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MONITORING OF TOOL VIBRATION FOR MAGNETORHEOLOGICAL FLUID CONTROLLED BAR DURING TURNING OF HARDENED AISI4340 STEEL

In recent times, the concept of hard turning has gained awareness in metal cutting as it can apparently replace the traditional process cycle of turning, heat treating, and finish grinding for assembly of hard, wear-resistant steel parts. The major apprehension in hard turning is the tool vibration, which affects the surface finish of the work piece, has to be controlled and monitored. In order to control tool vibration in metal cutting, a magnetorheological fluid damper which has received great attention in suppressing tool vibration was developed and used. Also an attempt has been made in this study to monitor tool vibration using the skewness and kurtosis parameters of acoustic emission (AE) signal for the tool holder with and without magnetorheological damper. Cutting experiments were conducted to arrive at a set of operating parameters that can offer better damping characteristics to minimize tool vibration during turning of AISI4340 steel of 46 HRC using hard metal insert with sculptured rake face. From the results, it was observed that the presence of magnetorheological damper during hard turning reduces tool vibration and there exist a strong relationship between tool vibration and acoustic emission (AE_{RMS}) signals to monitor tool condition. This work provides momentous understanding on the usage of magnetorheological damper and AE sensor to control and monitor the tool condition during turning of hardened AISI4340 steel.

1. Introduction

Conventionally, when cylindrical parts requiring high hardness as functional requirement are to be machined, the work piece is turned to the near

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net shape, hardened to the required hardness and ground to the final dimension. This lengthy process cycle can be avoided if the hardened work piece is directly turned to the final dimension. This is possible by hard turning. Hard turning is usually carried out using ultra hard cutting tools and needs extremely rigid machine tools that can sustain the severity of hard turning. These tools are very costly and may be unaffordable on the shop floor (Narutaki et al., 1979). But hard turning can be practiced on the shop floor with the existing machine tools and the performance may be improved further if some schemes are introduced (Klocke and Eisenblatter, 1997; Varadarajan et al., 2002). Since hard turning is an advanced manufacturing process, the methodologies for its control and monitoring are highly essential. In hard turning, tool vibration is considered as a significant parameter which has to be controlled since excessive tool vibrations during machining will increase the tool wear and cause poor surface finish (Altintas, 2012). Among the different tool vibration control strategies, the use of rheological fluid damper was found to be more effective than the conventional viscous damper (Torsten Butz and von Stryk, 1999).

Spencer Jr et al. (1997) was the first among the scientists who tested MR fluid techniques to improve cutting performance during machining. Wang and Fei (1999) tried to suppress chatter in boring bar making use of the nonlinear vibration characteristics of electrorheological fluid and developed an online chatter detection and control system. Carlson and Sproston (2000) investigated the properties and applications of commercially available MR fluids and it was observed that the MR fluids can operate at temperatures from –40 to 150 degree Celsius, with only slight variation in yield stress. Lord Corporation (2002) developed MR fluid shock absorbers for automobiles and it was observed that such shock absorbers can respond instantly and can control varying levels of vibration, shock and motions. Genc and Phule (2002) observed that by varying the parameters associated with MR fluids like volume, particle size and fraction of solids, the properties of the MR fluids can be varied. It was observed that during boring, chatter could be suppressed more effectively by adjusting the damping and natural frequency of the system using MR Fluid Dampers (Deqing Mei et al., 2009). Sathianarayanan et al. (2008) investigated the possible improvement of damping capability and suppression of chatter in boring tools using MR damper and observed that MR damper application reduces the possibility of chatter and improves the stability of boring operation. Sam Paul et al. (2012) used magnetorheological damper to reduce tool vibration during hard turning with minimal fluid application. Also for designing magnetorheological damper, they considered parameters like shape of the plunger, viscosity of the oil, size of the particle and type of current (Sam Paul et al., 2014; Sam Paul et al., 2015). The above mentioned studies reveal that the use of magnetorheoleogical damper was found to be effective if it is applied in a defined way.

In order to maintain precision and quality in the components, it is very important to monitor the condition of the tool during hard turning operation. Among the different monitoring techniques, acoustic emission (AE) has emerged as the most effective and reliable technique for process monitoring. AE is defined as the low amplitude, high frequency stress wave that is generated due to a rapid release of strain energy in a medium. The frequency range of the AE signal is much higher than that of the machine vibrations and environmental noises. Dornfield and E.K. Asibu (1980) conducted turning experiments in orthogonal metal cutting using HSS cutting tool to study the generation of AE signals during metal cutting process and they observed that AE based process monitoring is reliable in conventional turning. Dornfeld (1992) established the effectiveness of AE-based sensing methodologies in tool condition monitoring. Tansel et al. (2000) monitored the tool condition in microendmilling of aluminum and mild steel using AE sensor to detect tool breakage and to estimate tool wear. Xialoi Li (2002) presented a report on AE based tool wear monitoring methodology and he concluded that statistical tools can be used to predict tool wear from the output of AE sensors. Sharma et al. (2006) used adaptive neuro fuzzy method to predict tool wear using cutting forces, vibrations and acoustic emissions. Sam Paul and Varadarajan (2012) developed fusion model based on ANN and regression to predict tool wear. Based on their results it was observed that the predictions of the statistical model matched well with the experimental results. Scheffer et al. (2003) proposed a tool wear monitoring system for hard turning using cutting force dynamometer, AE sensor and temperature sensor. Prakash and Kanthababu (2013) used AE sensor in monitoring the tool condition based on wear for microend milling. From the literature review, one can observed that the application of AE sensor to monitor the tool condition during hard turning of AIS4340 steel has not been fully explored due to the complexity of the process. Even though many attempts were used in the past, those attempts consistently used statistical methods like ANN to accomplish reliable monitoring.

The present investigation aims at developing a magnetorheological damper that will assist hard turning to control parameters like tool vibration, surface roughness, cutting force and tool wear. When an electric field is applied to the MR fluids, the fluid becomes a semisolid and behaves as a viscoelastic spring with nonlinear vibration characteristics. This transition is reversible and can be achieved in a few milliseconds. Cutting experiments were conducted to arrive at a set of parameters that can reduce tool vibration and hence promote better cutting performance during turning of AISI4340 steel of 46 HRC using hard metal insert with sculptured rake face. The MR Fluid developed appears to hold promise as a means to reduce tool vibration and to improve the cutting performance. Also an attempt is made in this work to develop reliable and robust monitoring methodology to predict process conditions in hard turning along with magnetorheological damper using signals obtained from AE sensor and vibration sensor at different time intervals. This study will help to understand the effect of magnetorheological damper and its mechanism on tool vibration during hard turning.

2. Selection of tool and work material

Multicoated hard metal inserts with sculptured rake face geometry with the specification SNMG 120408 MT TT5100 from Taegu Tec were used in the present study. The tool holder used is hardened steel having the specification PSBNR 2525 M12. This selection was done based on the information available in the literature (Sam Paul and Varadarajan, 2013). The work piece material was an AISI 4340 steel which was hardened to 46 HRC by heat treatment. It is a general purpose steel having a wide range of application in automobile and allied industries by virtue of its good hardenability, enabling it to be used in fairly large sections. Bars of 80 mm diameter and 360 mm length were used in the present investigation. The chemical composition in weight % of AISI4340 steel are 0.41% C, 0.87% Mn, 0.28% Si, 1.83% Ni, 0.72% Cr, 0.20% Mo and rest Fe (Sam Paul and Varadarajan, 2013).

3. Control of tool vibration during hard turning

In order to improve the effectiveness of the process of hard turning, scheme to suppress tool vibration using magnetorheological damper was developed in this study. Magnetorheological (MR) fluids belong to a class of controllable fluids. The essential characteristic of these fluids is their ability to reversibly change from a free-flowing, linear, viscous liquid to a semi-solid with considerable yield strength in milliseconds when exposed to a magnetic field. When exposed to a magnetic field, the suspended particles in the fluid polarize and interact to form a structure aligned with the magnetic field that resists shear deformation or flow. This change in the material appears as a dramatic increase in apparent viscosity or the fluid develops the characteristics of a semi-solid state. The apparent viscosity and shearing stress can be controlled by changing the intensity of magnetic field (Sam Paul and Varadarajan, 2013). The viscosity of MR fluid increases as the strength of the magnetic field increases and even it can behave as semi-solid. When the applied magnetic field vanishes, the MR fluid reverts to its previous, more fluid state. The transformation between the liquid to the semi solid phase takes place very fast i.e. within few milliseconds. An attempt is made to develop such a damper for reducing tool vibration, tool wear, surface roughness and cutting force during hard turning.

3.1. Design and fabrication of magnetorheological damper

A line sketch of the MR Damper developed for this investigation is shown in Fig. 1. It consists of a plunger (P) made of stainless steel 410 which can moves inside a cup made of stainless steel 410 containing MR fluid. MR fluid is magnetized by passing current through the coil. Threads were cut at the end of the plunger that matched with the threads cut on a hole of the tool holder so that the plunger can be held rigidly with the tool holder. The coil consists of 800 turns of copper wire of 28 gauge. Figure 1 presents

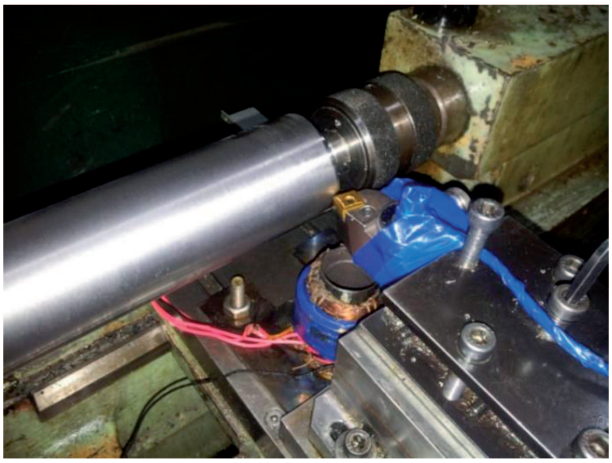

Fig. 1. Photograph of the experimental setup with MR fluid damper

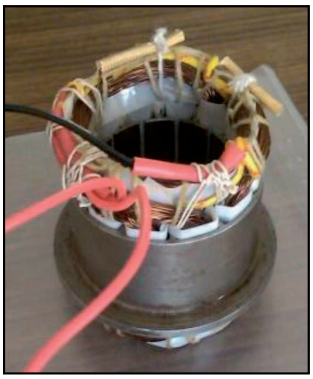

Fig. 2. Dissembled view of the MR damper

a photograph of the location of the MR fluid damper attached to the tool holder and a dissembled view of the MR Fluid Damper is shown in Fig. 2. When the coil is energized, MR fluid is activated and offers resistance to the motion of the plunger, hereby amping the tool vibration. The damping action of the MR Fluid damper depends on the following factors (i) the shape (S) of the plunger (ii) the viscosity index (p) of the fluid medium (iii) size (m) of the ferromagnetic particles used for making the MR fluid and (iv) the current (I) through the coil.

3.2. Experimentation

Cutting experiments were carried out on a Kirloskar Turn Master-35 lathe. A 27 run experiment was designed based on Taguchi technique in which the input variables namely the cutting velocity, feed and the depth of cut were varied at three levels. Experiments were conducted with two replications and each experiment lasted for 120 seconds. In this study, experimental work was carried out in dry turning. Cutting velocity, feed rate and depth of cut were varied at three levels (Low Medium and High) as shown in Table 1. The main cutting force, the average flank wear, average surface roughness and the amplitude of tool vibration were measured during each experiment and is presented in Table 2.

Table 1.

Ranges of cutting velocity, feed and depth of cut

Cutting velocity	80, 100 and 120 m/min.
Feed	0.08,0.1 and 0.12 mm/rev
Depth of cut	0.8, 1.0 and 1.2 mm.

The cutting velocity, feed rate and depth of cut combinations were arrived at based on the results of preliminary experiments and the recommendations of the cutting tool Manufacturers M/S Taegutec India (P) Ltd. These ranges are prescribed for turning in semi finish range for the tool-work combination and the experimental readings were taken based on the change in cutting velocity, feed rate and depth of cut conditions.

The strength of the damping produced by magnetorheological fluid damper mainly depends on the magnetic field which in turn depends on the supply voltage. The authors conducted preliminary research work related to current (I) through the coil of magnetorheological damper and they varied voltage across the coil for effective damping. These voltages were varied at three levels, i.e. 10 V (0.62 A), 20 V (1.24 A), 30 V (1.86 A). From the results, they observed supply voltage at high level (30 V) offered better damping capability as the strength of the magnetic field depends on the supply voltage.

Table 2.
Design matrix for the 27 run experiment and the observations during cutting experiments

Trial no	Cutting velocity V m/min	Feed rate F, mm/rev	Depth of cut D, mm	Cutting force N	Amplitude of tool vibration, mm	Flank wear VB_B, mm	Surface roughness Ra, μm
1	80	0.08	0.8	316.71	0.031	.0493	1.079
2	80	0.1	0.8	322.92	0.032	.0503	1.101
3	80	0.12	0.8	329.13	0.032	.0513	1.122
4	80	0.08	1	332.55	0.033	.0508	1.144
5	80	0.1	1	339.07	0.034	.0518	1.167
6	80	0.12	1	345.59	0.034	.0528	1.189
7	80	0.08	1.2	345.21	0.034	.0523	1.187
8	80	0.1	1.2	351.98	0.035	.0533	1.211
9	80	0.12	1.2	358.75	0.036	.0543	1.234
10	100	0.08	0.8	266.04	0.025	.0465	1.009
11	100	0.1	0.8	271.25	0.026	.0475	1.029
12	100	0.12	0.8	276.47	0.026	.0484	1.049
13	100	0.08	1	279.34	0.027	.0479	1.069
14	100	0.1	1	284.82	0.027	.0489	1.090
15	100	0.12	1	290.29	0.028	.0498	1.112
16	100	0.08	1.2	289.98	0.028	.0493	1.110
17	100	0.1	1.2	295.67	0.029	.0503	1.132
18	100	0.12	1.2	301.35	0.029	.0513	1.154
19	120	0.08	0.8	243.87	0.020	.0447	0.975
20	120	0.1	0.8	248.65	0.020	.0456	0.994
21	120	0.12	0.8	253.43	0.021	.0465	1.013
22	120	0.08	1	256.06	0.021	.0461	1.033
23	120	0.1	1	261.08	0.021	.0470	1.054
24	120	0.12	1	266.10	0.022	.0479	1.074
25	120	0.08	1.2	265.81	0.022	.0474	1.072
26	120	0.1	1.2	271.03	0.022	.0484	1.093
27	120	0.12	1.2	276.24	0.023	.0493	1.115

Higher the supply voltage, higher will be the strength of the magnetic field, better will be the damping ability and tool vibration will be less. However, an applied voltage at very high magnitude should also be avoided as this may lead a condition wherein the magnetorheological fluid will become a solid mass and loses its damping capability altogether. Moreover, higher supply voltage may also result in high temperatures and can lead to safety problems. Based on the information available in the literature, a 30 V (current of 1.86 A) DC power supply with a coil orientation that causes flow of current parallel to the axis of the damper along with a cone shaped plunger with the MR fluid consisting of ferrous particles of 75 micron size mixed with SAE oil 40 was used in the present study (Sam Paul and Varadarajan, 2015).

The main cutting force, average flank wear VB_B, amplitude of tool vibration and surface roughness R_a were measured during each experiment. The main cutting force was measured using a Kistler tool force dynamometer. Average flank wear was measured using a tool makers' microscope (Metzer make) with the least count of 0.005 mm and average surface roughness R_a was measured using Mahr TR100 surface roughness tester of type MarSurf GD 25. Amplitude of tool vibration was measured using a piezoelectric-type vibrometer where the pickup of the vibrometer was mounted at the top of the tool holder near to tool tip.

4. Monitoring of tool vibration using acoustic emission signal

In this investigation, an attempt was made to develop a reliable system for monitoring the process conditions in hard turning of AISI4340 steel using AE signals. For monitoring AE signal during cutting experiments, tool holder was connected with magnetorheological damper and AE signals were obtained from the tool holder with and without magnetorheological damper separately. Figure 3 shows a sample filtered AE_{RMS} signal of the tool holder obtained from Data Acquisition software through AE sensor. AE_{RMS} signals were acquired using an AE sensor Kistler 8152B211, which was mounted on the top of the tool holder very close to the cutting edge by means of a mounting stud. To make sure, accurate acoustic coupling silicon grease was applied at the interface between the tool holder and sensor. Signals from the sensor were pre-amplified and processed using piezotron coupler of Kistler 5125B1 make. This coupler has the provision to select suitable band pass filters and time constants for obtaining RMS signals. In all the experiments, a band pass filter of 50 kHz to 900 kHz was identified and a time constant of 0.15 ms was chosen for computing the RMS value of AE_{RMS}. In the coupler output point, filtered and AE_{RMS} signals will be available for further signal processing and the signals were viewed using NI

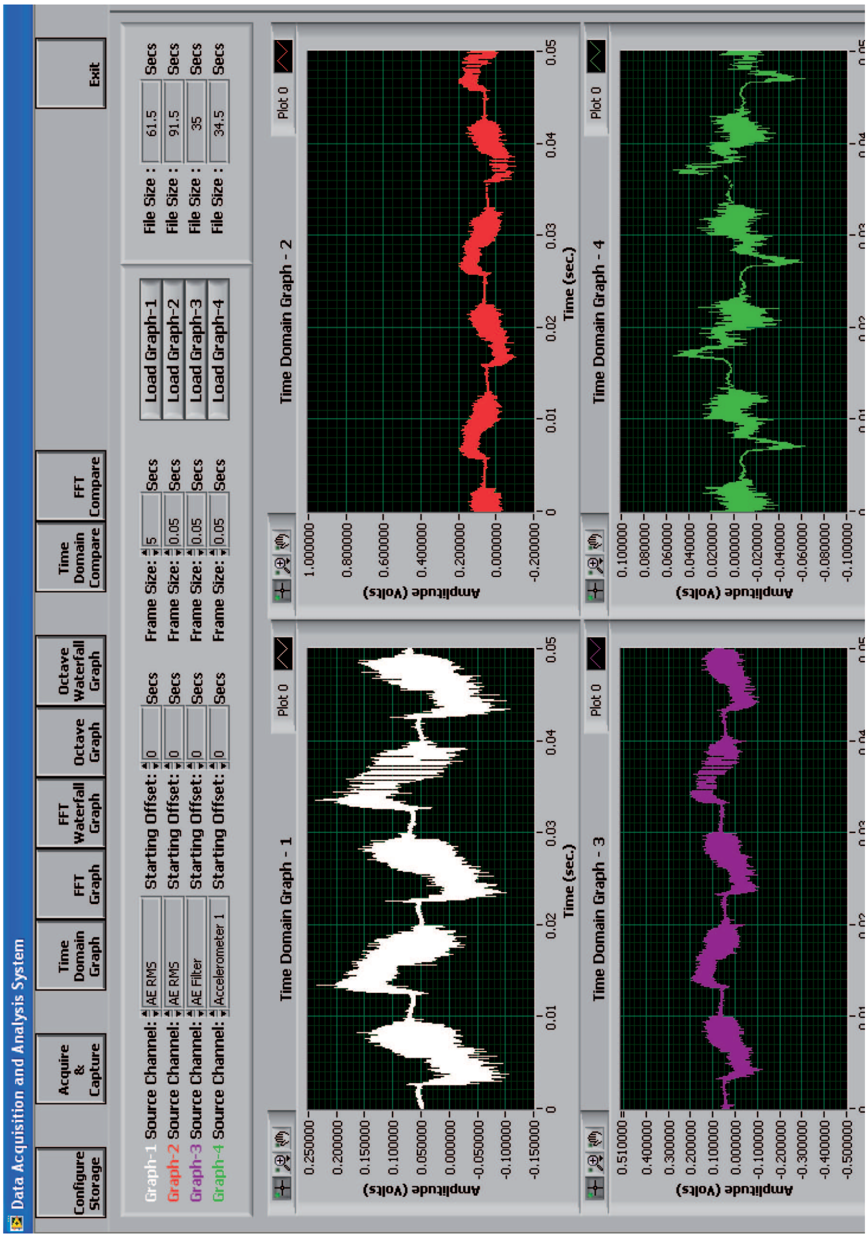

Fig. 3. Filtered AE signal for the tool during machining

Data Acquisition software. Also, tool vibration study was performed for the tool supported by magnetorheological damper with the input parameters kept at levels as indicated in Table 3 and the performance was compared with the AE signals during tool holder without magnetorheological damper. AE_{RMS} signals pertaining to different stages of tool vibration was captured using the

AE sensor and NI Data Acquisition software and the values of Kurtosis and skewness were computed for each signal.

5. Results and Discussion

5.1. Analysis on the effect of magnetorheological damper on tool vibration and cutting performance

The relative significance of input parameters on tool vibration is shown in Fig. 4 and Fig. 5 presents the relative significance of the input parameters on cutting force. The relative significance of input parameters on surface roughness and tool wear is shown in Fig. 6 and Fig. 7 respectively.

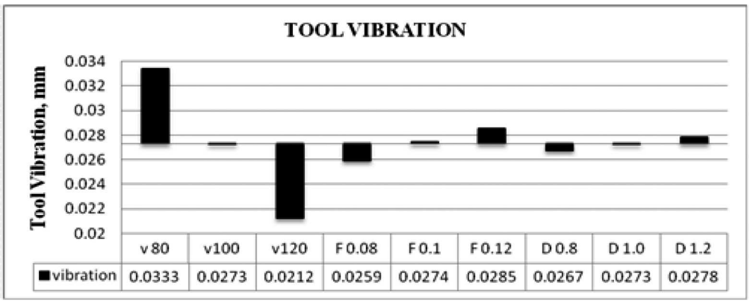

Fig. 4. Relative significance of input parameters on tool vibration

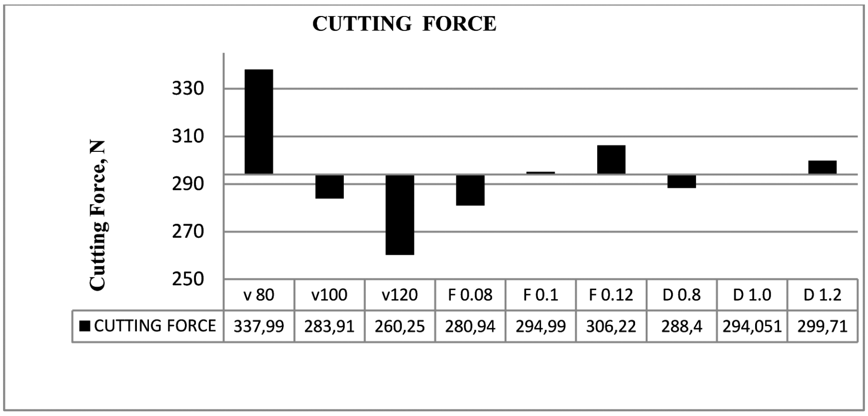

Fig. 5. Relative significance of input parameters on cutting force

The experimental results were analyzed using Qualitek-4 and the levels of input parameters for achieving minimum tool vibration, cutting force, tool wear and surface roughness are presented in Table 3.

Cutting experiments were conducted with the input parameters kept at levels as indicated in Table 3 and the performance was compared with the

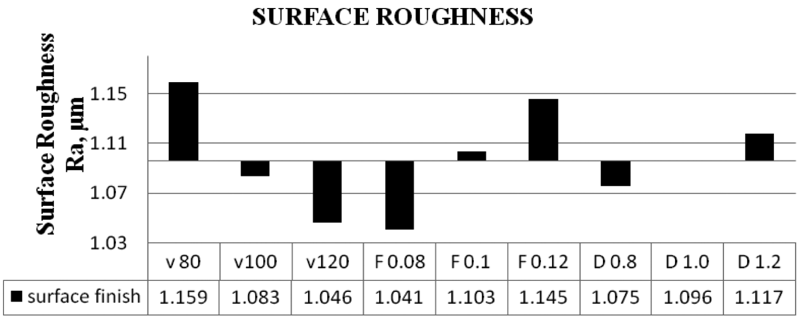

Fig. 6. Relative significance of input parameters on surface roughness

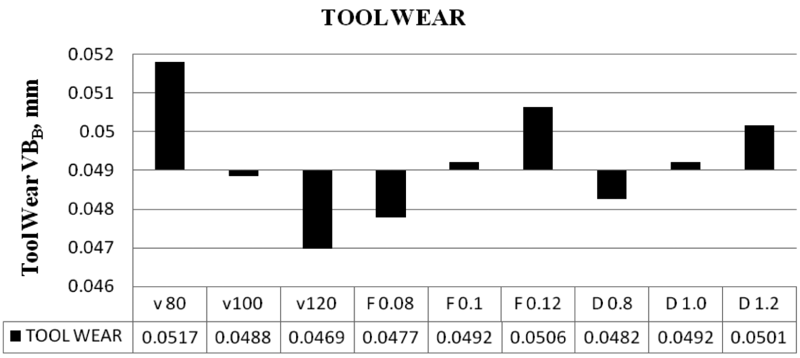

Fig. 7. Relative significance of input parameters on tool wear

Table 3.

Levels of input parameters for getting optimum performance

Sl. No.	Output parameters	Objective	Cutting Velocity (m/min)	Feed rate (mm/rev	Depth of cut (mm)
1.	Surface roughness (µm)	To minimize surface roughness	V3 (120)	F1 (0.08)	D1 (0.8)
2.	Flank wear (mm)	To minimize tool wear	V3 (120)	F1 (0.08)	D1 (0.8)
3.	Cutting force (N)	To minimize cutting force	V3 (120)	F1 (0.08)	D1 (0.8)
4.	Tool Vibration (mm)	To minimize tool vibration	V3 (120)	F1 (0.08)	D1 (0.8)

cutting performance during hard turning without MR Fluid. From this table, one can observe that for minimizing tool vibration, tool wear and for achieving better cutting performance, the cutting velocity should be kept at level 3 (120 m/min.), the feed rate should be at level 1 (0.08 mm/rev.) and the depth of cut used should be at level 1 (0.8 mm). A comparison of the cutting performance for the two cases is shown in Table 4 and it can be seen that the MR Fluid can suppress tool vibration by 57%, reduce tool wear by 52.6%, cutting force by 46% and improve surface finish by 38.5%.

Table 4.
Comparison of performance with MR fluid and without MR Fluid under the same cutting conditions

Parameters	with magnetorheological Damper	without magnetorheological damper	% improvement
Amplitude of tool vibration, mm	0.01925	0.04468	57
Cutting Force, N	238.7	442.2	46
Tool wear VB_B, mm	0.0368	0.0778	52.6
Surface roughness R_a, µm	0.852	1.386	38.5

During turning operation, because of high hardness of the work piece, there exist high cutting forces than usual forces, which will produce greater vibration and also reduce the performance of the cutting tool. Any system that can oppose the movement of the tool in the downward direction can provide better damping. From Table 4, one could observed that MR Fluid damper reduces cutting force by 46%. The damping force produced by damper increases the stiffness of machine tool structure, provides better damping action and reduces the total energy to perform cutting operation. Since the dynamic nature of main cutting force acting on the cutting tool during the hard turning which decreases due to increase in stiffness of the machine tool structure, vibration occurring in the machining tool also decreases by 57% effectively.

When the bouncing of the tool in and out of the work piece decreases, there is a reduction in the irregularities of the surface. As a consequence, surface finish improves considerably by 38.5% and this smooth surface limits the risk of crack initiation. Also when the dynamic rigidity of the cutting tool increases due to change in stiffness, the tool will have more life than a tool machining under vibrating conditions. This increase in tool life results in a decrease in tool wear, and from the results we can observe that tool wear reduces by 52.6%.

The strength of the damping depends on the magnetic field which in turn depends on the supply voltage and oil used. Moreover, the magnetic field can also be varied according to the required intensity of damping. Higher the supply voltage, higher the strength of the magnetic field and better the damping ability. Here, application of voltage of very high magnitude, of more than 30 V was avoided, as this may lead to a condition wherein the MR fluid will become a solid mass and lose its damping capability altogether. In this study, magnetorheological damper with 40 micron size iron particles, SAE 40 oil, 30 V supply voltage was used (Sam Paul et al., 2014).

An SAE 40 oil appears to give better damping and better cutting performance in terms of vibration and surface roughness. A fluid with higher viscosity can offer higher resistance to the movement of the plunger and hence offer better surface finish. Also, it appears that magnetic particle in the MR fluid should have certain minimum size to offer better performance. In the present investigation, iron particles of 75 microns size were used to investigate the effect of damper on cutting performance. Also, based on the availability and affordability of the iron particles size in the market, this size was chosen and used. If the size of the particles in the MR fluid is very small, there is a possibility of magnetized particles sticking together to form a solid mass when magnetized. But, if the size of the particle is sufficiently high, the tendency to form a solid block reduces and there will be a good distribution of the magnetized particles with the fluid occupying the region in between them. This distribution of magnetized particles in a pool of the fluid provides better resistance to the movement of the plunger, which consequently leads to better reduction in tool wear and improvement in surface finish.

5.2. Analysis of acoustic emission signal

AE signals captured during the experiments were amplified, filtered and recorded. Variation of Kurtosis and skewness of AE_{RMS} with respect to machining time for tool with and without magnetorheological damper are shown in Fig. 8 and 9 respectively.

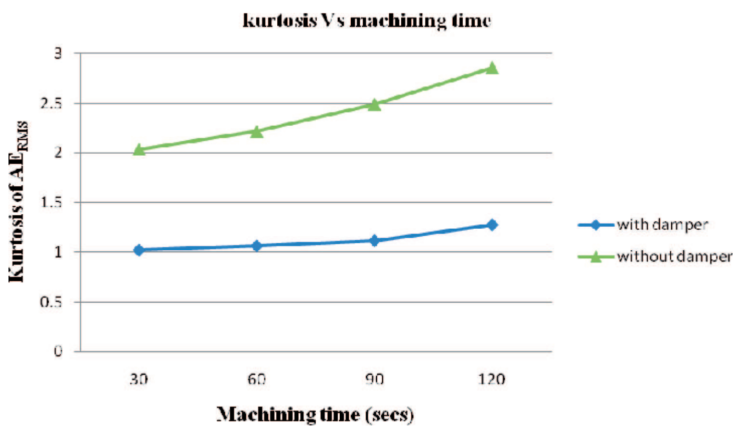

Fig. 8. Kurtosis of AE_{RMS} vs. machining time

From Fig. 8, one can observe that kurtosis based on AE_{RMS} values increased with increasing machining time for both tool with magnetorheological damper and without damper. However, when comparing both the plots of Fig. 8, the relatively difference in the kurtosis value is encouraging. In any distribution, kurtosis indicates high frequency of entries occurring close to the mean. The high values of kurtosis in tool without damper, as

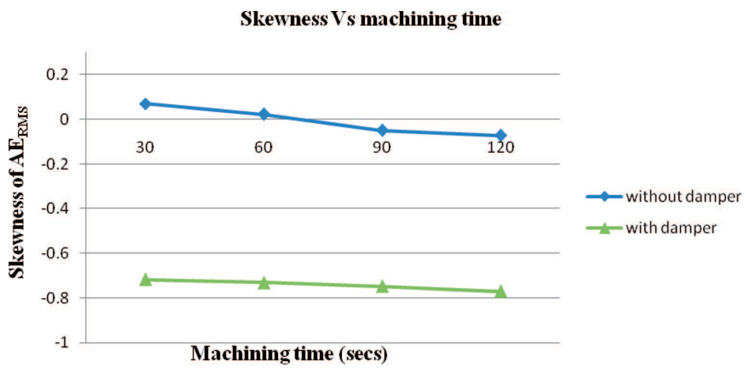

Fig. 9. Skewness of AE_{RMS} vs. machining time

mentioned in Figure 8, indicate that the emission due to rubbing becoming more when machining progresses. When machining time increases, higher rubbing will occur leading to the emission of high amplitude AE signals, which further increase the values of kurtosis. But in the tool subjected to magnetorheological damper, stiffness and rigidity of the tool was increased due to damping effect resulting in reduction in rubbing, which generate low amplitude AE signals. This directs to a decrease in value of kurtosis when compared to tool without damper. Also, it can be noticed that when the tool without damper is subjected to machining, there is a steep rise in the value of kurtosis instead of gradual, as evident from tool with magnetorheological damper. When the tool without damper is subjected to external force in machining, small inter atomic dislocation will take place, which give rise to propagation of cracks. From the tool with damper plot of Fig. 8, one can be observe that possibility of generation of crack propagation can be avoided due to the decrease in the value of kurtosis.

The computed values of skewness based on AE_{RMS} are shown in Fig. 9. This Figure shows that the skewness of AE_{RMS} signal decreases with increase in machining time which follows the trend explained by Dornfield and Asibu (1980). Based on the tool without damper curve from Fig. 9, it can be seen that left tail is longer and the mass of distribution is concentrated on the right. It indicates that very well-built acoustic emission bursts occur as machining time increases, resulting in high amplitude AE_{RMS} values which shift the mass of distribution to the right (Bhaskaran et al., 2012). Owing to this fact, greater rubbing will occur between tool and work piece when machining time increases, which further leads to emission of high amplitude AE signals. But, when the tool is subject to damping force through the magnetorheological damper, left tail no longer exists as compared to tool without damper. As a result, there is a reduction in rubbing which guide to the generation of low amplitude AE_{RMS} signals. Since the occurrence of rubbing reduces, life of the tool and its performance will be increased when the tool supported by damper is subjected to machining.

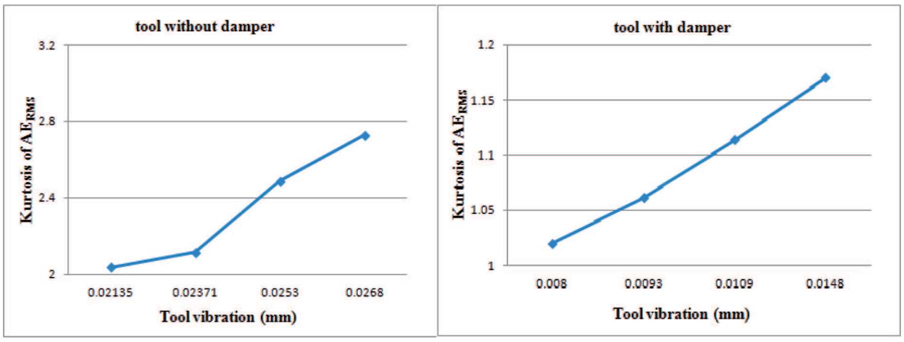

Fig. 10. Kurtosis of AE_{RMS} vs. amplitude of tool vibration

The computed values of kurtosis based on AE_{RMS} were plotted as a function of tool vibration at different machining time for tool with and without magnetorheological damper and is shown in Fig. 10. From the plot it can be observed that the kurtosis values increased with increasing tool vibration. For the tool without damper, this increase was found to be very sharp when the tool vibration reaches a value around 0.02371 mm i.e. when the machining time crosses 60 s. At this stage in machining, the motion diverges and energy is fed into the system through self-excitation, which makes the amplitude of tool vibration increasing continuously with time, and the system becomes unstable. This high amplitude of tool vibration demonstrates the external effect on tool holder. When this tool vibration increases abruptly, it appears that, due to very short range intermolecular interactions, there will be an intensification of internal forces that propagate from one particle to another throughout an extended part of the system. Moreover, this dislocation leads to formation of crack propagation. This is evident from tool without damper plot which reveals the increase of kurtosis of AE_{RMS} signal when the tool vibration moves beyond a value of 0.02371 mm. When tool vibration reached 0.0253 mm, the kurtosis AE_{RMS} value was found to be 2.5, whereas it was 2.1 when tool vibration was 0.02371 mm, which showed sharp rise in the kurtosis-based AE_{RMS} value. But, from tool with damper plot of Figure 10, it was found that kurtosis-based AE_{RMS} value was increasing gradually. Since the amplitude of tool vibration was reduced drastically due to the damping action produced by the magnetorheological damper, the total energy required to perform cutting operation would also be reduced (Dornfield and Asibu 1980). This factor prevents the formation of crack in the tool holder and produces kurtosis based AE_{RMS} values in a gradual manner. This effect was also found to be much weaker than that in the tool without damper.

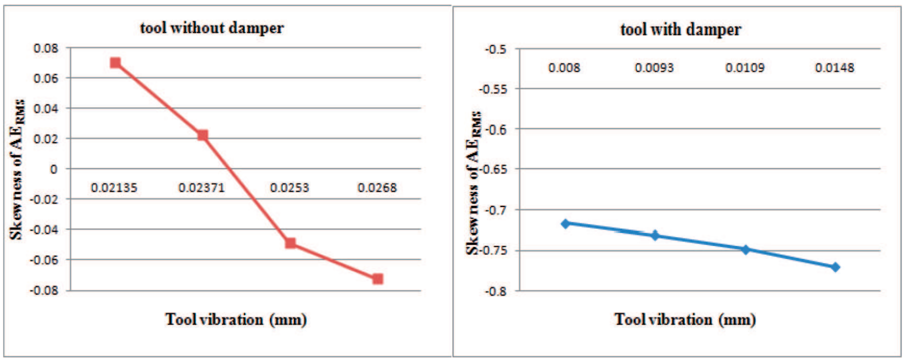

Fig. 11. Skewness of AE_{RMS} vs. amplitude of tool vibration

Experimental results of skewness based AE_{RMS} values plotted as a function of tool vibration at different machining time for tool with and without magnetorheological damper are presented in Fig. 11 and these plots show a decreasing trend of skewness value with increasing tool vibration. When comparing both plots of Fig. 11, it can be observed that very high amplitude of acoustic emission bursts occurs due to the greater rubbing between the tool and the workpiece for the tool without damper, which results in high amplitude AE signals. However, when the tool is subjected to damping, the main cutting force is reduced due to damping effect, thereby improving the rigidity of the tool. Due to this effect, skewness based on AE_{RMS} values for the tool with damper was comparatively lower, which confirm enhanced of life of the tool and smaller possibility of crack formation in the tool holder.

6. Conclusion

In the present investigation, a magnetorheological fluid damper suitable for turning of AISI4340 steel of 46 HRC using hard metal insert with sculptured rake face was designed, developed and tested to study the effect of such system on tool vibration, tool wear, surface finish and cutting force. A 27 run experiment was conducted, input parameters were optimized and the cutting performance values obtained using magnetorheological fluid damper were compared with the cutting performance during turning without magnetorheological fluid damper. Also, an attempt was made to compare the acoustics emission signals generated for the tool with and without magnetorheological fluid damper, and also to arrive at a simple monitoring system using AE_{RMS} signals. From the present study, the following conclusions were drawn:

- A magnetorheological fluid damper can effectively reduce tool vibration, tool wear, cutting force and improve surface finish.

- Moment parameters of AE_{RMS} signals like skewness, kurtosis are found to be vary swiftly for tool with damper when comparing with the tool without damper and these parameters can be used to reliably monitor the tool vibration.
- The decreasing tendency of skewness and increasing tendency of kurtosis were attributed to the stronger acoustic emission bursts coming from tool-work rubbing.
- This system can be further developed into a device that can provide variable damping to the cutting tool as the tool wear progresses, in order to achieve the best cutting performance by monitoring the tool wear of the workpiece.

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Monitorowanie wibracji narzędzia w czasie toczenia na twardo stali AISI4340 przy użyciu tłumika ze sterowanym płynem o właściwościach magnetoreologicznych

S t r e s z c z e n i e

W ostatnich latach, w obróbce skrawaniem wzrasta zainteresowanie koncepcją toczenia na twardo, ponieważ może ono zastąpić tradycyjny proces toczenia, utwardzania i szlifowania stosowany przy wykonywaniu twardych, odpornych na zużycie części metalowych. Głównym problemem przy twardym toczeniu są wibracje narzędzia, które muszą być monitorowane i kontrolowane, gdyż wpływają na wykończenie powierzchni elementu obrabianego. W celu kontrolowania wibracji narzędzia przy obróbce skrawaniem autorzy zastosowani tłumik z płynem o właściwościach reologicznych sterowanych polem magnetycznym. Podjęto także próbę monitorowania wibracji na podstawie parametrów skośności i kurtozy sygnałów akustycznych (AE) emitowanych przez uchwyt narzędzia, mierzonych w warunkach bez tłumika i z tłumikiem magnetoreologicznym. Przeprowadzono szereg eksperymentów z toczeniem stali AISI4340 o twardości 46 HRC przy użyciu narzędzia z płytką z twardej stali, o geometrycznie kształtowanym ostrzu, firmy Taegu Tec. Otrzymano zbiór parametrów roboczych, wyznaczając na ich podstawie lepsze charakterystyki tłumienia i osiągając minimalizację wibracji narzędzia. Wyniki eksperymentów wskazują, że obecność tłumika magnetoreologicznego redukuje wibracje i że istnieje silna zależność między wibracjami narzędzia i wartością skuteczną sygnału emisji akustycznych (AE_{RMS}). Praca przyczynia się do znacznie lepszego zrozumienia funkcji tłumika magnetoreologicznego i czujnika emisji akustycznych przy monitorowaniu stanu narzędzia przy toczeniu utwardzonej stali AISI4340.