Investigation and Analysis of Magneto Rheological Fluid Damper for Suppressing Tool Vibration during Hard Turning

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Abstract—Tool vibration is a frequent and major problem in the manufacturing industry where metal cutting operations take place. It mainly affects the surface finish of the work piece, tool life and produce irritating noise. In order to restrain tool vibration, it is necessary to develop and analyze suitable methods which increases stability and improves the cutting performance. The project aims at analyzing a MR Damper suitable for the operation. MR fluid is composed of oil and varying percentages of iron particles that have been coated with an anti-coagulant material. This new class of device known as Magneto Rheologycal (MR) dampers will match well with the requirements and constraints of applications, including the necessity of having very low power requirements. A simple MR damper model is created for the work. The influence of MR damper was checked by measuring various parameters such as tool vibration, cutting force, surface roughness and tool wear. Taguchi design of experiments was used for conducting the cutting experiment.

Key words: Taguchi Method, Hard Turning, Tool Vibration, Magnetorheologycal Damper, Minitab

I. INTRODUCTION

In turning operations the cutting tool is subjected to a dynamic excitation due to the deformation of work material during the cutting operation. In particular the surface finish is affected by the relative dynamic motion between the cutting tool and the work piece during machining. The identification of tool vibration as a limitation for machining was initially found by Taylor. The regeneration of waves on the work piece was identified as a potential cause of chatter in turning, by Arnold. In turning operations tool vibration related problems are of great interest. Tool vibration is a result of the dynamic interaction between the tool and the work piece which is present during the machining process that causes instability in the cutting process.

In machining, tool vibration is to be reduced because greater vibration will increase the tool wear which will result in reduction of tool life and produce poor surface finish in the machined work piece. Since the tool life and the surface finish of the work piece is of greater prominence and concern in the manufacturing industry, greater attention has been given to reduce amplitude of tool vibration. The vibration that is produced during the machining process can be sub-divided into few categories. Amongst the different chatters, self-excited vibration is actually of greater concern. Self-excited vibration is caused by the dynamic interaction between the cutter and the work piece during a turning process causes. Self-excited vibration begins to vibrate of their own accord spontaneously; the amplitude will increase until some nonlinear effect limits any further increase. They are generally classified into primary and secondary chatter. Primary chatter is not of greater importance and they are caused because of the friction between tool-work pieces, thermo-mechanical effect or by mode of coupling. Regenerative wavy surface on the work piece will lead to the secondary chatter and is the most destructive among all the other vibrations. Modulation effects in waviness usually caused by the tool vibrating radially relative to the component or axially is mainly due to the self-excited vibration between the tool and the work piece. Self-excited vibrations are characterized by the presence of a mechanism whereby a system will vibrate at its own natural or critical frequency, essentially independent of the frequency of any external stimulus.

MR fluids belong to a class of controllable non-Newtonian fluids. When MR fluids are exposed to a magnetic field they change their physical state from a free flowing linear viscous liquid to a semi-solid state in just few milliseconds. Lord Corporation developed MR fluid shock absorbers for automobiles and it was observed that such shock absorbers can effectively vary levels of chatter, shock and motions instantly. Investigations on boring tool holder with MR damper has been performed by Sathianarayanan et al. and it has been observed that the damper application reduced the chatter and effectively improves the stability of the boring operation. Chatter could be suppressed more effectively by adjusting the damping and natural frequency of the system using MR fluid dampers. Also surface finish and cutting performance has been been improved effectively by considering MR damper during hard turning. The intensity of the magnetic field produced will determine the viscosity of the MR damper and they are capable of replicating this process for infinite number of times. Sam Paul and Varadarajan studied the effect of MR damper on the amplitude of tool vibration and they observed that MR damper has reduced tool vibration effectively by adjusting the controlling parameters like the shape of the plunger, particle size and viscosity of the oil. In the present investigation, an attempt was made to study the effect of vibration damping ability of MR damper during hard turning operation. When an electric field is applied to the MR fluids, the fluid changes to a semisolid and this transition is reversible and can be achieved in a few milliseconds. Cutting experiments were conducted to arrive at a set of electrical and machining parameters that can develop better damping force during turning of OHNS steel of 48 HRC using hard metal insert with sculptured rake face which in turn reduces the amplitude of tool vibration effectively and obtained better cutting performances.

II. MAGNETORHEOLOGYCAL FLUID DAMPER

A magnetorheological fluid (MR fluid) is a type of smart fluid containing iron powder in a carrier fluid, usually a type of oil. When subjected to a magnetic field, the fluid increases its apparent viscosity, to the point of becoming a viscoelastic solid. Importantly, the fluid’s yield stress when in its active ("on") state can be controlled very accurately by

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varying the magnetic field intensity. The benifit of this is that the fluid's ability to transmit force can be controlled with an electromagnet, which increases its possibility for many control-based applications.

Magnetorheological (MR) fluids are suspensions which exhibits a rapid, reversible and tunable transition from a free flowing state to semi-solid state upon the application of an external magnetic field. These materials demonstrate dramatic changes in their rheological behavior in response to a magnetic field. MR fluids have attracted considerable interest recently because of their ability to provide a simple and rapid response interface between electronic controls and mechanical systems.

A. Fabrication of Magneto Rheologycal Fluid Damper

The damper consists of a plunger (P) which moves inside a cup containing MR fluid. MR fluid is magnetized by passing current through the coil. The damper is made according to the dimensions shown in Figure 1. The dimension chosen for the damper is based on the suitability of fixing the damper to the lathe bed. When the coil is energized, MR fluid is activated and offers resistance to the motion of the plunger, thereby damping the tool vibration. This damping action of the MR fluid damper depends on the following factors: (i) the shape of the plunger (S); (ii) viscosity index of the fluid medium (p); (iii) size of the ferro magnetic particle (m); and (iv) the current passing through the coil (I).

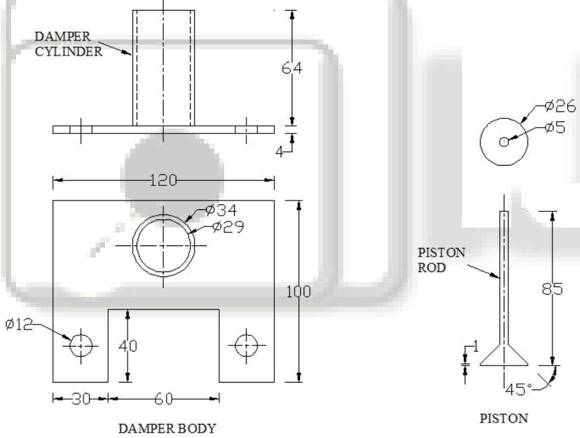

Fig. 1: Dimensions of the modeled MR Damper in mm

The specifications of the ferromagnetic particle size, the shape, the fluid used and the dimensions of the plunger are summarized in Table 1.

Size/dimensions of the plunger	Diameter of plunger = 5 mm
Size of the ferromagnetic particles	75 μm
Composition of the MR fluid	70:30 (70% magnetic particles and 30% oil)
Viscosity of the oil	SAE 40
Type of plunger	Conical

Table 1: Magnetorheological damper specifications

B. Electromagnetic Coil

Electromagnetic coil provide the necessary magnetic flux into the MR fluid. The coil was wound to withstand the maximum input voltage which was considered in the input parameter selection. The MR coil is made using copper wire of 28 gauge and axially wound to 400 turns. The experimental coil is shown in Figure 2.

Fig. 2: Electromagnetic coil

C. Damper Body and Plunger Material

The damper body and plunger material should be a non-magnetic material and corrosion resistance and plunger also should have good toughness and hardness. The material selected is stainless steel 304 grade. Stainless steel is chosen as the material for damper because iron fillings mixed with the oil should not stick to the surface of the damper body and the plunger when the coil is magnetized. The stainless steel of 304 grade has high toughness and hardness, so the material could sustain the force induced on the plunger rod by tool holder. The composition of the 304 grade steel is shown in table 2.

Fig. 3: Damper body

Fig. 4: Piston with piston head

Elements	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Chromium	Nickel	Nitrogen	iron
% Composition	0.08	2	0.045	0.03	0.75	18-20	8-12	0.1	Balance

Table 2: Composition of stainless steel 304

III. EXPERIMENTAL PROCEDURE

The suitable tool and workpiece material are carefully selected before conducting the experimental work.

A. Tool Selection

The tool selected is Multicoated hard metal inserts with sculptured rake face geometry with the specification SNMG 120408 MT TT5100 from Taegu Tec coated with TiC and

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TiCN. The tool holder used had the specification PSBNR 2525 M12. The basic dimension of tool holder is 25 mm - 25 mm - 145 mm and the tool holder used is shown in Figure 5, which presents the geometry, schematic view and cross section of tool insert is shown in Figure 6. The dimensions of the insert are shown in Table 3.

B. Workpiece Material Selection

The work piece selected is OHNS steel. OHNS steels are used as Blanking and stamping dies, Punches, Rotary shear blades, Thread cutting tools, Milling cutters, Reamers, Measuring tools, Gauging tools, Wood working tools, Broaches, Chasers. An ideal type oil-hardened steel which is economical and dependable for gauging, cutting and blanking tools as well as can be relied for hardness and good cutting performance. The work piece after machined to the required dimensions is hardened to 48 HRC on which the cutting experiment is proposed to be conducted. The workpiece dimensions are shown in Figure 7.

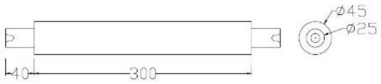

Fig. 7: Work piece dimensions in mm

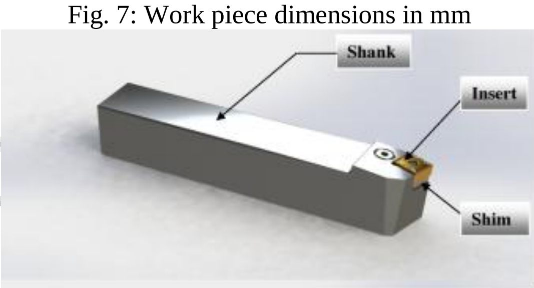

Fig. 5: PSBNR 2525 M12 tool holder.

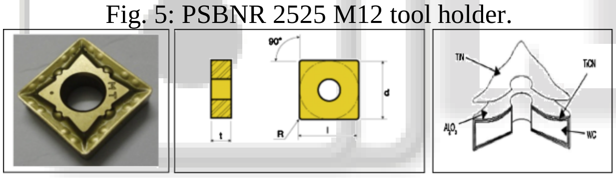

Fig. 6: Geometry, schematic view and cross section of SNMG 120408 MT TT5100 insert

Designation	L	d	R	t
SNMG 120408 MT TT5100	11.9mm	12.7mm	0.8mm	4.756mm

Table 3: Dimensions of the insert

C. Experimentation

The readings are plotted based on the 9 run experiment designed by Taguchi Technique. The parameters varied are cutting speed, Feed, Depth of cut and voltage. The iron powder size and viscosity of the oil is kept constant. Design matrix is the representation of input parameters and its values in a tabular form. The values of Cutting velocity in this investigation is taken as 80, 90 and 100 m/ min. Feed rate is taken as 0.07, 0.08 and 0.09 mm/rev. Depth of cut is taken as 0.3, 0.6 and 0.9 mm. Last parameter is voltage given to the coil taken as 10, 20 and 30v. These parameters were selected based on the literature review. Input parameters and its values described in design matrix shown in Table 4.

Input Parameters	Level 1	Level 2	Level 3
Cutting Velocity(m/min)	80(V_1)	90(V_2)	100(V_3)
Feed Rate (mm/rev)	0.07(F_1)	0.08(F_2)	0.09(F_3)
Depth of cut (mm)	0.3(D_1)	0.6(D_2)	0.9(D_3)
Voltage (V)	10(V_1)	20(V_2)	30(V_3)

Table 4: Taguchi design matrix

D. Selection of Orthogonal Array using Minitab Software

Minitab is statistical analysis software. In this investigation 4 input parameters each one varies in 3 different levels are selected. In Taguchi method, minimum number of optimum combinations is considered. The orthogonal array from the Minitab software is shown in Table 5.

Sl. No.	Velocity (mm/min)	Feed (mm/rev)	Depth of Cut (mm)	Voltage (V)
1	v1	f1	d1	V1
2	v1	f2	d2	V2
3	v1	f3	d3	V3
4	v2	f1	d2	V3
5	v2	f2	d3	V1
6	v2	f3	d1	V2
7	v3	f1	d3	V2
8	v3	f2	d1	V3
9	v3	f3	d2	V1

Table 5: Orthogonal array for 9 Run Experiment

E. Experimental Work

Cutting experiments were conducted on Kirloskar turn master lathe. A line sketch of the MR Fluid setup developed for this investigation is shown in Figure 8.

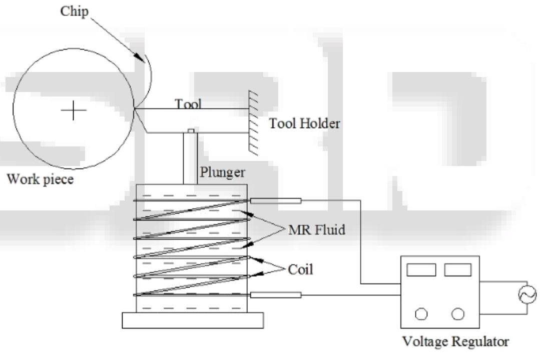

Fig. 8. Line sketch of MR Damper setup

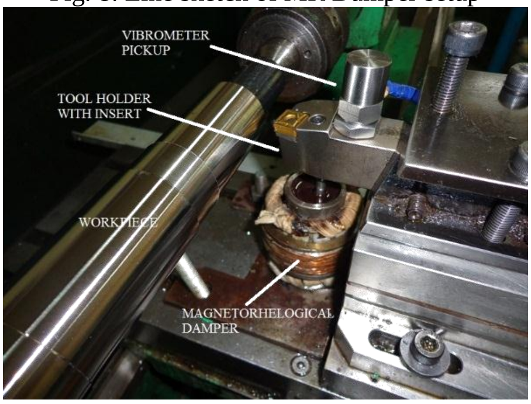

Fig. 9: MR Damper and vibrometer pickup attached to tool holder

IV. RESULT AND DISCUSSIONS

The cutting experiment was done based on the combination of input parameters obtained by Taguchi design orthogonal array. The results where plotted for Tool vibration, Surface finish, Cutting force and Tool wear.

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A. *Tool Vibration*

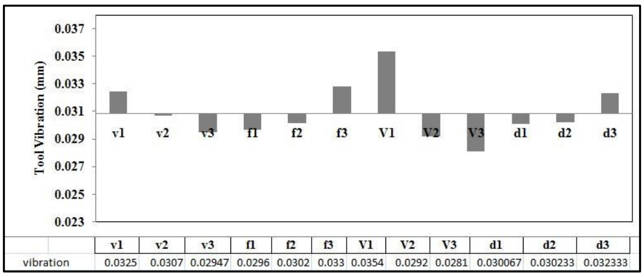

Fig. 10: Relative significance of input parameter on amplitude of tool vibration

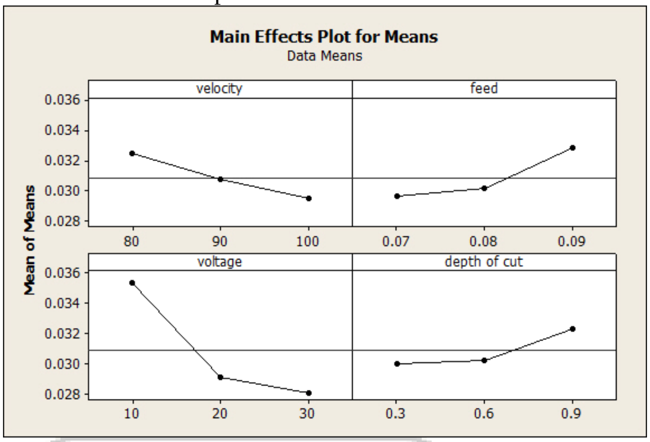

Fig. 11. Graph showing tool vibration at each levels

Source	DF	Seq SS	Adj SS	Adj MS	P
velocity	2	0.000014	0.000014	0.000007	10.53 %
feed	2	0.000018	0.000018	0.000009	13.53 %
voltage	2	0.000092	0.000092	0.000046	69.17 %
depth of cut	2	0.000010	0.000010	0.000005	7.52 %
Residual Error	0	*	*	*	
Total	8	0.000133			

Table 6: Analysis of variance for tool vibration

The percentage of influence of velocity on cutting force is 10.53% and that of voltage is 69.17%. The feed and depth of cut are influenced by 13.53% and 7.52% respectively as shown in Table 6.

B. *Surface Roughness*

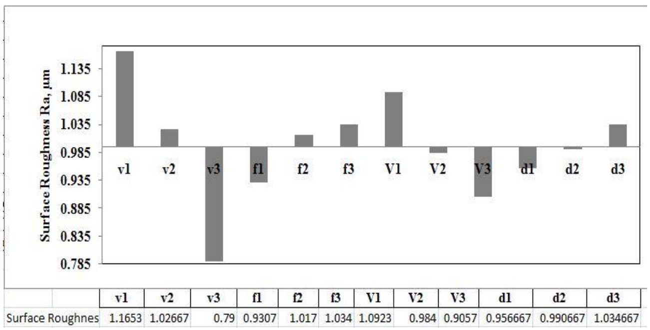

Fig. 12. Relative significance of input parameter on surface roughness

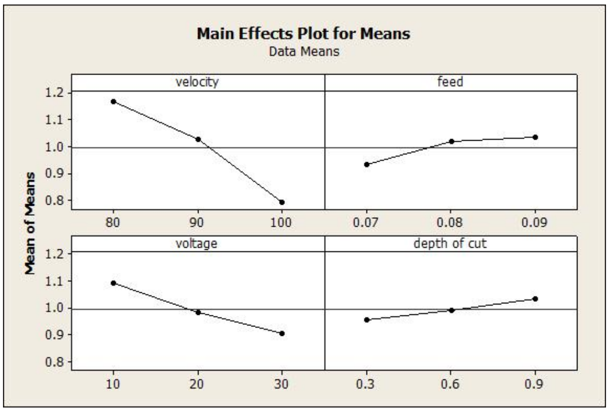

Fig. 13. Graph showing surface roughness at each levels

Source	DF	Seq SS	Adj SS	Adj MS	P
velocity	2	0.216115	0.216115	0.108057	72.88 %
feed	2	0.018501	0.018501	0.009250	6.24%
voltage	2	0.052717	0.052717	0.026358	17.78 %
depth of cut	2	0.009176	0.009176	0.004588	3.09%
Residual Error	0	*	*	*	
Total	8	0.296508			

Table 7: Analysis of variance for surface roughness

The percentage of influence of velocity on surface roughness is 72.88% and that of voltage is 17.78%. The feed and depth of cut are influenced by 6.24% and 3.09% respectively as shown in Table 7.

C. *Cutting Force*

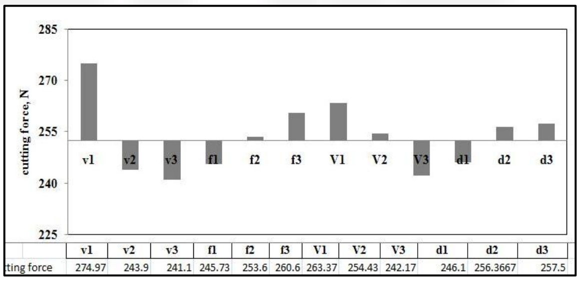

Fig. 14: Relative significance of input parameter on cutting force

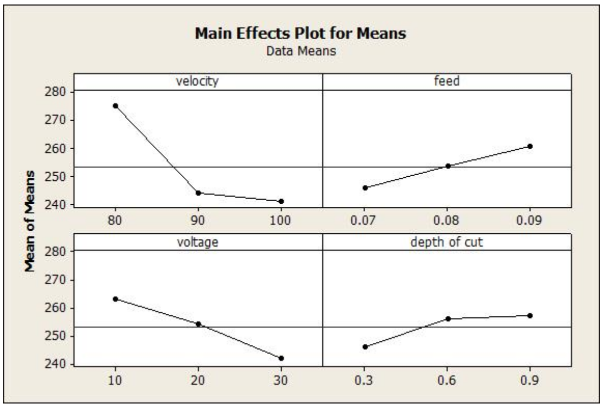

Fig. 15: Graph showing cutting force at each levels

Source	DF	Seq SS	Adj SS	Adj MS	P
velocity	2	2119.93	2119.93	1059.96	62.91%

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feed	2	333.36	333.36	166.68	9.89%
voltage	2	679.72	679.72	339.86	20.17%
depth of cut	2	236.65	236.65	118.32	7.02%
Residual Error	0	*	*	*	
Total	8	3369.66			

Table 8: Analysis of variance for cutting force

The percentage of influence of velocity on cutting force is 62.91% and that of voltage is 20.17%. The feed and depth of cut are influenced by 9.89% and 7.02% respectively as shown in Table 8.

D. Tool Wear

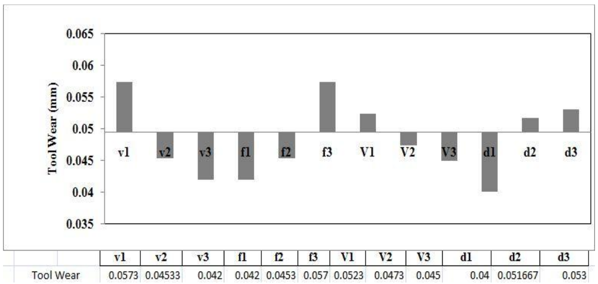

Fig. 16. Relative significance of input parameter on tool wear

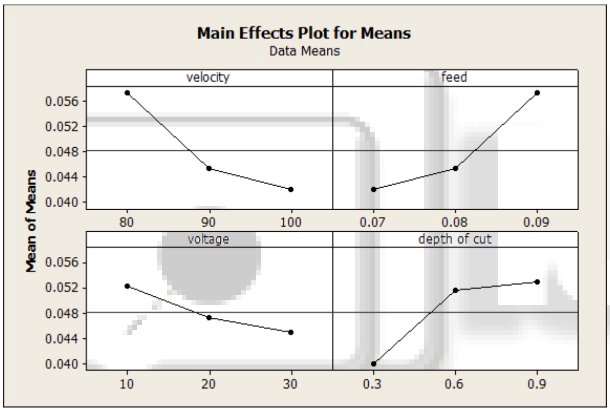

Fig. 17. Graph showing tool wear at each levels

Source	DF	Seq SS	Adj SS	Adj MS	P
velocity	2	0.000390	0.000390	0.000195	33.28 %
feed	2	0.000390	0.000390	0.000195	33.28 %
voltage	2	0.000084	0.000084	0.000042	7.17%
depth of cut	2	0.000307	0.000307	0.000153	26.19 %
Residual Error	0	*	*	*	
Total	8	0.001172			

Table 9: Analysis of variance for tool wear

The percentage of influence of velocity and feed on tool wear is 33.28% and that of voltage and depth of cut is 7.17% and 26.19% respectively as shown in Table 9.

D. Confirmatory Experiment

Objective	Velocity (mm/min)	Feed (mm/rev)	Voltage (V)	Depth of cut (mm)
To minimize Tool Wear	100	0.07	30	0.3
To minimize Cutting Force	100	0.07	30	0.3
To minimize Surface Roughness	100	0.07	30	0.3
To minimize Amplitude of Tool Vibration	100	0.07	30	0.3

Table 10: Input parameters for getting optimum performance

From table 10, it is observed that to minimize tool wear and cutting force ,the velocity, feed and depth of cut should be kept at level 1 ie, velocity at 100, feed at 0.07and depth of cut at 0.3 and voltage should be kept at level 3 ie, voltage at 30. Better surface roughness and tool vibration are obtained at velocity at 100, feed at 0.07 and depth of cut at 0.3. As observed from table better cutting performance is obtained commonly for all the objectives is at feed and depth of cut at level 1 and voltage at level 3.

In the confirmatory experiment, machining was done with and without damper and the difference was tabulated. When the velocity, feed, voltage and depth of cut are taken as 100, 0.07, 30 and 0.3 respectively, the output parameters obtained are 0.033 for tool wear, 208.6 for cutting force, 0.596 for surface roughness and 0.019 for amplitude of tool vibration. With the same machining input parameters the cutting experiment is again done, but this time, without the MR damper and readings were plotted. The readings obtained are 0.079 for tool wear, 314.2 for cutting force, 0.836 for surface roughness and 0.048 for amplitude of tool vibration. The Table 11 shows the result obtained during both turning.

Parameters	With damper	Without damper
Tool wear	0.033	0.079
Cutting force	208.6	314.2
Surface roughness	0.596	0.836
Amplitude of tool vibration	0.019	0.048

Table 11: Readings plotted for with and without damper

V. CONCLUSIONS

In this study, an attempt was made to investigate the effect of a magnetorheological fluid system on tool vibration during hard turning of OHNS steel. A magnetorheological fluid system has been developed and series of experiments have been carried out using Taguchi 9 run design matrix. The results show a definite advantage for turning with magnetorheological damper when compared to conventional turning. When the set of levels of parameters for optimum performance were used, there was 40% reduction in amplitude of tool vibration, 71% reduction in surface roughness, 66% reduction in cutting force and 42% reduction in tool wear when compared to a conventional turning scheme without MR fluid damper.

The experiment has been successfully carried out and relative significance of each input parameter has been identified. From the present study the following observations were made:

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1) A magnetorheological fluid damper can reduce tool wear effectively during hard turning with minimal fluid application.
2) Best cutting performance is obtained at velocity - 100 mm/min, feed - 0.07 mm/rev, depth of cut - 0.3 mm and voltage - 30 V, for the input parameter chosen for the investigation.
3) The presence of magnetorheological fluid system can bring forth 40% reduction in amplitude of tool vibration, 66% reduction in cutting force, 71% improvement in surface finish and 42% reduction in tool wear during hard turning.

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