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Experimental Investigation of Magneto Rheological Damping Effect on Surface Roughness of Work Piece during End Milling Process

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Metal cutting processes involve interaction of the machining forces with the work piece. In this processes the vibrations are induced in machine tools which have adverse effect on tool life, surface integrity and occurrence of undesirable chatter phenomenon. In order to enhance the quality of surface of the work piece after machining and avoid chatter marks and breakage of tool, this paper gives a unique method to detect and suppress the chatter effect on the work piece finis. This method incorporates the features of Magneto-Rheological fluid which utilizes the input current as source to modify the magnetic field to enhance the variable stiffness and produce damping effect to control the end mill cutter vibration and suppress the chatter. The variables stiffness and damping can be maintained by the damper input current to attain desired magnetic field in the MR damper. In this work the chatter detection is observed by means of a remarkable Bingham number. The different machining parameters are considered in the experimental work and the results are compared with and without the magneto rheological damping effect and the results shows the enhancement of surface quality and reduced the chatter marks on the work piece by producing Magneto- Rheological damping to the end mill cutter during machining.

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1. Introduction

End mill cutter during machining experiences deflection, vibration which inhibits the production rate and quality of machined surface. Excessive deflections may cause early wear of the tool and also to the bearings of the spindle housing. Vibrations also raise the regenerative chatter on the surface during machining. In order to suppress this undesired characteristic during end milling it is necessary to suppress this chatter phenomenon. Many researchers are working in vibration control and chatter phenomenon and conducted experiments with different techniques in past decades, Li and Hu utilizes the concept of dynamic Absorber, Tewan used absorber mass with a piezoelectric absorber. Marra et al developed a dynamic controller (H_∞) with an actuator to control vibration effects during cutting process. Wong et al uses the concept of electromagnetic actuators, Wong designed the controller LQR and uses fitters for on-line chatter control with ER fluid. Suppression of chatter can be attained using different modes such as passive control mode, semi-active control mode and active control mode. In this paper semi active mode is used to control vibrations in an end mill cutter in which the application of Magneto Rheological fluid is used for dynamic damping effect, having voltages (5-10v), power consumption (25-50v), input current ranges from (0.5-3A), Input voltage (10-30v), Temperature (15-90^{o}C) due to the above advantages, Magneto Rheological fluids are versatile in application to control the vibrations of end mill cutter. In the present work the importance of Magneto Rheological damper is discussed with an assembly to hold the end mill cutter with desired rotational rpm of cutter. Palanikumar developed a model for surface roughness through response surface method (RSM) while machining GFRP composites. Four factors five level central composite rotatable design matrix was employed to carry out the experimental investigation. Analysis of variance (ANOVA) was used to check the validity of the model, Muthukrishnan et al. developed two modeling techniques used to predict the surface roughness namely ANOVA and ANN. They used the response surface methodology (RSM) to explore the effect of these parameters on surface roughness, Liu and Cheng presented a practical method for modeling and predicting the machining dynamics and surface roughness/waviness in peripheral milling. They considered cutting speed, feed rate and depth of cut of end milling operations for predicting surface roughness and predicted a linear equation for surface roughness related to experimental study. The researchers also used response surface methodology (RSM) to explore the effect of such cutting parameters as cutting speed, feed rate and depth of cut on surface roughness. Aladdin et al. also established a mathematical model for predicting the tool in the end milling process of 190 BHN steel under dry cutting conditions. The model included the following variables: cutting speed, feed rate and axial depth of cut. It also verified the suitability of the prediction model via ANOVA. This paper focuses on machining of Al and EN Steels which is widely used in engineering applications.

2. Description of MR Concept

Magneto-Rheological fluids are smart materials because their characteristics can be controlled through the application of a magnetic field. They are composed of oil usually mineral or silicone based and ferrous particles that are on the order of 0.05-10 microns in diameter. MR fluids are capable of achieving much higher yield strengths. In the presence of an applied magnetic field, the ferrous particles become magnetic dipoles, which connect to each other along lines of magnetic flux, forming linear chains parallel to the field. This phenomenon solidifies the suspension oil and restricts the fluid movement, developing yield strength. The degree of change is related to the magnitude of the applied magnetic field, and may occur in less than a few milliseconds. The ferrous particles are randomly dispersed in the medium when there is no magnetic field applied, as shown in Fig. 1. In the presence of a magnetic field, the particles start to move to align themselves along lines of magnetic flux forming the chains of ferrous particles, creating yield strength. Because this change occurs instantly, MR fluids are attractive for real-time control applications.

Fig. 2 shows the Cross-section of typical MR damper to explain the operation of MR fluid dampers. MR dampers have electromagnetic coils wound in their pistons, and MR fluid-filled reservoirs. Voltage in the electromagnet coils creates a magnetic field around the fluid gap between the housing and the piston. When the piston rod enters the housing, the MR fluids pass through the annular orifice gap to the other side of the reservoir. As in the damper depicted in Fig. 2 there are two activation regions, which resist the flow of fluid from one side of the piston to the other when a magnetic field is present. While the viscosity of the MR fluid remains constant, it's apparent viscosity changes when it is exposed to a magnetic field. In other words, the MR fluid mixture thickens, and even becomes solid, when it meets a magnetic field. The magnetic field also changes the shear strain rate of the MR fluid, which becomes more sensitive to shearing with an increasing magnetic field. As the magnetic field strength increases, the resistance to fluid flow at the activation regions also increases until it reaches the saturation current. The resistance to fluid flow in the activation regions causes the MR dampers to produce force. This

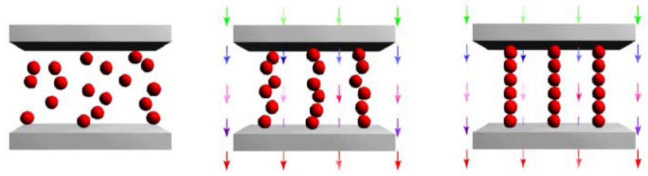


Fig. 1 Activation of MR Fluid (a) No Magnetic Field Applied (b) Magnetic Filed Applied and (c) Ferrous Particles Formed

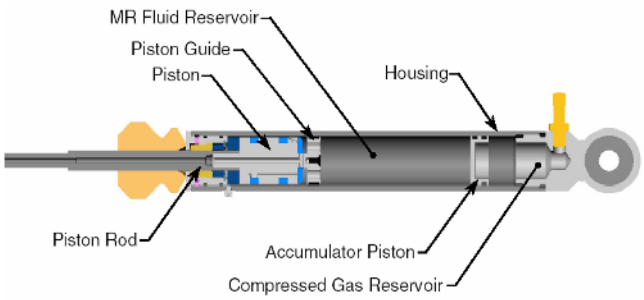


Fig. 2 Typical MR damper

mechanism is similar to that of hydraulic dampers, in which force is caused by fluid passage through an orifice. LORD RD-1005-3 (Short stroke) dampers are compact, magneto-rheological (MR) fluid dampers suitable for industrial suspension applications. Continuously variable damping is controlled by the increase in yield strength of the MR fluid in response to magnetic field strength, Fast Response Time – responds in less than 15 milliseconds to changes in the magnetic field, Easy to Use – provides simple electronics and straight forward controls, Durable – provides excellent long term stability. Storage - Dampers should be stored at -40 to +100°C (-40 to +212°F). The LORD RD-1005-3 dampers are mono tube shocks containing high-pressure nitrogen gas (300 psi). Handle with care and do not heat or puncture body. Stroke, 55 mm (2.17 inches) Extended Length, 208 mm (8.2 inches), Body Diameter, 42.1 mm (1.66 inches) max, Shaft Diameter, 10 mm (0.39 inches).

3. Chatter Detection System

In this paper proposed chatter detection system involves a Bingham Number (B_N) which is defined as the ratio of yield stress to viscous stress, with this choice of parameter results are qualitative and quantitative. The controllable magnetic field damping force is expressed in terms of Bingham Number.

The excitation of the end milling cutter is assumed to be sinusoidal displacement and it exerts the force on MR damper piston and is moved with piston velocity v_p. The variation of Bingham number with respect to piston velocity is given in Table 2 with high velocity of the piston, that is when the deflection of end mill cutter during machining is more lower will be the Bingham number and maximum magnetic field damping force C_{md} is provided in order to make the cutting condition stable. The damping force is controlled by input current I and the magnetic field

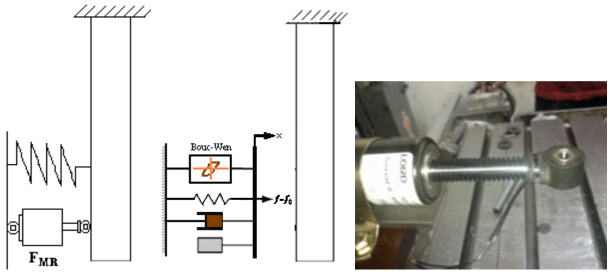


Fig. 3 Allocation of MR Damper at the tool tip and Bearing placed at eye end of damper

damping force is given by MR Damping force

$$F_{mr} = F_{yf}\,(\mathrm{I})\ \mathrm{sgn}\left(\frac{\alpha}{B_N}\right) + \mathrm{C_{md}}\,(\mathrm{I})\ \mathrm{sgn}\left(\frac{\alpha}{B_N}\right)$$

Magnetic Field Damping C_{md} (I) = 23 + 25(I)

Yield Force Developed $F_{yf} = 8.28(I)^{1.85}$

Where α is a constant = $(\tau_y * g_s)/\eta$, B_N = Bingham Number

Where τ_y = Yield Shear due to Applied Magnetic Field

g_s = Gap Size in which MR Fluid Flows, η = Plastic Viscosity of Fluid

To validate the accuracy predictions, milling tests will be performed along with MR DAMPER to hold the shank of the milling cutter during the machining process, which helps in preventing machine tool chatter. Damper will not allow the tool to have lateral deflection and it is mounted on the work piece table and moves along with the tool to control the chatter deflection. MR damper will be held on fixed housing which in bolted on the work table. The other associated devices include data acquisition systems, milling tool dynamometer, accelerometer and displacement sensors, and control kit to regulate the damper input current. End mill cutter deflects from its mean position or run out effect predominates under the influence of maximum force components during machining. Therefore cutting components induces sinusoidal excitation at the end mill cutter at tool tip. The damper piston rod velocity plays a vital role in exciting the magnetic field in the MR damper, the piston rod displacement is compensated by the damping force $\mathbf{F_{mr}}$ which is produced due to input current given to the MR damper. The input current frequency is evaluated by the spindle drive current frequency at which the spindle experience maximum force thereby setting the frequency as chatter frequency to the control element that MR damper get activated at that particular chatter frequency so that it produces the damping effect to the end mill cutter where it experiences the maximum cutting forces during machining. The input current produces the desired damping force with respect to the piston rod velocity ($\mathbf{v_p}$). Numerical simulations are carried out for the effect of magnetic damping force during the end milling process using MATLAB.

4. Numerical Simulation

The application of the input current which is set at spindle drive current, so that the yield force developed in the gap thickness and provides the effective resistance force to the movement of the piston under the sinusoidal excitation of the cutter. This yield force of highly viscous fluid helps in reducing the run out effect of the end mill cutter from its mean position. Fig. 4 shows the variations of yield force by increase in input current.

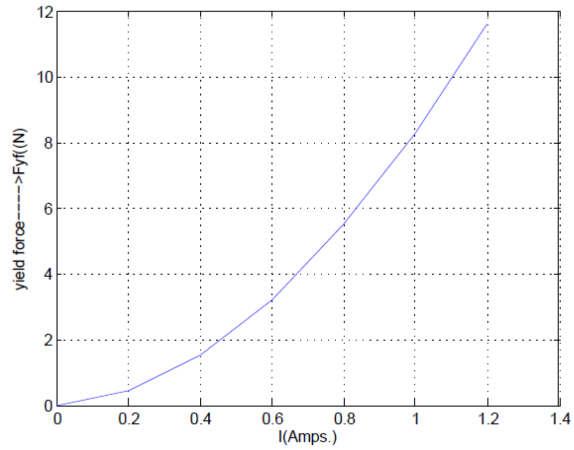


Fig. 4 Variation of yield force vs. Input current

Table 1 Variation of yield force with input current

I amp	0.0	0.2	0.4	0.6	0.8	1.0	1.2
Fyf N	0	0.4216	1.519	3.218	5.479	8.281	11.601

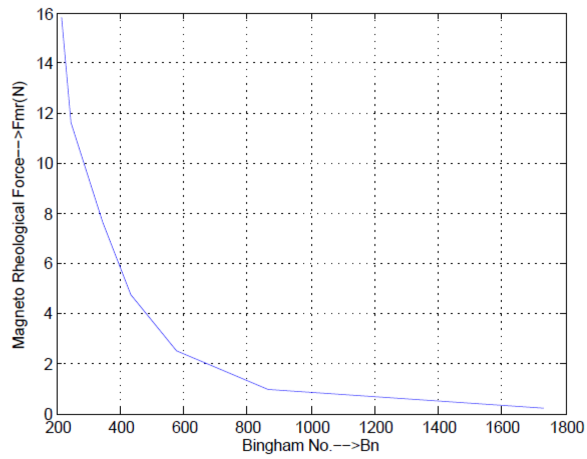


Fig. 5 Variation of magneto rheological force vs. Bingham number

Table 2 Variation of piston velocity and Bingham Number

V_P m/sec	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
B_N	1730	865	576.7	432	346	288	247	216

Fig. 5 shows the variation of Magneto rheological force by varying Bingham Number. MR Damper piston velocity plays a vital role in minimizing the deflection of end mill cutter from its mean position and it inversely proportional to the Bingham Number. If the velocity of piston is decreases the Bingham number increases which is a chatter indicator since more force is required for the cutter to be in its mean position. This force is developed due to resistance offered to the piston displacement. The variation of the damping force with Bingham Number is given in Table 2. This on line detection technique helps in attaining the stability of the end mill cutter during machining and increase the surface quality with reduction in tool breakage.

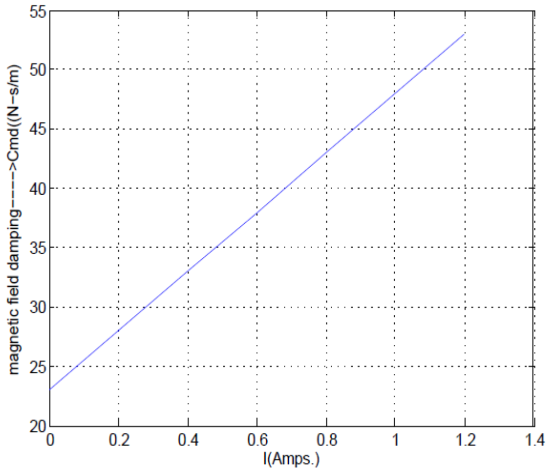


Fig. 6 Variation of magnetic field damping and input current

Table 3 Variation magnetic field damping and Input current

I amp	0.0	0.2	0.4	0.6	0.8	1.0	1.2
C_{md} Ns/m	23	28	33	38	43	48	53

The spindle drive current is used as an input controlling current to the MR Damper in order to activate the magnetic field inside the magnetic coil of damper. The maximum forces are encountered during cutting. These dynamic cutting forces gives regenerative chatter. The maximum force components frequency and the spindle drive current frequency are correlated and set the threshold frequency at which the damper will activated and provides the desired damping force. This dynamic controlling reduces the deflection and minimizes the chatter effect. The variation of magnetic field damping and input current is given in Table 3.

Regenerative chatter in machining occurs mainly due to instability of machining process along with end machine structure, the natural frequency of the end mill is in close vicinity of the regenerative chatter frequency. The displacement of the end mill cutter is mainly due to forces encountered during machining. The chip thickness during machining will vary and is equal to the difference between waviness of the surface.

5. Experimental Setup

In the present study for experimental work cases considered are a web and "I" structures. This section details the size and shape of each feature and illustrates the different thicknesses. Each studied feature combines to form complex geometric structures such as, boxes, ribs, fins, slots etc. Each thickness and height of the feature in this investigation stays constant and the thickness changes. The approach was to change the thickness of each feature while maintaining a constant length (3 in) and height (1.5 in). Table 4 tabulates a dimensional description of the features and outlines range thickness. Figure 8 illustrates the geometrical shape and the dimensions of the features examined in this study.

5.1 Case I: Web structure

A web is a freestanding feature that is constrained only at the bottom. The web thickness is constant and much smaller than the other 2 dimensions. Fig. 2 represents a web. A turbine propeller fin and heat sinks are examples of a web feature.

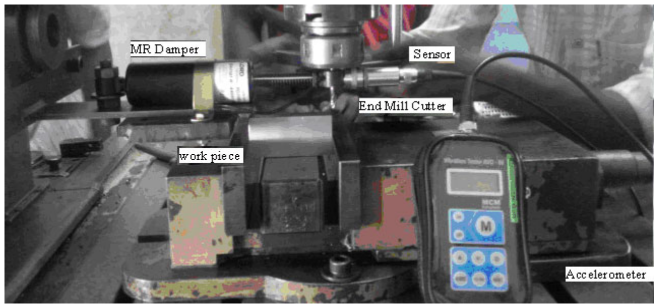


Fig. 7 Experimental Setup

Table 4 Dimension thickness Ranges of two features examined

Range of thickness	
Case 1 (Web)	0.050 in - 0.100 in
Case 2 ("I" Structure)	0.050 in - 0.070 in

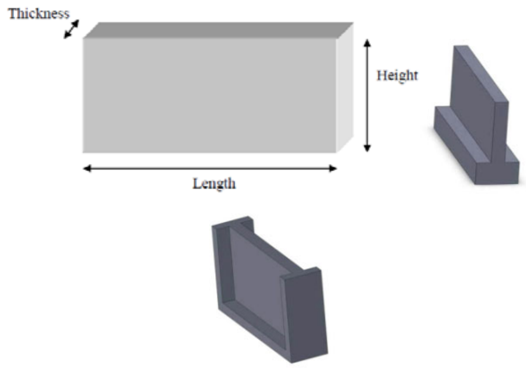


Fig. 8 Geometric shape and dimensions of work pieces web structure and I Structure

5.2 Case II: "I" Structure

A wall is a feature that is constrained at the bottom and on two opposing sides. The wall's thickness is constant and much smaller than the other two dimensions. A wall is an example of a portion of box. There are two different geometric end-mills for this tool selection process. The two main end-mills used in milling are standard solid HSS and carbide end mills. However, the standard geometry is limited by the features geometry and other variables, in order to maintain stability during machining thin features.

The following are the equipments used during the experiment as shown in Fig. 7. A typical millimeter may include features such as the ability to measure voltage, current and resistance. A millimeter can be a hand-held device useful for basic fault finding and field service work or a bench instrument which can measure to a very high degree of accuracy. They can be used to diagnose and find electrical faults in automotive and home electrical circuits, appliances, electronic devices and light switches. A digital multi-meter is a small handheld device with a digital display and two probes. The probes are insulated lead wires with metal tips. They are used to touch different parts of a circuit and test it. The results are displayed on the digital readout. A digital multi-meter has its own power source. They can test for

Table 5 Material Properties and dimensions used in the web

Material	7075-T6 aluminum
Elastic Modulus	10.4 Giga psi
Shear Modulus	3.92 Giga psi
Mass Density	0.0975
Poisson's ratio	0.33
Length	3 in
Height	1.5 in
Web thickness	0.050 in 0.075 in 0.088 in 0.100 in
"I" structure thickness	0.050 in 0.070 in 0.075 in
Wall thickness	0.020 in 0.025 in 0.030 in 0.050 in

continuity, voltage, amps, and ohms. Vibration tester AVD 80 model is used to measure the acceleration, velocity and displacement of the tool. Vibration Tester AVD-80 Micro controller based has been designed as simple diagnostic tool for preventive maintenance. All three useful measurements are possible. Displacement, velocity and acceleration modes allow a user to perform basic vibration analysis. Vibration measurements (in terms of RMS velocity in mm/s. Pk-Pk and Acceleration in m/s^2 RMS, Pk-Pk and Displacement in um RMS. Pk-Pk). The magnetic probe is attached to the rotating tool covered by an assembly provided to prevent the probe from abrasion. Thus, the 3 main parameters which are helpful in vibration analysis can be measured. The technical data includes displacement measuring range from 0.1 to 2828 um peak ot peak, acceleration measuring range 0.1 to 199.9 m/s^2 Peak -PK, True RMS, velocity measuring range 0.1 to 199.9 mm/s True RMS, PK-PK, Resolution 0.1mm/s, vibration transducer is piezo electric type accelerometer.

6. Experimental Procedure

This paper involves the experimental study on surface finish of different materials such as aluminum and mild steel. A block of aluminum or mild steel is taken and is cut in to a desired dimension of 76 x 38 x 19 mm. It is then machined on milling machine using a 6 mm end mill cutter in regular passes. By applying certain constraints, T structure and web structures are finished. These blocks are refined by down milling process. Milling cutters used for the experimental work was HSS and carbide having two and four flutes with shank diameter 6 mm. The Universal Milling Machine (UMM) is used for machining. In this experimental work the following are the factors considered (1) Speed, (2) Depth of cut (3) Damper input current. The Response is (A) displacement and (B) run out.

The test material is of length 78 mm, breadth 38 mm and thickness 19 mm, composed of aluminum and mild steel. A 6 mm end mill cutter HSS and carbide tools is fixed on UMM with the help of a collets. Work piece is fixed on the table with the help of fixtures and clamps. Parallelism and straightness of the fixture is examined and set with the help of dial indicator. For testing the perpendicularity of the work piece, a tri square is used. Damper assembly is attached to the head of the machine with the help of nuts and bolts. The damper assembly comprises of clamps, T-Shaped welded plate to support the damper and bearings to hold the tool. Tool is inserted through an end of the damper. Vibration tester is attached to that end of the damper. Dial indicator is attached such that the stylus makes contact with the rotating tool. After the whole assembly of the equipment, at different speeds, depth of cuts, current, values of acceleration, velocity, tool deflection, and run out are measured. Eventually, surface roughness values and micro structures were examined.

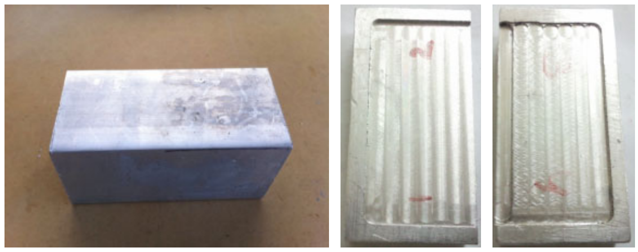


Fig. 9 Raw Aluminum Block and Aluminum blocks after machining

Table 6 Factorial levels considered in RSM

Factor levels	-2	-1	0	1	2
Spindle speed, N (RPM)	200	250	350	400	500
Feed rate, f (mm/min)	65	65	65	65	65
Depth of cut, d (mm)	0.1	0.2	0.3	0.4	0.5

7. Response Surface Method

Response surface modeling was used to establish the mathematical relationship between the response (Yu) and the various process parameters. The general second order polynomial response surface mathematical model, which analyses the parametric influences on the various response criteria, can be described as follows

$$Y_u = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{j>1}^{k} b_{ij} x_i x_j \quad (1)$$

Where Y_u is response and xi (1, 2, k) are coded levels of k quantitative variables. The coefficient b_0 is the constant term; the coefficients b_i, b_{ii}, and b_{ij} are the linear, quadratic, and interaction terms. After logarithmic transformation the nonlinear form of Eq(1) was converted into a linear form, which then was used to develop response surface regression model. To establish the prediction model, a software package Minitab was used to determine the coefficients of mathematical modeling based on the response surface regression model.

S = 0.559017 PRESS = 10,
R-Sq = 99.73% R-Sq(pred) = 98.91% R-Sq(adj) = 99.52%

S = 1.40008 PRESS = 83.7994,
R-Sq = 87.06% R-Sq(pred) = 70.88% R-Sq(adj) = 81.61%

With out damper
The regression equation for displacement:
$Y = 236.514 + 143\, X_0 - 7.55\, X_1 + 0.050\, X_2$
$- 105.556\, X_0 * X_0 + 0.060\, X_1 * X_1$
Y = Displacement μm, X_0 = Depth of cut mm,
X_1 = Feed rate mm/min, X_2 = Spindle speed RPM

Table 7 Estimated Regression Coefficients for displacement without MR damper

Term	Coefficient	SE Coefficient	T	P
Constant	236.514	181.97	1300	0.230
Depth of cut	143.889	9.146	15.732	0.000
Feed rate	-7.550	5.819	-1.297	0.231
Spindle speed	0.050	0.009	5.436	0.001
Depth of cut *Depth of cut	-105.556	12.930	-8.164	0.000
Feed rate *Feed rate	0.060	0.047	1.289	0.233
Spindle speed *Spindle speed	0.000	0.000	-5.586	0.001

Table 8 Estimated Regression Coefficients for displacement with MR damper

Term	Coefficient	SE Coefficient	T	P
Constant	217.209	358.679	0.606	0.552
Depth of cut	-58.185	17.985	-3.235	0.004
Feed rate	-5.833	11.433	-0.510	0.616
Spindle speed	-0.028	0.018	-1.530	0.142
Damper Input current	-7.267	1.213	-5.993	0.000
Depth of cut *Depth of cut	89.630	25.404	3.528	0.002
Feed rate *Feed rate	0.047	0.091	0.510	0.616
Spindle speed *Spindle speed	0.000	0.000	1.144	0.267
Damper Input current *Damper Input current	1.604	0.572	2.807	0.011

With damper

The regression equation for displacement:

$$Y = 217.209 - 58.185\, X_0 - 5.833\, X_1 - 0.028\, X_2 - -7.267\, X_3 + 89.630\, X_0 * X_0 + 0.047\, X_1 * X_1 + 1.604\, X_3 * X_3$$

Y = Displacement µm, X_0 = Depth of cut mm,

X_1 = Feed rate mm/min, X_2 = Spindle speed RPM,

X_3 = damper input current Amps

8. Results and Discussion

The experiment has been performed on various EN steel and aluminum specimens under varying parameters according to the design of experiments. The aim of study is to predict the effects of cutting parameters on the variations of speed and depth of cut during end milling operation of EN steel and aluminum. In recent trends of manufacturing industry, the high speed machining, especially high speed milling plays an important role. Few examples are the fabrication of moulds and aerospace industry, where large amount of material are removed from a large structure. The milling process is most efficient, if the material removal rate is as large as possible, while maintaining a high quality level. The most critical limitations in machining productivity and part quality are the occurrence of the instability phenomenon called regenerative chatter. The chatter is a self excitation phenomenon occurring in machine tools, in which the cutting process tends to decrease the machine structural damping ending with an unstable behavior. It results in heavy vibrations of the tool causing an inferior work piece.

Table 9 Comparison of Ra Values with and without damping effect

Material	Tool	Section	Without Damper Ra	With Damper Ra
Aluminum	4 –Flutes HSS	Web	0.8	0.4
		I-Section	1.3	0.9
	2 –Flutes HSS	Web	1.68	0.56
		I-Section	2.71	1.56
Mild steel	4 –Flutes CARBIDE	Web	2.82	1.82
		I-Section	1.56	1.02

4F Without damper 100x (Al)	4F WD With damper 100x (Al)	2 Flute without damper 100x (Al)	2 Flute with damper 100x (Al)

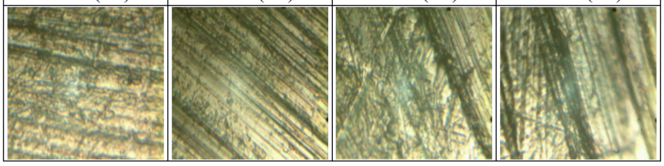


Fig. 10 Microstructures of work piece

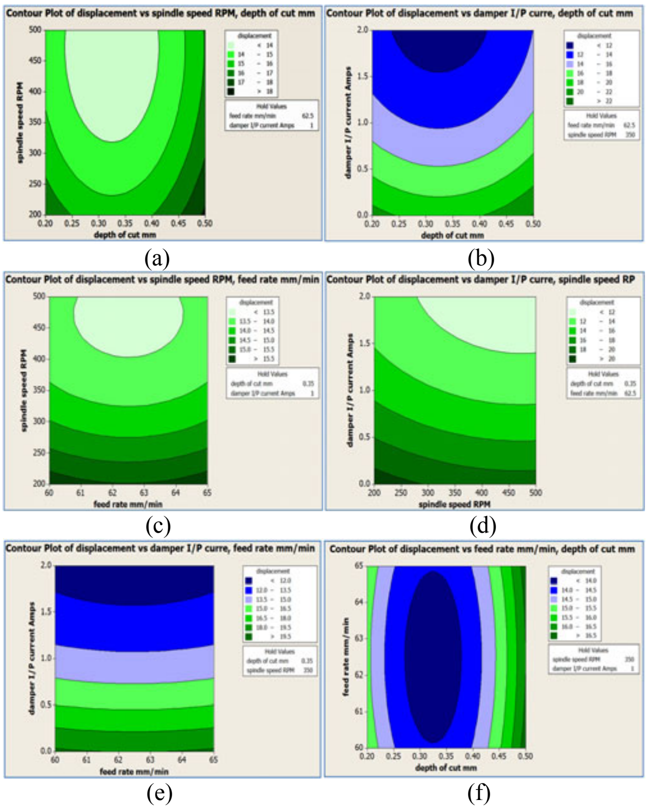


Fig. 11 Counter plots for 2 Flute HSS tool and Al Work Piece with damper

9. Experimental Surface Roughness Values Obtained from Talysurf

Displacement of the end mill cutter observed to be less than 14 µm at in between 300 to 500 RPM at various depth of cut as shown in Fig. 11(a), the displacement of the cutter reduces as the input current to the damper increases for 0-2 Amps at different depth of cuts as shown in Fig. 11(b), it was observed that at higher speed and different feed rates displacement of the cutter decreases as observed

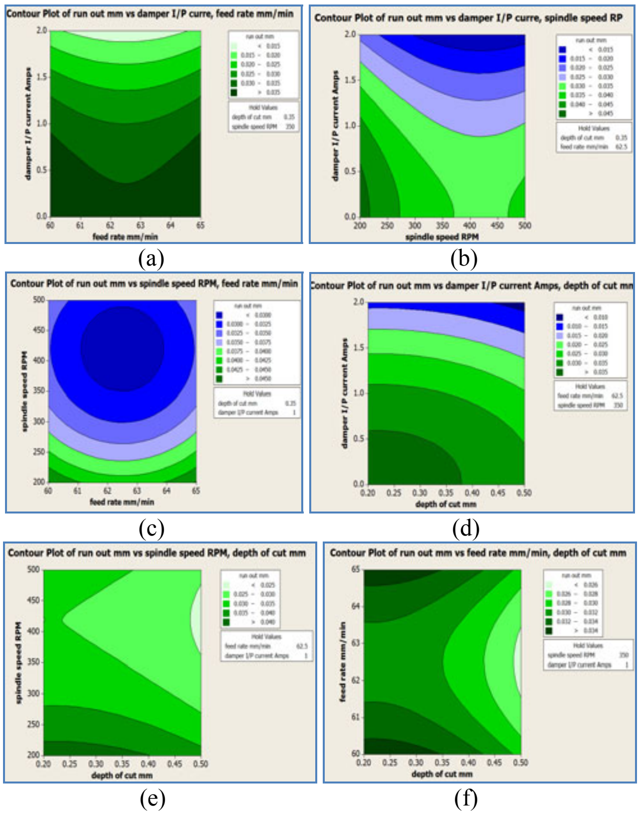


Fig. 12 Counter plots for RUN OUT in 2 Flute HSS tool and Al Work Piece with damper

in Fig. 11(c).

Displacement of the end mill cutter observed at varies speed while varying input current Fig. 12(a), the displacement of the cutter reduces as the input current to the damper increases for 0-2 Amps, Fig. 12(b), it was observed that at higher speed and different feed rates displacement of the cutter decreases as observed in Fig. 12(c).

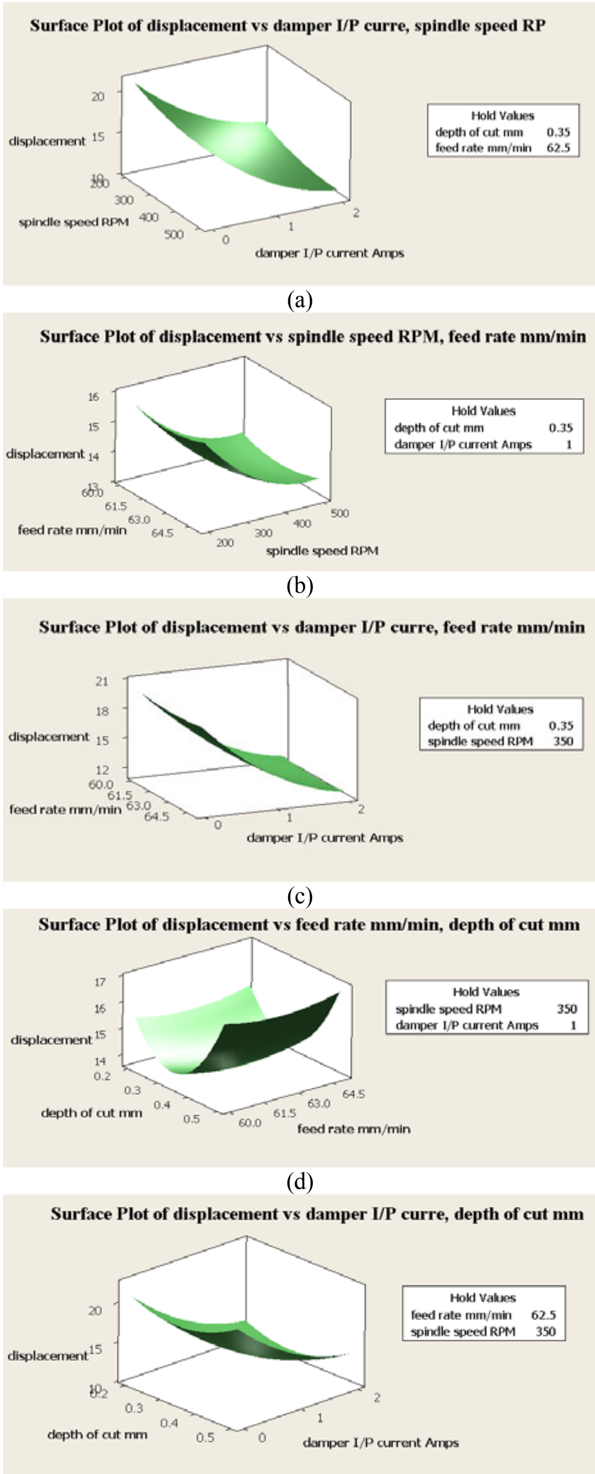
The RUN OUT measured from the experimental data, by varying the damper input current ranges from 0 Amps to 2 Amps at depth of cut 0.35 mm and spindle speed 350 RPM, the RUN OUT of the cutter is less than 0.015 mm. For 500 RPM and the varying feed rate, the runout is observbed to be less than 0.025 mm. The Run out of the cutter is considerably reduced and is less than 0.01 mm for a depth of cut of 0.5 mm. The R_a value for 500 rpm at 0.5 depth of cut and feed rate 63 mm/min with damper is 0.4 µm and for without damper is 0.8 µm.

10. Maximum Material Removal Rate

The maximum material removal rate is given in table for different machining parameters, it is observed from the experimental data material removal rate is increased for various depth of cuts by incorporating MR Damper.

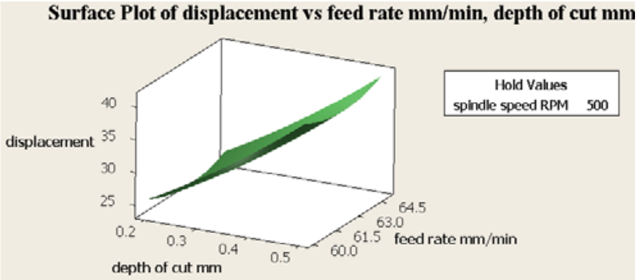
11. Power Spectral Analysis

In the previous section, we showed that monitoring of displacement of the cutter during cutting process plays an important role in detection of chatter in milling operations. The power spectra Analysis has been carried out in the range from 1.0 to 1.0 kHz. Fig. 16 shows the power spectra of the displacement of the cutter obtained in stable machining and when chatter occurred the spindle rotation, and feed were 500 rpm, and 0.5 mm depth of cut. From the Power spectral analysis it was observed that the vibration of the cutter is suppressed during machining for higher depth of cut.

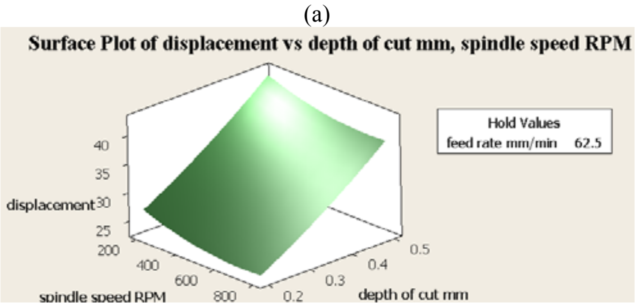


(e)

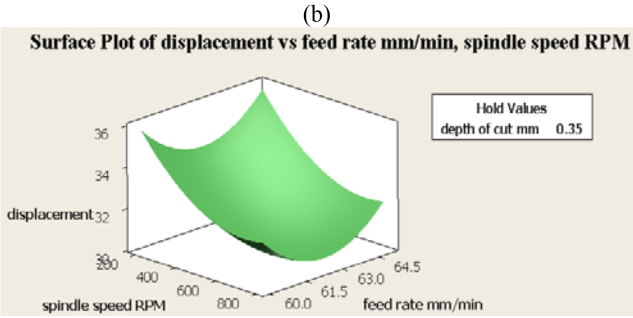
Fig. 13 Surface plot for 2 Flute HSS tool and Al work piece with damper



(a)

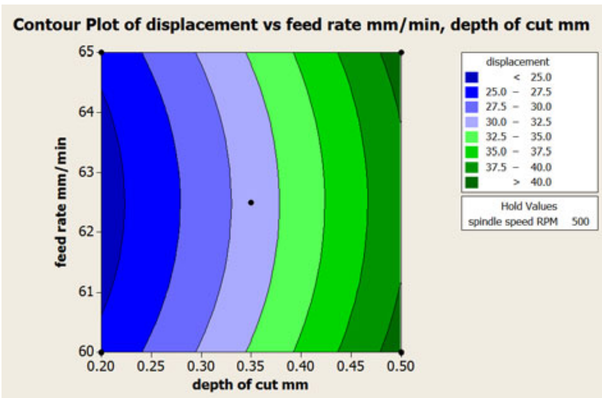


(b)

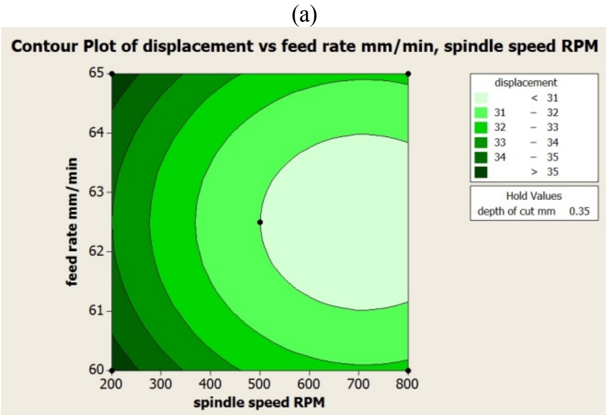


(c)

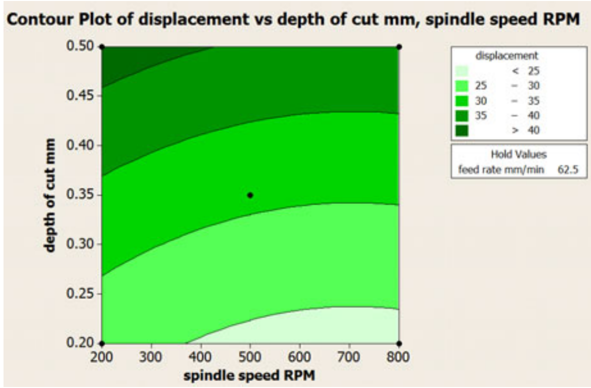
Fig. 14 Surface plot for 2 Flute HSS tool and Al work piece without damper



(a)



(b)

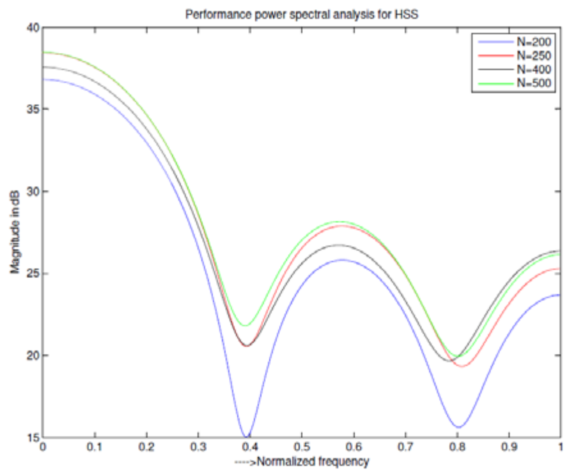


(c)

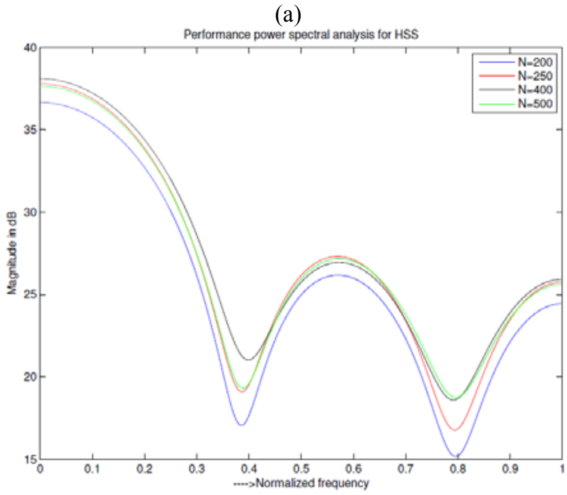
Fig. 15 Counter plots for 2 Flute HSS tool Al work piece with out damper

Table 10 The maximum material removal rate for different machining parameters

Axial Depth of cut - 0.5 mm			Axial Depth of cut - 0.5 mm			Axial Depth of cut - 0.5 mm		
Speed	Feed	MRR	Speed	Feed	MRR	Speed	Feed	MRR
200	65	48.75	200	65	29.25	200	65	19.5
200	63	47.25	200	63	28.35	200	63	18.9
200	60	45	200	60	27	200	60	18



(a)



(b)

Fig. 16 Power spectral Analysis for HSS at various spindle speeds at 0.5 and 0.3 Depth of cut

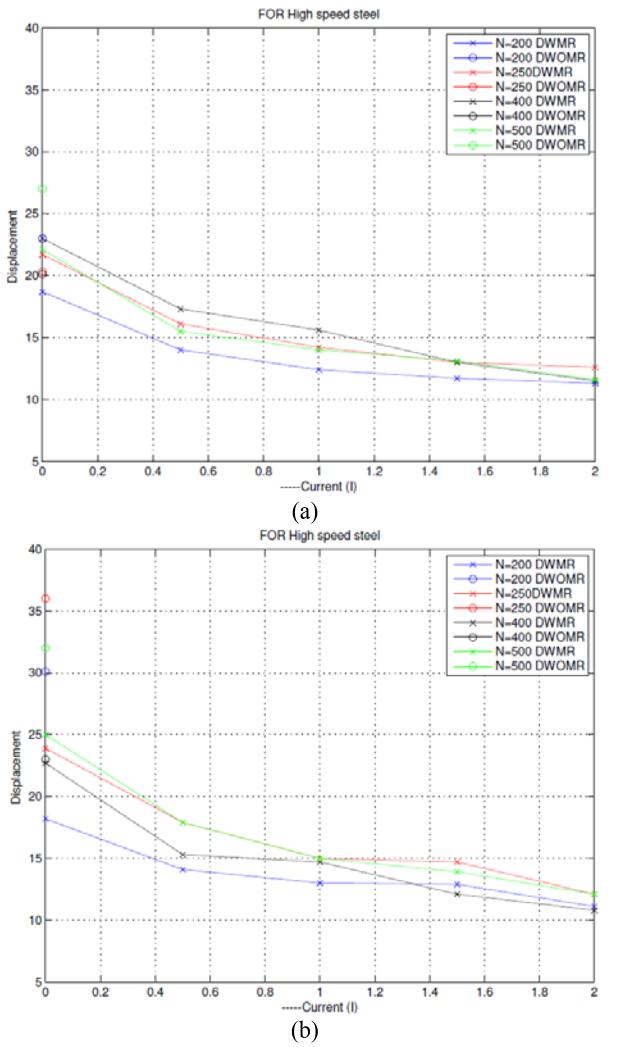


Fig. 17 Comparison of the Displacement of the cutter for HSS tool and 0.3 depth of cut, at various speeds RPM, with and without MR Damper

12. Conclusion

RSM technique has been very successful in designing high-quality products, in it the design horizon is enlarged to all technical and econonomical properties important to the product. The numerous combinations of design parameter settings cannot efficiently be controlled by human judgment, which results in time and cost consuming but can easily be controlled by using DOE techniques. The RSM methods offers a strategy for finding optimal, stable results based on a predefined set of analyzed parameter combinations. Design of experiment is expected to gain more accurate answers on system behavior and interaction effects, especially when created on basis of fractional factorial designs. In this paper an approach is proposed for selecting the preferred set of parameters for optimal cutting conditions of End Milling process. The selection criteria for parameters are based on physical measured outputs of machining i.e. surface roughness. The conclusions are derived from the experimental study and can be concluded in the following steps.

1. RSM design of experiment techniques can be efficiently used in the optimization of machining parameters in end milling process in order to enhance the surface finish of the machined surface.
2. Optimum parameter setting for surface roughness is obtained at a cutting speed of 500 rpm, feed rate 63 mm/min and depth of cut 0.5 mm.
3. Formulation of equation is done with the help of which displacement of the cutter and run out can be predicted.
4. Contour and surface plots obtained through this study can be used as standard for selecting parameters for desired surface finish.

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