$\xi=\frac{f_2-f_1}{2f_{res}} \qquad (3)$$

Where ζ is the damping ratio, f_1 and f_2 are the frequency corresponding to amplitude of $f_{res}/\sqrt{2}$. With the help of Eq. 3, damping ratio was calculated as 0.0135, 0.0205, 0.0335 and 0.0571 at different voltage of 20V, 30V, 40V and 50V respectively at 300 Hz. The maximum effectiveness of the MR damper was found at 50V, which indicates that settling time required to suppress the vibration was only 0.066 second. Whereas, machining at lower cutting speed of 70 m/min (Fig. 8(a)) reveals that vibration response of the tool when MR damper was attached was not much effective. Due to some internal disturbance in semi-viscous MR-particle, damping force exerted in the direction of magnetic flux to suppress the tool vibration is high and it tends to displace piston at higher stroke length of 10 mm-15 mm that leads to increase in amplitude of cutting tool vibration. Damping ratio was calculated for machining at lower cutting speed of 70 m/min and supply voltage of 20V, 30V, 40V and 50V at 300 Hz and was found to be 0.0133, 0.0154, 0.0149 and 0.0125 respectively. Moreover, settling time required to diminish the tool vibration was about 0.017 second more than settling time required at cutting speed of 110 m/min.



IFERP
connecting engineers... developing research
ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

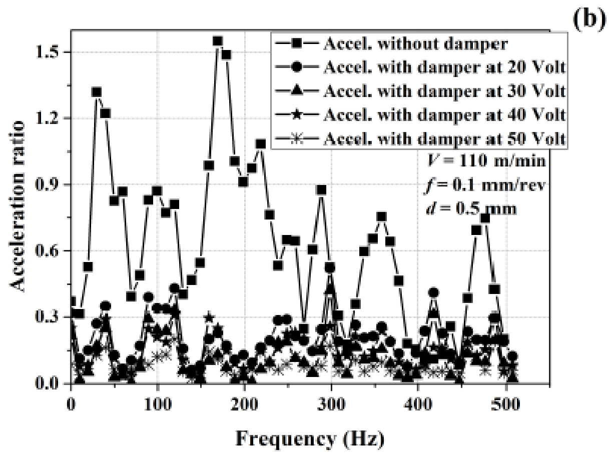


Figure 8: Acceleration transmissibility curve with respect to frequency on machining AISI D2 steel (f = 0.1 mm/rev, d = 0.5 mm) at varying voltage (a) V = 70 m/min (b) V = 110 m/min

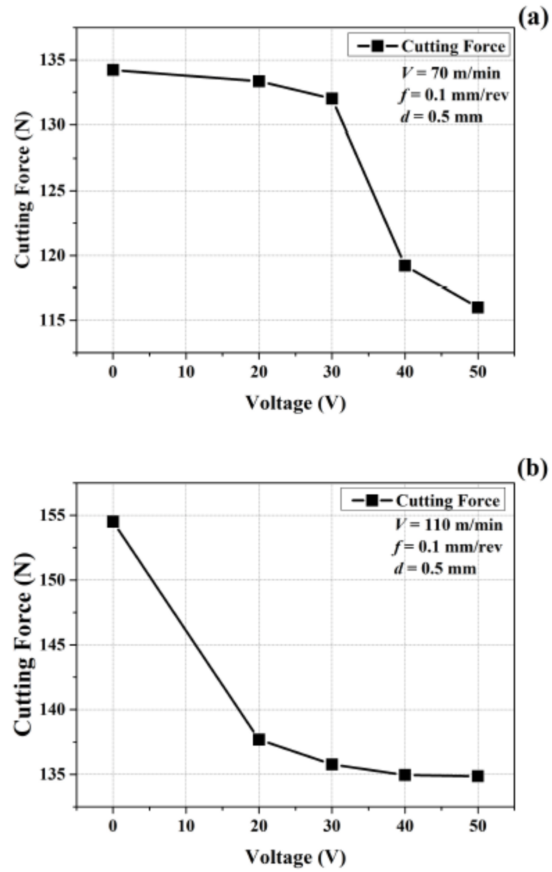


Figure 9: Variation of Cutting force with applied voltage on machining AISI D2 steel (f = 0.1 mm/rev, d = 0.5 mm) (a) V = 70 m/min (b) V = 110 m/min

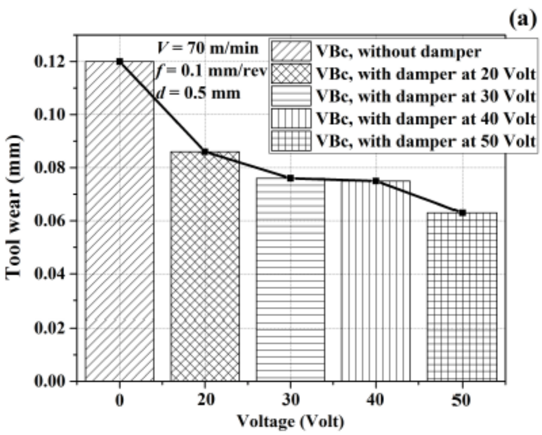
Fig.9 depicts the variation of cutting force with applied DC voltage at two different cutting speeds. The value of cutting force without damper (at 0Volt) is high but with the application of damper the value of cutting force decreases and reaches a minimum value at 50V.This is due to the fact that when the voltage across the damper increases, the viscosity of the MR fluid increases and hence the damping ability increases leading to reduction in cutting force. The value of cutting forces from Fig. 9(a), 9(b) can be expressed in a quantitative manner in terms of percentage reduction. In general, there is a certain decrease in value of cutting force at cutting speed of 110 m/min and 70 m/min (at constant cutting feed of 0.1 mm/rev and constant depth of cut of 0.5 mm) when MR damper was attached to the tool. With the application of damper there is 13.58% decrease in cutting force at cutting speed of 70m/min whereas at higher speed of 110m/min, the reduction was 10.89%. This can be due to the fact that at higher cutting speed the amplitude of tool vibration is more. Since the damping ability of the damper was regulated by the applied voltage to its coil which was kept constant at 50V, the decrease in cutting force at higher cutting speed was less. So tool vibration has been reduced to a certain value but not significantly as in lower cutting speed. To achieve a significant reduction, the damping ability should be increased which can be done by increasing the voltage across the damper.

Tool wear is an important parameter to achieve stable machining process in hard turning. As tool wear progresses, the friction generated between the tool and work material increases leading to non-uniform cutting force and temperature. The tool wear further reduces the finishing quality of the work material because of the development of undulation or the chattering on work material surface which further makes the system unstable.

Fig.10 shows the variation of flank wear with applied voltages at cutting speed of 110m/min and 70m/min at constant cutting feed of 0.1 mm/rev and constant depth of cut of 0.5 mm. The 6 graphs indicate that the flank wear decreased with the increase in the value of voltage across the damper. At cutting speeds of 70m/min and 110m/min, the minimum flank wear was observed at 50V. This is due to the fact that when voltage across the damper increased the damping ability of the damper increased and hence the tool vibration reduced, leading to decrease in the flank

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 6, June 2017

wear. However, due to the fact that beyond 50V, the temperature occurring at the coil was too high, experiments could not be conducted at voltages higher than 50 V. With the application of damper there was 47.5% reduction in flank wear at the cutting speed of 70m/min whereas at higher speed of 110m/min, reduction was only 16.53%. This is due to the fact that, high cutting speed leads to temperature rise between tool flank face and workpiece, which results in higher flank wear



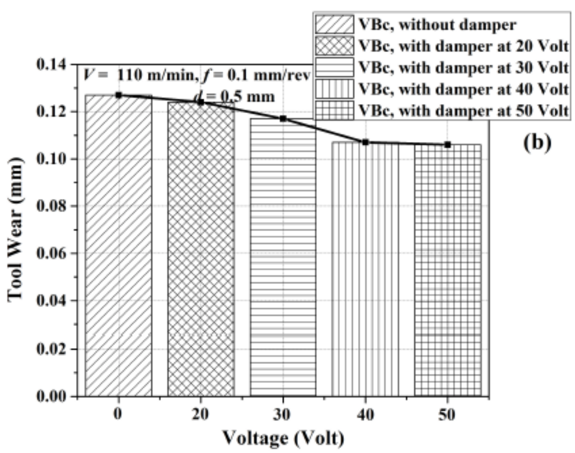


Figure 10: Variation of tool wear with applied voltage on machining AISI D2 steel (f = 0.1 mm/rev, d = 0.5 mm (a) V = 70 m/min (b) V = 110 m/min

decreases with the increase in the voltage across the damper. At cutting speeds of 70m/min and 110m/min (at constant cutting feed of 0.1 mm/rev and constant depth of cut of 0.5 mm), the minimum surface roughness was observed at 50V. This is due to the fact that when voltage across the damper increases the damping ability of the damper increases and hence the tool vibration reduces to a great extent, leading to accurate positioning of the tool and hence better surface finish.

Similarly surface roughness can also be analysed quantitatively in terms of percentage decrease in surface roughness. There is a decrease in surface roughness by 19.65% at 70m/min whereas at higher cutting of 110m/min reduction in surface roughness was 27.36%. This is due to the fact that at higher cutting speed there is more tool vibration but at a particular voltage the damping ability is constant. At higher cutting speed the coefficient of friction increases leading to increase in frictional force between the tool and workpiece.

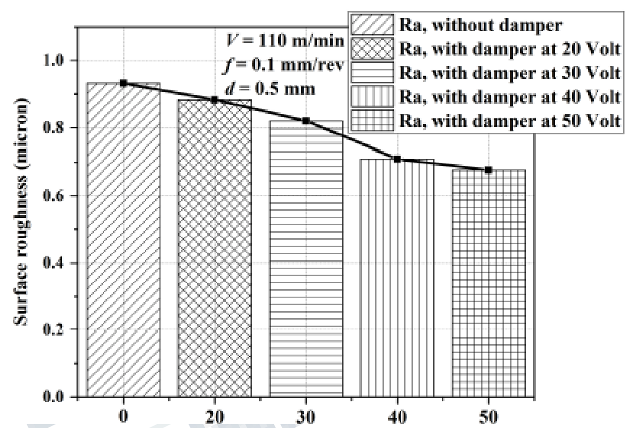


Figure 11: Surface roughness value with applied DC source voltage on machining AISI D2 steel at V = 110 m/min, f = 0.1 mm/rev, d = 0.5 mm.

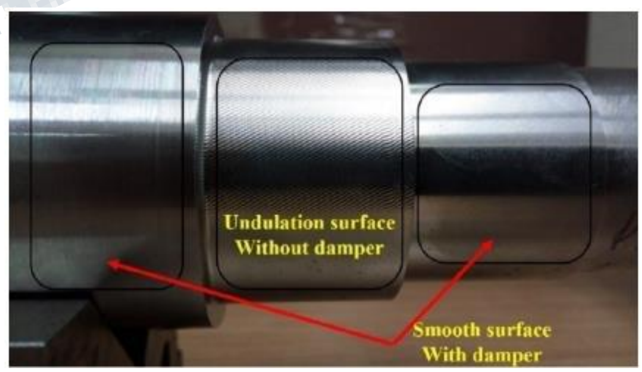


Figure 12: Effect of damper in improving the surface finish

CONCLUSIONS

In the present work, magneto rheological active damper was used for controlling the machine tool vibration. The MR damper is a controllable damper as it contains MR fluid (non-Newtonian fluid) whose properties can be controlled by external magnetic field. MR fluid was characterized using a Rheometer while the vibration characterization of MR Damper was carried out on LDV. Experiments were carried out on CNC Lathe in two phases: first no damper was placed below the tool and second when MR damper was placed below the tool. With proper interaction of hardware (Dynamometer, Accelerometer, Charge Amplifier, DAC) and software (NC Codes, Lab VIEW), the vibration of tool was monitored and controlled online. The effects of different parameters of magneto-rheological damper on cutting parameters were analysed. Based on the current investigation, the following conclusions can be drawn:

1. With the application of damper there is 47.5% reduction in flank wear at the cutting speed of 70m/min whereas at higher speed of 110m/min, reduction was only 16.53%. This is due to fact that, high cutting speed leads to temperature rise between tool flank face and workpiece, which results in higher flank wear.

2. There is a decrease in surface roughness by 19.65% at 70m/min whereas at higher cutting of 110m/min reduction in surface roughness was 27.36%. This is due to fact that at higher cutting speed there is more tool vibration but at a particular voltage the damping ability is constant. At higher cutting speed the coefficient of friction increases leading to increase in frictional force between the tool and workpiece.

3. With the application of damper there is 13.58% decrease in cutting force at cutting speed of 70m/min whereas at higher speed of 110m/min, the reduction was 10.89%. This can be due to fact that at higher cutting speed the amplitude of tool vibration is more. Since the damping ability of the damper was regulated by the applied voltage to its coil which was kept constant at 50V, therefore the decrease in cutting force at higher cutting speed was less.

4. Damping ratio at 70 m/min and 110 m/min at 50Volt are 0.0125, 0.0571 respectively. This study suggests that at higher cutting velocity, MR damper was also able to suppress the amplitude of cutting tool vibration during machining. This is efficient unless the strength of the magnetic field in the direction of magnetic flux is enough to cancel (damp) the higher frequency of cutting tool vibration.

5. With bi-viscous and hysteretic behaviour of MR fluid, the MR-particle needs certain time to settle and become responsive to suppress cutting tool vibration. Settling time was found to be 0.066 second and 0.017 second at higher and lower cutting speed respectively.

6. With the application of MR damper there is 13.58% decrease in power consumption at cutting speed of 70m/min whereas at higher speed of 110m/min, the reduction in power consumption was 10.89%. Thus it reflected that with the application of MR Damper, the power consumption for machining also decreases.

7. Thus it can be concluded that with the application of the present electro-magneto rheological damper, dynamic responses during machining in hard turning were successfully enhanced to make the system stable and free from regenerative effect of the cutting process. Thus MR damper can easily be implemented in machine tool system, making it highly competent to control the tool vibration on-line.

REFERENCES

[1] A. Bhattacharyya, Metal cutting: Theory and practice, eighth ed., New central book agency (P) Ltd, Kolkata, 2012.

[2] S.S. Rao, Mechanical vibrations, fifth ed., Prentice Hall, Upper Saddle River, New Jersey, 2011.

[3] Yang Yan, Li Hui, Kang Bo-seon, “Analysis of magnetorheological fluid damper”, J. Cent. South Univ. Technol. (2007) 14(Suppl. 1): 263-265.

[4] ShuqiGuo, Shaopu Yang, Cunzhi Pan, “Dynamic modeling of magnetorheological damper behaviours”, J. Intelligent Material Systems and Structures (2006) 17(1): 3-14.

[5] M. Xiao, S. Karube, T. Soutome, K. Sato, “Analysis of chatter suppression in vibration cutting”, Int. J. Machine Tools and Manufacture (2002) 42(15): 1677-1685.

[6] Y.S. Tarng, J.Y. Kao, E.C. Lee, “Chatter suppression in turning operations with a tuned vibration absorber”, J. Material Processing Technology (2000) 105(1-2): 55-60.

[7] Gabriel R. Frumusanu, Ionut C. Constantin, VasileMarinescu, AlexandruEpureanu, “Development of a stability intelligent control system for turning”, Int. J. Adv. Manuf. Technol. (2003) 64(5): 643-657.

[8] Emad Al-Regib, Jun Ni, Soo-Hun Lee, “Programming spindle speed variation for machine tool chatter suppression”, Int. J. Machine Tools and Manufacture (2003) 43: 1229-1240.

[9] Gyuhae Park, Matthew T. Bement, Daniel A. Hartman, Ronald E. Smith, Charles R. Farrar, “The use of active materials for machining processes: A review”, Int. J. Machine Tools and Manufacture (2007) 47: 2189-2206.

[10] H. Metered, P. Bonello, S.O. Oyadiji,“The experimental identification of magneto rheological dampers and evaluation of their controllers”, Mechanical Systems and Signal Processing (2010) 24: 976-994.

[11] S.G. Chen, A.G. Ulsoy, Y. Koren,“Computational stability analysis of chatter in turning”, J. Manufacturing Science and engineering (1997) 119: 458-460.

[12] Ivana Kovacic, “The chatter vibrations in metal cutting-theoretical approach”, FactaUniversitatis, (1998) 1(5): 581-593.

[13] H.B. Lacerda. V.T. Lima,“Evaluation of cutting forces and predicting of chatter vibrations in milling”, J. of the Braz. Soc. Of Mech. Sci. & Eng. (2004) 26(1): 74-81.

[14] R. Rusinek, M. Wiercigroch, P. Wahi, “Modelling of frictional chatter in metal cutting”, Int. J. Mechanical Sciences (2014) 89: 167-176.

[15] J. Lipski, G. Litak, R. Rusinek, K. Szabelski, A. Teter, J. Warminski, K. Zaleski, “Surface quality of a work material’s influencing on the vibrations of the cutting process”, J. Sound and Vibration (2002) 252(4): 729-737