Impact of Titanium and Activated Carbon Stabilizers on the Rheological Property of Magnetorheological Fluid during Turning Process

Ajay Vasanth. X, P. Sam Paul, G. Lawrance, A. S. Varadarajan

Abstract*: Vibration has been a major constraint in the machining industries as it has catastrophic effects on the machining parameter. Though there have been several attempts made by the researchers each had their own limitations and constraints. In metal cutting, Magnetorheological fluid (MRF) has proved to be effective in vibration suppression when employed as a semi-active damper. MRF is a smart non-Newtonian fluid which has the capacity to alter its viscosity instantaneously on the application of magnetic field. Along with this property and its robust nature they have used in a wide variety of places as a damper. One major limitation is its settling of magnetic particles which are suspended in a non-magnetic fluid. The settling rate will be further aggravated when the current supplied to coil is increased. Increased current will increase the heat produced in the coil which in turn will heat the non-magnetic fluid wherein its viscosity gets reduced. This problem of settling of iron particles can be prevented by adding stabilizers, similarly the size of particles also has an immediate effect on settling. In the current investigation Titanium and Activated carbon was added as stabilizers to magnetorheological fluid and then the viscosity change brought about in the fluid was studied. Further to support and add clarity to the work variable cutting speed and feed test was also performed. From the experimental results it was evident that stabilizers (activated carbon by 0.1% of weight) in MRF has increased the viscosity and thereby aided in an effective turning process of hardened SS410 steel.

Keywords: magnetorheological fluid, non–Newtonian fluid, stabilizers

I. INTRODUCTION

Modern day machining industry mainly focuses on ensuring that machining is performed at the optimum point. Optimal condition refers to the point where machining cost and time are relatively low, produced product is of a better quality with improved tool life. These can be achieved when machining is performed under better machining parameters.

Revised Manuscript Received on October 15, 2019.

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There are numerous factors that has to are present for guaranteeing maximum optimal condition. Out of these numerous factors vibration and specifically tool vibration has been a major disquiet from the initial point and is still deliberated as an unresolved mystery in machining industries. The problems of vibration was introduced in the machining sector by Taylor [1] and it was also stated as a main parameter that causes a serious kick back for effective machining and it was also mentioned by many researchers [2] – [4]. There were many theories that were stated during the initial stages when tool vibration was identified as a major problem. One of the theory proposed that tool vibration was mainly depended on depth of cut applied during machining [5] – [7]. Other theory suggested that tool vibration was depended on the stiffness of the tool [8], tool geometry [9] – [11], and many more. All though they were able to provide some insight to tool vibration they always failed to impress and give a detailed picture of tool vibration as it varied with randomness [12]. Later it was stated by many researchers that tool vibration is mainly depended on the interaction between the tool and workpiece or in other words referred as dynamics of machining process [13] – [15].

Tool vibrations by itself were categorized into two, out of which the type referred as chatter was the most destructive [16]. They are caused by the relative motion and the dynamic interaction between the tool and workpiece. To reduce this category of tool vibration many dampers were put to use in all most all the machining process. The primary and the basic dampers are passive dampers. Attempts were made to include passive dampers in turning, boring and in all other machining process [17], [18]. They were cost effective and since they were simple in design implementing passive dampers were also easy. They were not able to cope-up for the uncertainties which is an inherent property of tool vibration [12], [19]. A new breed and variety of damper were required wherein the damping capability can be varied according to the need, they were referred as semi-active dampers. A main restraint in these dampers is tuning because if not tuned properly they will amplify tool vibrations rather than decreasing it. Siddhpura and Paurobally [16] in their work stated that a phase shift

Φ was produced because of the difference between the waviness produced of previous machining to the waviness produced due to current machining and it was an important factor for tuning of semi-active dampers. It was further mentioned that the phase shift should be either 0 or 2π for the damper to work effectively and tuning the damper to match this value was a mind-numbing task [16].

This led to evolution of magnetorheological fluid (MRF) damper wherein the tuning can be done easily and a better damping can be achieved. MRF are smart non-Newtonian fluid whose viscosity depends on the applied external magnetic field [20]. If no magnetic field is applied they behave like a normal free flowing fluid, but at the instant of applying external magnetic field their viscosity changes and they get convert to a non-Newtonian fluid and starts to resist motion. The reason behind that is the suspended magnetic particle in a non-magnetic fluid gets aligned in the trend of the applied magnetic field. Since they work in the pre-yield region they completely rely on the viscosity change, and the viscosity change is that property which allows them to be used in dampers.

Though the use of MRF in dampers seems to be encouraging they have a setback which is settling of suspended magnetic particles in the non-magnetic fluid. The rate of settling of magnetic particles will be further accelerated as copper winding used for creating magnetic field will be heated on the application of current. It was stated that magnetic field produced is in direct accord with the current supplied to the coil [21], increasing the current will produce a higher magnetic field but will also increase the rate of settling of particles. Settling of magnetic particles also depends on the size and shape apart from that agglomeration is another major factor. Agglomeration refers to the condition where infinitely small particles adhere with each other and form irregular shaped larger particles. To overcome this settling problems stabilizers were added in MRF, which will ensure that the particles remain suspended in the non-magnetic fluid for a longer duration. There are very few traces in the literature that highlight the point of stabilizers, and most importantly the role of stabilizers in MRF dampers were looked in a meagre level.

In this work a detailed experimental investigation on the role of stabilizers in MRF damper was carried in addition to the study of the influence of particle size. The change of viscosity when exposed for prolonged duration of higher amperage current were studied and the optimum level of stabilizers in MRF damper were found using viscometer and the optimum MRF was used in the damper in real time hard dry process turning and its effect on the cutting parameters were studied. It was found that stabilizers in MRF dampers were very effective even in high current and thus aided in achieving a better turning process of hardened material in dry condition.

II. SELECTION OF TOOL AND WORKPIECE

For this experimental work SS410 steel was adopted, they have a high percentage of chromium compared with grades of stainless steel (Table 1). It is because of this they are resistant to corrosion. Since they are resistant to corrosion they have found its applications in the field of medical and surgical instruments, oil refinery distillation systems and petrochemical equipment industries [22]. The presence of martensitic structure in SS410 steel will further add to the complexity of machining. Experimentation was to be performed in hard dry condition hence the material was heat treated to increase the hardness to 45 HRC. A bar of 300mm length and 50mm diameter was used for this investigation.

Table- I. Composition of SS410 steel (percentage by weight)

Constituent	% by weight
Chromium	11.8
Manganese	0.40
Carbon	0.14
Nickel	0.20
Silicone	0.30
Iron	Balance

III. MAGNETORHEOLOGICAL FLUID DAMPER

The constituents of a magnetorheological fluid (MRF) damper consists of MRF, a copper coil for supplying magnetic field, a piston which will be attached to the vibrating tool and a plunger which will kept inside a cylinder filled with MRF (Figure 1). The vibration from the tool will be transmitted to the plunger whose motion will be restricted since it is kept inside a cylinder filled with MRF. The restriction of motion will be depended on the viscosity change of MRF which will be dependent on the external magnetic field. It is worth mentioning that the annular gap between the plunger and the inner diameter of the cylinder should be less than 1mm for a better damping [23].

A. Synthesis of magnetorheological fluid

Magnetorheological fluid (MRF) is a non-Newtonian fluid, when there is no application of magnetic field they will behave like a normal free flowing Newtonian fluid. But on the application of an external magnetic field its viscosity changes on that instant and it behaves like a non-Newtonian fluid. The change in viscosity happens because the magnetic particles in the non-magnetic fluid align themselves in the trend of the magnetic field. The viscosity change relies completely on the applied magnetic field [24].

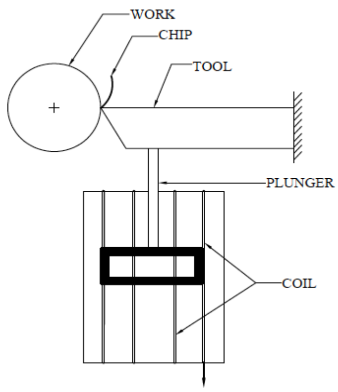

Fig. 1.Sketch of MR damper assembly

There are few traces where the influence of composition of MRF, ratio of magnetic particles to non-magnetic fluid were studied [20]. It was stated that for a ratio of 70:30, 70% of magnetic particles to 30% non-magnetic fluid by weight produced a better damping effect. The base non-magnetic fluid used was SAE40, since they do not alter its viscosity to a great deal with respect to temperature. If higher concentration of magnetic particles were used in MRF then particles have settled at very dissolute rate. Similarly, it was also stated in the same work that direction of current should be aligned to the direction where the vibration has to be controlled.

In this work the ratio of magnetic particles to base non-magnetic fluid will be kept at 70:30 (percentage by weight) and the direction of current supply will be aligned to the direction where the vibration has to decreased, or in other words in the opposite direction of main cutting force. A direct current (DC) current supply will be supplied to the coil as it has been proposed by Sam Paul et al. [25] as it was proposed that DC offered a better damping force compared with alternate current (AC). It was also stated that shape of the plunger has an influence on the damping ability and further it was found that a conical shaped plunger had a better damping ability [20].

IV. EXPERIMENTATION

LVDV – E Brookfiled's viscometer was used for conducting the initial experiments. The experiments were conducted at 60rpm and 100rpm spindle speeds. The stabilizers that were used included Titanium and activated carbon. After finding the optimum stabilizers, the same will be used in the damper during actual hard dry turning process. Thus, the whole experimentation was focused to improve the performance of a MRF damper.

A. Effect of stabilizers on viscosity of magnetorheological fluid

The effect of stabilizers [26] – [28] and the size of the magnetic particles [29] were considered as separate entities in a few research works but their corresponding combined analysis were not performed. Most of the works stressed on the effect of stabilizers and its corresponding viscosity change. A detailed survey on the effect of stabilizers on viscosity of MRF has been carried for a clear and better understanding and there also it was evident that size of particles was not considered [30]. In the research work activated carbon and titanium was used as both of them have shown great potential in the case of heat absorption [31], [32].

In this research work 0.1% (0.16g), 0.2% (0.32g), 0.3% (0.48g) fraction (by weight) of activated carbon and titanium were added to MRF and its effect on viscosity during real time operating scenario were studied. There were two sizes of magnetic particles that were used for this study Particle 'A' were the size varies from 20µm to 40µm and Particle 'B' were the size varies from 40µm to 70µm. Both the particles had more 99% (by weight) of iron content in it. The current supplied for achieving magnetic field was kept constant at 3A. Thus, a constant magnetic field was applied for all the experiments. The reason for a constant supply of 3A of current to the winding is higher supply of current will ensure higher magnetic field which will ensure higher magnetorheological effect. Apart from it higher current will also ensure that a higher heat will be produced in the coil which will also affect the viscosity of non-magnetic fluid, in this case SAE 40 oil. Though supplying higher amount seems to be a fair deal, they might have catastrophic effect on the damper by damaging the coil permanently. In their work, Paul et al. [33] stated that higher current ensured higher temperature and reduced viscosity but failed to express the effect for prolonged exposure to higher current in this study the above mentioned will be bridged.

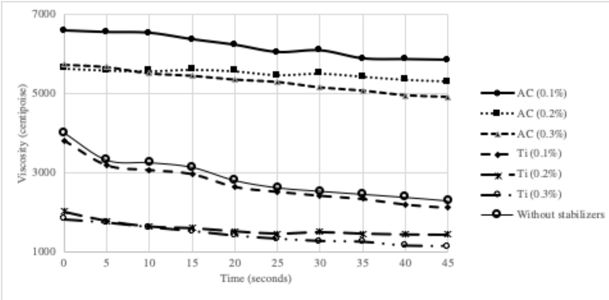

Fig. 2.Viscosity of MRF with magnetic particles of size 20µm to 40µm

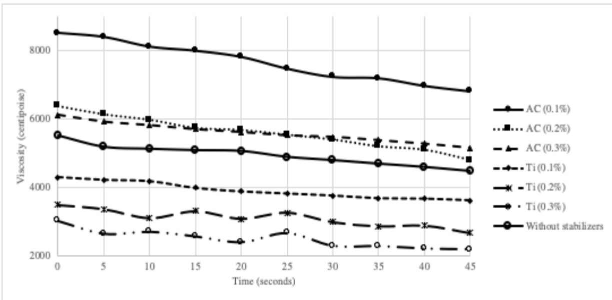

Fig. 3.Viscosity of MRF with magnetic particles of size 40µm to 70µm

The experimental values of the viscosity of MRF with and without stabilizers are presented in Figure 2, Figure 3, Table 2 and Table 3. It was evident that activated carbon with a concentration of 0.1% (by weight) in a MRF where the size of magnetic particles varies from 40µm to 70µm has increased the stability of MRF by improving its viscosity even after prolonged exposure to high current of 3A. For further validation MRF with stabilizers were examined during hard dry turning process.

Table- II. Viscosity of MRF with and without stabilizers (magnetic particle size 20 µm – 40µm)

Time (s)	Viscosity of magnetorheological fluid						
	With stabilizers						Without stabilizers (cP)
	0.1%		0.2%		0.3%		
	AC	Ti	AC	Ti	AC	Ti	
0	6600	3820	5650	2030	5740	1840	4006
5	6560	3200	5600	1800	5680	1760	3382
10	6540	3080	5580	1660	5520	1640	3278
15	6380	2980	5620	1620	5460	1540	3112
20	6240	2660	5580	1540	5360	1420	2853

25	6060	2540	5480	1480	5300	1340	2690
30	6100	2440	5520	1520	5160	1280	2616
35	5900	2360	5440	1480	5080	1260	2487
40	5880	2220	5360	1460	4960	1160	2304
45	5864	2140	5320	1453	4920	1151	2304

Table- III. Viscosity of MRF with and without stabilizers (magnetic particle size 40 µm – 70µm)

Time (s)	Viscosity of magnetorheological fluid						
	With stabilizers						Without stabilizers (cP)
	0.1%		0.2%		0.3%		
	AC	Ti	AC	Ti	AC	Ti	
0	8520	4300	6380	3480	6120	3020	5520
5	8400	4220	6140	3360	5920	2640	5190
10	8120	4180	5980	3100	5820	2700	5130
15	8000	3980	5740	3300	5700	2560	5090
20	7820	3880	5680	3080	5620	2389	5064
25	7480	3820	5540	3260	5520	2660	4892
30	7240	3760	5400	2980	5480	2280	4794
35	7200	3680	5200	2860	5380	2275	4690
40	6980	3670	5100	2880	5280	2200	4592
45	6820	3620	4800	2660	5160	2180	4473

B. Experimental setup

Kirloskar turn master-35 lathe was used for carrying out experimentation. Depth of cut was maintained as a constant and variable cutting speed and variable feed test were performed (Table 4). Two replications of experiments were performed and the average values were considered and each experiment lasted for 100 seconds. Based on the experimentation of [20] the ratio of MRF were taken as 70:30 (70% of non-magnetic fluid, SAE 40 and 30% of magnetic particles). And the shape of the plunger was kept as conical for all the experiments.

Table- IV. Experimental condition for variable cutting speed and variable feed test

Parameters	Variable cutting speed test	Variable feed test
Cutting velocity (m/min)	140, 120, 100	0.08
Feed rate (mm/rev)	120	0.06, 0.08, 0.1
Depth of cut (mm)	0.4	0.4

During the experimentation, Kistler tool force dynamometer, Mahr TR100 of type MarSurf GD 25 and piezo-electric type vibrometer were used for measuring cutting force, average surface roughness (Ra) and amplitude of tool vibration respectively. In this study the amplitude of tool vibration was measured in the upright direction, where-in it will have a detrimental effect [34].

V. OBSERVATION FROM THE EXPERIMENTS

In addition to the viscosity test, cutting experiments were also performed to study the consequence of MRF dampers (with and without stabilizers). From the experimental results it was evident that compared to a conventional hard dry turning inclusion of a MRF damper has brought forth a better cutting performance and further the inclusion of 0.1% (by weight) of activated carbon to a magnetic particle of size 40µm to 70µm in MRF have produced a much better cutting performance. This was also evident from the viscosity test performed with MRF with a 3A current supplied for 45 seconds (Table 3 and Figure 3).

A. Influence of Particle Size and Stabilizers

The size of magnetic particles affects the viscosity which in turn also affects the damping nature of MRF. When a smaller sized magnetic particle was employed in the preparation of MRF both with and without stabilizers had a major noticeable point which was agglomeration. They started to get agglomerated even after a very small duration of time, thus the smaller sized particles increased its size and became heavier and started to settle even without any application of current to the coil. When a current of 3A is supplied to the coil they further accelerate the settling of magnetic particles because of heating and it can be observed in Table 2 and Figure 2. Thus, smaller size particles are not suited for the preparation of MRF because of agglomeration. Larger sized magnetic particles did not undergo agglomeration thus regardless of stabilizers they offered a better viscosity than smaller sized magnetic particles (Table 2 and Table 3).

It was observed that the inclusion of MRF damper has brought forth a better cutting performance since it has increased the stiffness of the vibrating tool. Increasing the stiffness of tool reduced tool vibration which in turn produced a better cutting performance. It was also stated that increasing the current increased magnetic field which increased the viscosity of MRF. And an inherent problem that comes with it is the I^2R heating, where 'I' represents the current supplied to the coil and 'R' represents the resistance of the copper winding in the coil. The need of a damper will not be required in the initial stage of machining as the turning tool will be sharp. During the course of turning the tool will start to lose its sharpness and towards the end of its life the tool will be in need of a highly effective damper. MRF dampers lends its use in these conditions as the damping ability is in direct relation to the current supplied to the coil. When a high current is supplied there are places where it can be catastrophical, when the current is beyond the threshold value of the coil it can cause permanent damage. Even the current is well within the threshold limit higher current will increase the heat in the coil by I^2R heating wherein the viscosity of the base non-magnetic fluid will be altered such that the settling of magnetic particles will be accelerated. Though they are not catastrophic as the former they do cause problem in their own domain, mainly it will decrease the efficiency of the MRF damper in the longer run. This is where stabilizers are added to MRF to increase stability and reduce the settling of magnetic particles there by increasing the damping capacity of MRF damper even when exposed to higher ampere of current for longer duration.

Though Titanium has a better capacity to remove the heat in MRF, they are relatively heavier metal thus its presence in MRF has caused the magnetic particles to settle.

Further when current was increased and kept for longer duration the condition further worsened and the settling of magnetic particles increased. The presence of Titanium in MRF regardless of the size of magnetic particles has affected the viscosity in the negative manner.

Numerous work has been carried out to find the structure of activated carbon [35] – [37] and it was stated that regardless of methods adopted to produce activated carbon they have a mesh structure. This structure captures the magnetic particles inside them and does not allow them to settle at faster phase. Even at prolonged higher amperage current they don't allow the magnetic particles to settle. Though smaller size particles have the concern of agglomeration the presence of activated carbon has brought forth a better viscosity (Figure 2 and Table 2). From Figure 3 and Table 3 it is evident that 0.1% (by weight) of activated carbon in larger sized magnetic particle had a better viscosity and even after a prolonged usage at 3A it had least effect on its viscosity. Higher percentage of activated carbon has created more meshed structure in MRF and the magnetic particles gets settled in that mesh, and their response to the magnetic field gets affected by it. Thus, increasing the concentration of activated carbon has increased the mesh and thus magnetic particles was not able to respond to external magnetic field as they won't be able to form the chain structure and therefore will not allow for a viscosity change as desired.

B. Variable Cutting Speed and Variable Feed Test

In the hard dry turning process MRF with larger sized magnetic particles (40µm - 70µm) and 0.1% activated carbon was used on the MRF damper. Variable cutting speed and variable feed tests were performed keeping the depth of cut as a constant in all the experiments (Table 4). The experiments were carried in conventional method and the obtained cutting parameters were compared with the cutting parameters obtained when a MRF damper was employed (with and without stabilizers). It was quite evident that when MRF with 0.1% activated carbon was added to MRF and was used in the damper they produced a better cutting performance compared with all other turning conditions.

The presence of activated carbon in the MRF ensured that the mesh structure is formed in such a fashion that they don't allow the magnetic particles to settle but in the same allows the magnetic particles to align in the direction of applied magnetic field. Table 6 shows the cutting parameter enhancement that has been brought about by the inclusion of MRF dampers (both with and without stabilizers) and it clearly exhibits that MRF with stabilizers perform better compared to conventional MRF. The addition of 0.1% of activated carbon in MRF of larger sized magnetic particle improved the viscosity at higher temperature (produced because of high current) which was evident from Figure 3 and Table 3.

When the same was employed during dry hard turning process they improved the damping as they offered higher resistive force than the normal MRF as they offered a higher viscosity. And higher damping force improved the stiffness of the turning tool which in turn improved the dynamics of machining process. This can be observed in Table 5 when compared to the conventional dry hard turning MRF with 0.1% of activated carbon and larger sized magnetic particles have produced a better cutting performance. Table 6 exhibits the percentage improvement of cutting force, tool vibration and surface roughness brought forth by the introduction of MRF dampers with and without stabilizers.

Table- V. Comparison of parameter with MRF dampers (with and without stabilizers)

Cutting Velocity (m/min)	Feed Rate (mm/rev)	Depth of cut (mm)	Main Cutting Force (N)			Tool Vibration Amplitude (mm)			Average Surface Roughness, (µm)		
			Dry	MRF	MRF with 0.1% AC	Dry	MRF	MRF with 0.1% AC	Dry	MRF	MRF with 0.1% AC
140	0.08	0.4	68.38	43.59	27.35	0.100	0.033	0.021	0.391	0.391	0.391
120	0.08	0.4	59.27	27.10	16.57	0.054	0.036	0.034	0.391	0.391	0.391
100	0.08	0.4	47.72	37.14	8.62	0.046	0.042	0.036	0.391	0.391	0.391
120	0.1	0.4	33.69	30.98	16.25	0.100	0.034	0.032	0.483	0.483	0.483
120	0.08	0.4	68.38	27.10	16.57	0.054	0.036	0.034	0.483	0.483	0.483
120	0.06	0.4	86.64	48.69	35.17	0.105	0.035	0.031	0.483	0.483	0.483

Table- VI. Cutting parameter enhancement with MRF dampers

Cutting Velocity (m/min)	Feed Rate (mm/rev)	Depth of cut (mm)	Percentage Improvement with MRF dampers (%)					
			Main cutting force		Tool Vibration Amplitude		Surface Roughness	
			MR F	MRF with 0.1% AC	MR F	MRF with 0.1% AC	MR F	MRF with 0.1% AC
140	0.08	0.4	36.26	37.25	67.00	79.00	12.02	26.09
120	0.08	0.4	54.28	38.87	33.33	37.04	20.31	30.13
100	0.08	0.4	22.16	76.78	8.70	20.87	51.02	65.23
120	0.1	0.4	8.05	47.53	66.00	68.00	11.80	36.85
120	0.08	0.4	60.37	38.87	33.33	37.04	20.31	30.13
120	0.06	0.4	43.80	27.77	66.67	70.48	33.21	49.78

VI. CONCLUSION

In the current research examination, the effect of stabilizers on MRF dampers were analyzed during dry hard turning. In view of this MRF were synthesized with concentration 0.1%, 0.2% and 0.3% (by weight) with titanium and activated carbon separately and from the performed experiments the observations are:

- MRF developed with larger size magnetic particles are more stable compared with smaller sized particles as their viscosity remain high even for longer duration at elevated temperature.
- MRF with stabilizers as activated carbon had a better viscosity compared with MRF which had titanium as its stabilizers as the mesh structure in activated carbon prevented the iron particles from settling.
- MRF with 0.1% (by weight) of activated carbon has ensured that a MRF is more stable and has higher viscosity and also offers better cutting performance.
- MRF with higher concentration of activated carbon were not responsive to magnetic field change. Increasing the concentration of activated carbon had increased the mesh structure, thus the trapped magnetic particle does not align to a greater level on the application of magnetic field.

REFERENCES

1. F. Taylor, 'On the art of cutting metals', *Trans. ASME*, vol. 28, 1907.
2. N. Arnold, 'Cutting Tools Research: Report of Subcommittee on Carbide Tools: The Mechanism of Tool Vibration in the Cutting of Steel', *Proc. Inst. Mech. Eng.*, vol. 154, pp. 261–284, 1946.
3. W. A. Knight, 'Chatter in turning: Some effects of tool geometry and cutting conditions', *Int. J. Mach. Tool Des. Res.*, vol. 12, no. 3, pp. 201–220, 1972.
4. H. E. Merritt, 'Theory of Self-Excited Machine-Tool Chatter: Contribution to Machine-Tool Chatter Research—', *J. Eng. Ind.*, vol. 87, no. 4, pp. 447–454, 1965.
5. J. Tlusty and M. Polacek, 'The Stability of Machine Tools against Self Excited Vibrations in Machining', *Int. Res. Prod. Eng. ASME*, pp. 465–474, 1963.
6. S. A. Tobias and W. Fishwick, 'The chatter of lathe tools under orthogonal cutting conditions', *Trans. ASME*, vol. 80, pp. 1079–1088, 1958.
7. M. Thomas, Y. Beauchamp, A. Y. Youssef, and J. Masounave, 'Effect of tool vibrations on surface roughness during lathe dry turning process', *Comput. Ind. Eng.*, vol. 31, no. 3, pp. 637–644, 1996.
8. S. A. Tobias, 'Machine tool vibration research', *Int. J. Mach. Tool Des. Res.*, vol. 1, no. 1, pp. 1–14, Sep. 1961.
9. Y. K. Chou and H. Song, 'Tool nose radius effects on finish hard turning', *J. Mater. Process. Technol.*, vol. 148, no. 2, pp. 259–268, 2004.
10. M. N. Hamdan and A. E. Bayoumi, 'An approach to study the effects of tool geometry on the primary chatter vibration in orthogonal cutting', *J. Sound Vib.*, vol. 128, no. 3, pp. 451–469, 1989.
11. S. Kumar, D. Singh, and N. S. Kalsi, 'Investigating the Effect of Approach Angle and Nose Radius on Surface Quality of Inconel 718', *J. Inst. Eng. India Ser. C*, 2017.
12. X. Zhang, L. Zhu, D. Zhang, H. Ding, and Y. Xiong, 'Numerical robust optimization of spindle speed for milling process with uncertainties', *Int. J. Mach. Tools Manuf.*, vol. 61, pp. 9–19, 2012.
13. E. Budak and E. Ozturk, 'Dynamics and stability of parallel turning operations', *CIRP Ann. - Manuf. Technol.*, vol. 60, no. 1, pp. 383–386, 2011.
14. D. W. Wu and C. R. Liu, 'An Analytical Model of Cutting Dynamics. Part 1: Model Building', *J. Eng. Ind.*, vol. 107, no. 2, pp. 107–111, 1985.
15. D. W. Wu and C. R. Liu, 'An Analytical Model of Cutting Dynamics. Part 2: Verification', *J. Eng. Ind.*, vol. 107, no. 2, pp. 112–118, 1985.
16. M. Siddhpura and R. Paurobally, 'A review of chatter vibration research in turning', *Int. J. Mach. Tools Manuf.*, vol. 61, pp. 27–47, 2012.
17. C. V. Biju and M. S. Shunmugam, 'Investigation into effect of particle impact damping (PID) on surface topography in boring operation', *Int. J. Adv. Manuf. Technol.*, vol. 75, no. 5, pp. 1219–1231, 2014.
18. J. Munoa *et al.*, 'Chatter suppression techniques in metal cutting', *CIRP Ann.*, vol. 65, no. 2, pp. 785–808, 2016.
19. M. Löser and K. Großmann, 'Influence of Parameter Uncertainties on the Computation of Stability Lobe Diagrams', *Procedia CIRP*, vol. 46, pp. 460–463, 2016.
20. P. Sam Paul, A. S. Varadarajan, X. Ajay Vasanth, and G. Lawrance, 'Effect of magnetic field on damping ability of magnetorheological damper during hard turning', *Arch. Civ. Mech. Eng.*, vol. 14, no. 3, pp. 433–443, 2014.
21. R. Kishore, S. K. Choudhury, and K. Orra, 'On-line control of machine tool vibration in turning operation using electro-magneto rheological damper', *J. Manuf. Process.*, vol. 31, pp. 187–198, 2018.
22. R. T. Loto, 'Study of the corrosion behaviour of S32101 duplex and 410 martensitic stainless steel for application in oil refinery distillation systems', *J. Mater. Res. Technol.*, vol. 6, no. 3, pp. 203–212, 2017.
23. Z. Parlak, T. Engin, and İ. Çallı, 'Optimal design of MR damper via finite element analyses of fluid dynamic and magnetic field', *Mechatronics*, vol. 22, no. 6, pp. 890–903, Sep. 2012.
24. J. M. Ginder, L. c. Davis, and L. d. Elie, 'Rheology of magnetorheological fluids: models and measurements', *Int. J. Mod. Phys. B*, vol. 10, no. 23n24, pp. 3293–3303, Oct. 1996.
25. P. Sam Paul, A. S. Varadarajan, and S. Mohanasundaram, 'Effect of magnetorheological fluid on tool wear during hard turning with minimal fluid application', *Arch. Civ. Mech. Eng.*, vol. 15, no. 1, pp. 124–132, Jan. 2015.
26. Y. Rabbani, M. Ashtiani, and S. H. Hashemabadi, 'An experimental study on the effects of temperature and magnetic field strength on the magnetorheological fluid stability and MR effect', *Soft Matter*, vol. 11, no. 22, pp. 4453–4460, May 2015.
27. J. C. Lambropoulos, C. Miao, and S. D. Jacobs, 'Magnetic field effects on shear and normal stresses in magnetorheological finishing', *Opt. Express*, vol. 18, no. 19, pp. 19713–19723, Sep. 2010.
28. B. J. Park, F. F. Fang, and H. J. Choi, 'Magnetorheology: materials and application', *Soft Matter*, vol. 6, no. 21, pp. 5246–5253, Nov. 2010.
29. C. Sarkar and H. Hirani, 'Effect of Particle Size on Shear Stress of Magnetorheological Fluids',

Smart Sci., vol. 3, no. 2, pp. 65–73, Jan. 2015.
30. M. Ashtiani, S. H. Hashemabadi, and A. Ghaffari, 'A review on the magnetorheological fluid preparation and stabilization', *J. Magn. Magn. Mater.*, vol. 374, pp. 716–730, Jan. 2015.
31. Z. Chen, F. Shan, L. Cao, and G. Fang, 'Synthesis and thermal properties of shape-stabilized lauric acid/activated carbon composites as phase change materials for thermal energy storage', *Sol. Energy Mater. Sol. Cells*, vol. 102, pp. 131–136, Jul. 2012.
32. J. Xiao, L. Tong, C. Deng, P. Bénard, and R. Chahine, 'Simulation of heat and mass transfer in activated carbon tank for hydrogen storage', *Int. J. Hydrog. Energy*, vol. 35, no. 15, pp. 8106–8116, Aug. 2010.
33. P. S. Paul, J. A. Iasanth, X. A. Vasanth, and A. S. Varadarajan, 'Effect of nanoparticles on the performance of magnetorheological fluid damper during hard turning process', *Friction*, vol. 3, no. 4, pp. 333–343, 2015.
34. K. S. Moon and J. W. Sutherland, 'The Origin and Interpretation of Spatial Frequencies in a Turned Surface Profile', *J. Eng. Ind.*, vol. 116, no. 3, pp. 340–347, 1994.
35. M. S. Solum, R. J. Pugmire, M. Jagtoyen, and F. Derbyshire, 'Evolution of carbon structure in chemically activated wood', *Carbon*, vol. 33, no. 9, pp. 1247–1254, Jan. 1995.
36. L. Li, P. A. Quinlivan, and D. R. U. Knappe, 'Effects of activated carbon surface chemistry and pore structure on the adsorption of organic contaminants from aqueous solution', *Carbon*, vol. 40, no. 12, pp. 2085–2100, Jan. 2002.
37. C. Chiang, P.-C. Chiang, and C.-P. Huang, 'Effects of pore structure and temperature on VOC adsorption on activated carbon', *Carbon*, vol. 39, no. 4, pp. 523–534, Apr. 2001.

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