STUDY OF THE EFFECT OF MACHINING PARAMETERS ON END MILLING CUTTING FORCE OF HARDENED 65 MANGANESE STEEL

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Abstract: Manganese steel being the toughest steel commercially available is widely used in railroad rails, rock crushing machinery etc. It is characterized with high strength, ductility, toughness and excellent wear resistance in the most punishing application as well as quick work hardening. This properties makes it one of the difficult to machine materials because its machinability is usually accompanied with low productivity occasioned by high cutting force, high cutting temperature, poor surface quality and short tool life. Accordingly, the use of convectional cutting fluid is a common technique for improving machinability and has been acknowledged since early 20th century. However the environmental and health hazard associated with these cutting fluids together with developing governmental regulations have necessitated for green manufacturing system of production. In view of the above, the main work of this paper include the investigation of the effect of the machining parameters like speed, feed and depth of cut on the cutting force in the end milling of hardened 65 Manganese steel (45 HRC), with carbide end mill, under dry cutting process, using one factor at a time design of experiment (DOE). With the aid of Origin pro 8.0 software, the graphical representations of the performance indices with respect to the input parameters was presented and Response Surface Methodology (RSM) was used to analyze the performance of these parameters in respect to the cutting force. The results of Analysis of variance (ANOVA) shows that Depth of cut was the most influential factor. Accordingly, within the range of values selected for the test, the parameters were optimized and the empirical formula for the cutting force was established.

Keywords: Cutting Force, Empirical Formula, Surface Roughness, Anova, Doe, Rsm.

I. INTRODUCTION

Machining remains the most important types of forming. However, this method of production has changed significantly over decades, with cutting process requirements becoming more stringent. Product of impressive quality are expected to be achieved with individual machining operations while remaining cost-effective and sustainable. Detailed knowledge of the cutting process is indispensable in actually meeting these requirements. The acting forces and torques which are essential prerequisites for drawing conclusion about the technology and cutting parameters are important indicators here. These forces can be only be measured and analyzed with sophisticated sensor solution.[1] Dynamic change in cutting force is one of the major sources causing the vibration in cutting process by which the machining accuracy is detoriated, Thus accurate modeling of cutting force is necessitated for the prediction of machining performance and to determine the mechanism and machining parameters that affect the stability of machining operations.[2]

Accordingly, Response Surface Methodology (RSM), which is a collection of mathematical and statistical technique that are useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objectives is to optimize the response. RSM also quantifies the relationship among one or more measured responses and the vital input factors. [2]

II. EXPERIMENTAL DETAILS

2.1. Working Material

Manganese steel was discovered by Hadfield in 1882 and since then it has become one of the most important steels where Erosion of components takes place by continued abrasion impact. Manganese steels are universally known as the most useful abrasion resistant material. It is characterized with good metallurgical quality such as high purity and uniformity, good surface quality by strictly controlling surface defect and decarburization, good mechanical properties especially on elastic limit, strength limit and tensile ratio, as well as accurate shape and dimension. The product is a common spring steel with extensive applications. It is mainly used in the manufacture of cushion spring, clockwork spring, oil pump speed adjusting spring, plunger spring, absorber spring, clutch spring and brake spring etc. Manganese steel is classified as difficult to cut material due to the 11% to 14% manganese content. It work hardened very quickly because it's high elastic and plastic deformation property [5]

The work piece of 150mm by 80mm by 50mm was hardened to 45HRC by the use of heat treatment (heating quenching and normalizing). The chemical composition of the work piece is as shown in table 1 below.

2.2. Cuttingtool

Carbide end mill was employed throughout the experiment. It is selected because of its Suitability in ma-

chining hard materials like carbon steel and stainless steel as well as its desirability in high production line, because it produces better surface finish, and allows faster machining with no or little wear. It can also with stand higher temperature when compared with standard high speed steel cutting tools. The material is usually called cemented carbide, hard metal or tungsten-carbide cobalt, because its matrix comprises of aggregate of tungsten carbide particle with metallic cobalt. [3]

2.3. Experimental set-up

2.3.1Design of Experiment (DOE)

This presents the method and techniques employed in designing and implementing the experiment. The machining experiment was carried out using FNC 86 milling machining center. One factor at a time DOE was employed, and three cutting parameters (Speed, feed and depth of cut) were selected. Also, cutting force was measured as performance characteristics throughout the experiment. The DOE, adopts five levels of each cutting parameter and the cutting force (Axial, Radial and Tangential) was measures using Kistler Dynamometer. i.e 5×5×3= 75 iterations as shown below:

Table 1. Machining parameters and levels

Parameters	Unit	Levels				
		1	2	3	4	5
Spindle speed	RPM	600	700	800	900	1000
Feed rate Depth of cut	mm/Rev mm	24 0.01	56 0.02	96 0.03	144 0.04	200 0.05

2.3.2Cutting Force Measurement: A three component Kistler dynamometer type 2825D-02, with charge amplifiers was used along with computer to measure and record cutting forces. The three cutting parameters were programmed using G-code and inputted into the CNC machine, varying one variable at a time. Accordingly, In the DynoWare software (an interface that connects the Computer and the dynamometer hardware), a maximum of 30 seconds were selected as measuring time frame for cutting, while all other settings remain default. Feed Force (Fx), Radial Force (Fy) and Tangential Force (Fz) were measured and recorded. The set-up is as shown below:



Figure1: Dynamometer Set-Up

III. EXPERIMENTAL RESULTS

Table 2. Design matrix and experimental results for cutting force

N	V	F	D	CUTTING FORCE(N)			
				Fx	Fy	Fz	Fr
1	600	24	0.01	50.38	41.72	156.93	170.02
			0.02	51.01	52.38	148.78	165.77
			0.03	38.08	27.89	170.49	176.9
			0.04	24.85	20.67	198.7	201.31
			0.05	29.06	18.13	237.56	240.02
2	700	56	0.01	56.15	52.76	139.3	159.19
			0.02	50.91	46.49	155.42	170.03
			0.03	44.16	40.46	178.25	188.04
			0.04	34.74	31.12	208.34	213.5
			0.05	33.52	29.62	209.88	214.6
3	800	96	0.01	40.68	34.31	130.5	140.93
			0.02	50.36	47.43	122.04	140.28
			0.03	44.43	42.43	134.91	148.24
			0.04	33.92	34.94	161.01	168.21
			0.05	29.84	31.57	174.53	179.85
4	900	144	0.01	40.36	34.94	148.2	157.52
			0.02	50.34	46.91	137.7	153.93
			0.03	45.59	44.07	138.89	152.68
			0.04	31.88	36.48	169.16	157.96
			0.05	26.03	29.74	193.51	197.5
5	1000	200	0.01	53.01	51.25	132.77	151.87
			0.02	49.04	46.97	138.36	154.13
			0.03	38.26	38.31	156.93	166.01
			0.04	25.31	31.51	189.96	194.21
			0.05	33.53	32.68	189.42	195.12
1	600	24	0.01	57.71	49.41	121.3	143.13
		56		51.33	48.87	164.57	179.18
		96		45.46	45.15	155.94	168.59
		144		56.27	50.73	173.34	189.17
		200		58.8	51.54	146.51	166.07
2	700	24	0.02	49.01	40.9	140.43	154.26
		56		10.26	20.77	294.28	295.19
		96		35.85	44.48	178.47	187.39
		144		49.01	34.81	186.87	196.3
		200		52.4	43.54	160.89	174.72
3	800	24	0.03	32.14	38.6	189.63	196.17
		56		37.84	52.08	153.46	166.42
		96		34.34	58.13	171.26	184.09
		144		32.89	57.86	167.14	179.9
		200		39.81	60.52	149.26	165.91
4	900	24	0.04	39.4	52.27	183.27	194.62
		56		33.32	63.35	210.43	222.27
		96		41.56	59.54	154.3	170.53
		144		35.22	60.47	161.39	175.91
		200		32.32	59.5	154.63	168.81
5	1000	24	0.05	49.3	54.1	159.11	175.14
		56		28.57	61.88	225.1	235.19
		96		30.6	62.14	194.68	206.64
		144		32.35	52.66	142.67	155.48
		200		31.92	57.1	147.17	161.05
1	600	24	0.01	57.76	54.43	99.82	127.53
	700			56.42	53.38	96.7	124.03
	800			56.88	52.72	97.63	124.69
	900			56.51	52.84	98.95	125.6
	1000			54.87	50.57	114.43	136.61
2	600	56	0.02	41.66	49.9	158.78	171.57
	700			43.3	53.45	166.73	180.36
	800			48.47	52.82	155.87	171.57
	900			49.61	55.25	168.4	184.04
	1000			52.19	56.13	148.54	167.15
3	600	96	0.03	37.96	47.41	228.7	236.63
	700			32.79	57.08	187.3	198.53
	800			38.53	58.24	148.9	164.46
	900			38.7	60.38	191.15	204.16
	1000			37.74	61.19	188.87	202.09
4	600	144	0.04	30.81	46.24	215.61	222.66
	700			38.11	64.25	177.15	192.26
	800			39.93	62.33	155.34	172.07
	900			38.77	63.35	150.18	167.54
	1000			16.97	59.14	202.06	211.22
5	600	200	0.05	13.66	32.86	219.96	222.82
	700			13.11	54.5	201.46	209.11
	800			22.56	61.22	182.29	193.61
	900			33.42	56.39	191.22	202.14
	1000			14.14	55.86	187.47	196.13

Figure 2: Graphical Representation Of Cutting Force

3.1. Data Analysis

3.1.1Graphical RepresentationCutting force Vs DOC, Feed and Spee

3.1.1.1Interpretation

looking at Table 2 as well as figure 2, it can be observed that the tangential cutting force (Fz) is the main cutting force, characterized by higher magnitude, followed by the axial (Fx) and lastly the radial (Fy). Accordingly, DOC and Feed, relates directly proportional to the Main cutting force, while speed is inversely proportional to the main cutting forces. The

resultant cutting force (F_r) is given by the expression: $Fr = \sqrt{[(Fx)^2+(Fy)^2+ (Fz)^2]}$.

3.1.2 Analysis of Variance (ANOVA)

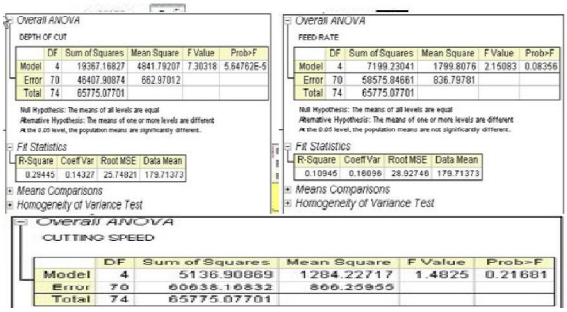


Figure 3: Analysis Of Variance

3.1.2.1Interpretation

Looking at the three tables, the interpretation of ANOVA shows that at 95% confidence (α=0.05)i.e when P-Value is less than or equal to 0.05, all the three cutting parameters are found to be relevant in the cutting process. However, depth of cut possesses the most significant effect on cutting force, followed by the Feed. Accordingly, an increase in the spindle speed with a decrease in feed and depth result to smaller cutting force which in turn leads to low cutting temperature and tool wear.

3.1.3 Main Effect Plot

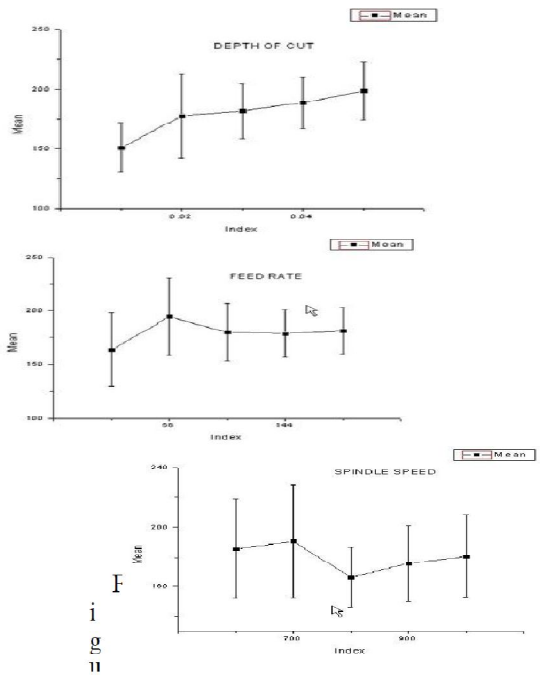


Figure 4: Main Effect Plot

3.1.3.1Interpretation

From Figure 4, it can be observed that the best DOC needed for optimum cutting is the 0.01mm. This is because it produces the minimum mean for the cutting force. Similarly, 24 mm/Rev is the optimum feed. Accordingly, 800 RPM is the optimum spindle speed needed for the cutting, as shown by the main effect plot.

IV. ESTABLISHMENT OF EMPERICAL FORMULAR FOR END MILLING FORCE

4.1Introduction: The forces acting on a tool and the workpiece are called cutting forces. In the cutting process, cutting forces directly influence the generation of cutting heat and further influences tool wear, tool life and the quality of the machined surface. In production, cutting forces are the important basis for the calculation of cutting power and for the design and application of machine tools, cutting tools and fixtures. [6]

To establish empirical formulas, a single factor method and a multi factor method can be used. As far as this paper is concern, the single factor method was adopted. In this method, the cutting force is measured under condition in which only one of the factor is varied at a time and the others are kept fixed, then the empirical formulae for cutting force can be established while dealing with the data measured. The regular forms of empirical formulae of cutting force is as follows;

$$F_r = C_{f_r} a_p^{X_{f_r}} f^{Y_{f_r}} V_n^{Z_{f_r}} K_{fr} \qquad (1)$$

Splitting equation (1), we get

$$F_r = C_{ap} a_p^{X_{f_r}} K_{fr1} \qquad (2)$$

$$F_r = C_f f^{Y_{f_r}} K_{fr2} \qquad (3)$$

$$F_r = C_v V_n^{Z_{fr}} K_{fr3} \qquad (4)$$

Update Table

	A	B	C	D
1	Equation	y = a*x^b		
2	Adj. R-Square	0.54609		
3			Value	Standard Error
4	CUTTING FORCE	a	426.24006	141.07528
5	CUTTING FORCE	b	0.22264	0.09314

Where C_{ap}, C_f and $C_v$are the effect coefficients whose values are related to experimental conditions;

X_{f_r},Y_{f_r} and Z_{f_r} are effect indices of back engagement of the cutting edge (a_p), Feed (f) and Spindle speed V_n on the cutting force.

K_{f_r} Is the correlation coefficient on the cutting force due to difference between calculation condition and experimental condition. [6]

For example, considering the establishment of empirical formula for resultant cutting force (F_r), with a series of experimental values fora_p-F_r , f -F_r and V -F_r, we can link this pint to two straight lines in the

dual logarithm charts and the straight line equations are

$$\lg F_r = \lg C_{a_p} + X_{f_r} \lg a_p \quad (5)$$

$$\lg F_r = \lg C_f + Y_{f_r} \lg f \quad (6)$$

$$\lg F_r = \lg C_v + Z_{f_r} \lg V \quad (7)$$

Equating equations 1 and 2;

$$C_{fr} a^{X_{fr}} f^{Y_{fr}} V_n^{Z_{fr}} K_{fr} = C_{ap} a^{X_{fr}} K_{fr}$$

$$C_{fr1} = C_{ap} / [f^{Y_{fr}} \times V_n^{Z_{fr}}] \quad (8)$$

Accordingly, equating equations 1 and 3;

$$C_{fr2} = C_f / [a_p^{X_{fr}} \times V_n^{Z_{fr}}] \quad (9)$$

Finally, equating equations 1 and 4;

$$C_{fr3} = C_v / [a_p^{X_{fr}} \times f^{Y_{fr}}] \quad (10)$$

Hence, X_{f_r}, Y_{f_r} and Z_{f_r} are the slopes and C_{ap}, C_f and C_v are the intercept of a_p-F_z, f -F_z, V -F_r, straight line on ordinate respectively.

Looking at equation (2), (3) and (4), they all comply with Allometric form i.e Y = Ax^B where;

A represent (C_{a_p}, C_f or C_v) as the intercept and B represents (X_{f_r}, Y_{f_r} or Z_{f_r}) as the slope of the equation and $Fr = \sqrt{[(Fx)^2+(Fy)^2+(Fz)^2]}$, is the resultant force.

For the purpose of this study, the spindle speed which has less influence on the cutting force as shown by the Anova table, would be neglected in the derivation of the empirical formula. Therefore, C_v and Z_{f_r} are equal to zero.

Allometric Curve fitting for Resultant Force(Fr)

- For varied DOC

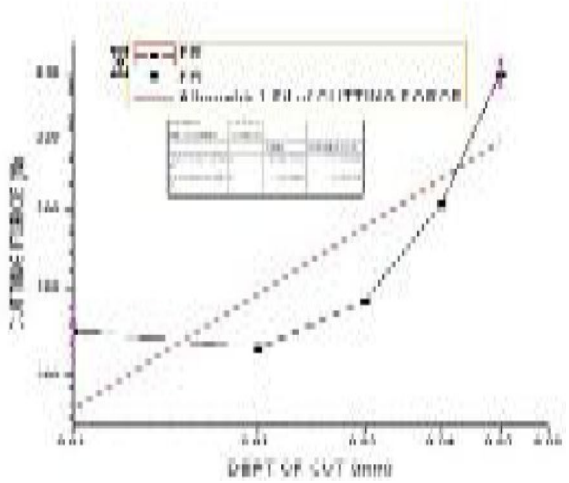


Figure 5: Allometric Curve Fitting For Varied DOC

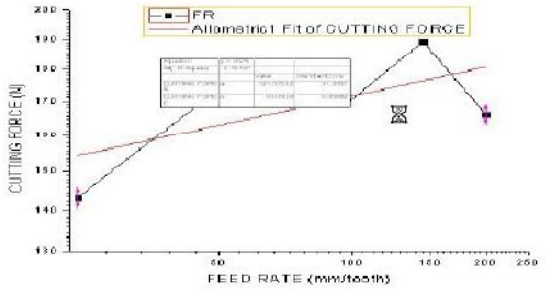
From the table, intercept (a) = 426.24006 and slope (b) = 0.22264, substituting into equation (8), we have;

C_{fr_1} = 426.24006 / [$0.01^{0.22264}$]

= 1188.3223

Where f = F/ (n*V) and F is the feed rate in mm/rev, n is the no. of tooth and V is the spindle speed in RPM. Hence, f = 24/ 4*600 = 0.01mm/tooth.

- For Varied feed



Update Table

	A	B	C	D
1	Equation	y = a*x^b		
2	Adj. R-Square	0.18127		
3			Value	Standard Error
4	CUTTING FORCE	a	121.37532	31.3567
5	CUTTING FORCE	b	0.07508	0.05682

Figure 6: Allometric Curve Fitting For Varied Feed

From the table, intercept (a) = 121.37532 and slope (b) = 0.07508, substituting into equation (9), we have;

C_{fr_2} = 121.37532/ [$0.01^{0.07508}$]

=171.5104

C_{f_r} = [1188.3223+171.5104] / 2 = 679.9164

From this, we can say the approximate form of empirical formula is given by;

$\mathbf{F_r = 680\ a_p^{0.075} f^{0.223}}$

Note: The spindle speed is neglected in the derivation.

SUMMARY CONCLUSION

A design system of one factor at a time which was used in this experiment has great impact in determining the most influential factors of experiment as well as finding the best combination of parameters (optimization of cutting parameters). It also has a great impact in the establishment of empirical formula, especially when the formula is a function of some or all the input parameter (Cutting conditions).

A response surface methodology (RSM) used in this research has equally shows efficiency in the analysis of the experimental results. It is a group of mathematical and statistical technique that is useful for modeling the relationship between an input parameters and output variables. It saves cost and time on the conduct of experiment by reducing the overall number of required test. In addition, it helps to describe and identify with great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. .

The RSM was developed using origin pro8.0 software and shows that between the three process parameters (speed, feed and depth), the depth of cut is the most significant factor that determine good performance characteristics (Cutting force). It also shows that while feeds and depth of cut relates directly propor-

tional to the performance characteristics, the speed relates inversely. Accordingly, within the range of values selected for this experiment, the optimum cutting parameters are medium speed (800RPM), low feed (24mm/rev) and low depth of cut (0.01mm) as seen from Main Effect Plot. Finally, the empirical formula developed at constant speed, for the Resultant cutting force is given by

$$\mathbf{F_r = 680}\ a_p^{0.075} f^{0.223}$$

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