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Optimization of Grinding Cycle Time for End Mill Manufacturing

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Abstract— **Productivity improvement is the major challenge in any manufacturing sector. Cycle time plays a key role in productivity improvement. In this connection Experimentation was conducted in end mill manufacturing company. The practical problem formulated when company failed to meet response time of customers when mass production was adopted. The major contributor to this failure was negative variation between the actual time and standard time of end mill grinding. In this paper an attempt is made to reduce this cycle time, by optimizing the parameters affecting cycle time namely feed rate and cutting speed.**

Statistical procedure of design of experiments (DOE) was adopted in optimization of process parameters. Strategically planned and systematically controlled tests help to determine relationship between the response variable and input parameter. The DOE was planned for 2 factors and 3levels. The result of experimentation was analyzed using Analysis of variance (ANOVA) on Minitab v17. It was found that 40% reduction in grinding cycle time could be achieved by optimizing the process parameters.

Index Terms— **Analysis of Variance (ANOVA), Design of experiments (DOE).**

I. INTRODUCTION

End mill is a type of milling cutter, used in industrial milling applications. It is distinguished from the drill bit in its application, geometry, and manufacture. While a drill bit can only cut in the axial direction, a milling bit can generally cut in all directions, though some cannot cut axially. The flat end mills are commonly used in industry for high speed machining. They are characterized by a complex geometry with many geometric parameters, which deals with some complicated processes in machining with grinding CNC machine[7-8].

End mill manufacturing takes place in four major steps namely Fluting, Gashing, End face Gash and OD Eccentric. Fluting: Number of required longitudinal grooves are ground on the Periphery of the cylindrical blank. Gashing: Number of required short angular grooves are ground on the start of flute face. End Face: Number of required longitudinal cutting edges are ground on the Gashed front face. OD Eccentric: Number of required axial cutting edges are ground on the periphery of Fluted outer diameter.

DOE is a systematic method to determine the relationship between factors affecting a process and the output of that process. Steps involved in DOE are planning, screening, optimization, Robustness testing, Verification and perform the actual experiment [9].

The major operating input parameters that influence the output response cycle time are (i) Machine parameters (ii) Grinding wheel parameters (iii) Process parameters (iv) Work piece Parameter [2]. The present work considers influence of the process parameters of feed rate, cutting speed and depth of cut. During the plant study it was found that end mill grinding needed single pass, hence depth of cut is not considered in this study.

This paper demonstrates a systematic procedure of using general full factorial design to analyze process parameters with the objective of reducing cycle time. The experimental detail of using factorial design to determine and analyze the optimal control parameters is described, further in this paper.

II. OBJECTIVES OF THE PROJECT

The aim of this work is to reduce the grinding cycle time in end mill manufacturing by optimizing process parameters namely; cutting speed and feed rate. Hence the main objective put forth is to identify the factors affecting cycle time. The other objectives of the experimental work are:

- To select the major process parameters that will affect cycle time.
- To check the stability of end mill grinding process before optimizing the process parameters.
- To design the experiment for assessing end mill grinding process parameters.
- To optimize selected end mill grinding process parameters.
- To check the stability of end mill grinding process after optimizing the process parameters.

General full factorial method provides statistical and systematic approach in understanding the importance of process parameters. General full factorial method investigates each and every combination of the parameters unlike fractional factorial which studies the parameters with lesser no of experiments

III. EXPERIMENTAL PROCEDURE

Experimentation is conducted on CNC grinding machine in end mill manufacturing. In this experimentation all factors which affect cycle time for grinding of end mill are considered and analyzed by fishbone diagram and is shown in Fig.2.

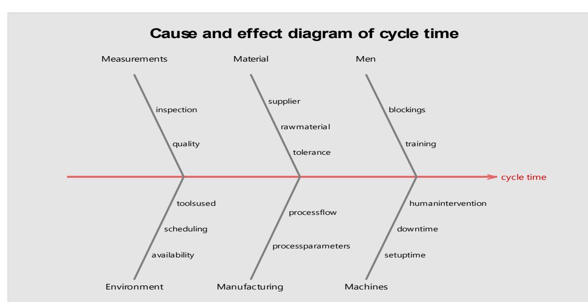

Figure 1

From the fishbone diagram and brain storming session conducted with plant employees the main factors which affect process parameters are found to be feedrate and cutting speed. The DOE plan is setup for two factors and three levels and process is given run the corresponding values of response variable, cycle time are calculated for the chosen values of factors and levels. The required data collected during experiments were analyzed using ANOVA in

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Minitab v17. The randomization of the variables, standard residual, and interactions of the variables were analyzed. The values are drawn from the observation made from the ANOVA analysis carried out, the main effect plot and interaction plots are plotted for the parameters keeping optimum the best combination. Care is taken that no negative deviation in surface finish and other quality issues/ tolerances in end mill manufacturing occurs. After optimizing the parameters the process is given long run with the best combination of optimum parameters and baseline measurements are collected and analyzed with the aid of I-MR chart.

End mill manufacturing consists of five operations in CNC grinding machine namely Flute from solid, Flute polish, End face gash, End face finish and OD Eccentric.

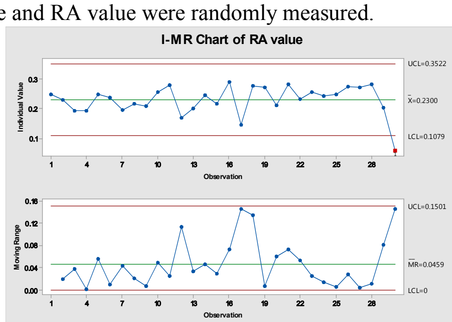
IV. DATA COLLECTION, RESULTS AND ANALYSIS

The aim of ANOVA is to investigate which of the input parameters significantly affect the performance characteristic. In the analysis F-test value was used at 95% confidence level to decide the significant factors affecting the process. Statistically, larger the F value bigger is the effect due to variation in that particular input parameter. ANOVA was applied to test what process parameters were statistically significant.

Five replicates of experiments were conducted on end mill grinding CNC Machine for four different operations such as Flute from solid, Flute Polish, End Face Gash and End Face Finish. These experiments are conducted to determine effect of parameters namely, cutting speed and feed rate on continuous response variable namely cycle time. Analysis of Variance (ANOVA) was then performed on these data using statistical software MINITAB V17.

A) Baseline Measurement before study

The baseline measurements were taken to compute process stability for end mill grinding. This ensures the stability of grinding process before the study. During the general long production run, cycle time and RA value were randomly measured.



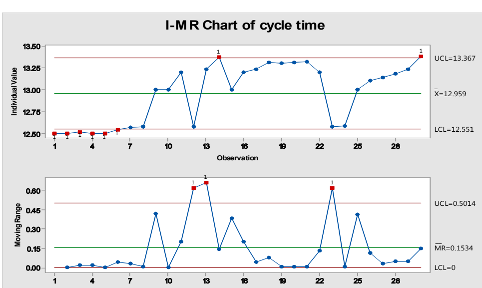


Figure 2 I-MR chart of RA value before study Figure 3 I-MR chart of cycle time before study

The I-MR (Individual-Moving Range) chart shows in Figure 2 and 3 have almost all measurements within the control limits. Hence grinding process is found to be stable with respect to both the output parameter RA value and cycle time.

Results of ANOVA are analyzed operation wise in following section:

Operation	cutting speed	feed rate	Fluting cycle time				
Flute from Solid	16	55	3:51	3:53	3:52	3:51	3:51
		100	3:05	3:07	3:05	3:06	3:06
		140	2:45	2:45	2:46	2:47	2:47
	19	55	3:42	3:43	3:42	3:42	3:44
		100	2:24	2:24	2:26	2:25	2:25
		140	1:52	1:50	1:52	1:50	1:51
	22	55	3:40	3:42	3:41	3:40	3:40
		100	2:24	2:24	2:24	2:23	2:23
		140	1:52	1:50	1:52	1:51	1:51

B) Flute from Solid

Table 1 Flute from Solid

For flute from solid operation data, the figure 3 shows the plot of the fitted means indicate the following:

- **Cutting Speed:** Treatment values of 19 or 22m/s resulted in lesser cycle time than 16 m/s.
- **Feed Rate:** 140mm/rev resulted in least cycle time than 55 and 100mm/rev.

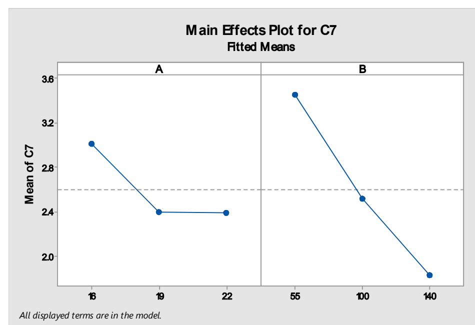


Figure 4 main effect of flute from solid

- The grand mean reference line is drawn at 2.597min.
- By comparing the Slopes of the lines on the plots, relative magnitude of the factor effects can be compared. These plots show that feed rate has the larger effect followed by cutting speed on response variable cycle time.

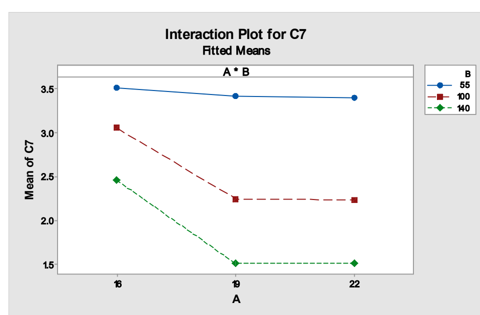


Figure 5 interaction effect of Flute from solid

Figure 4 shows the interaction effect of the flute polish below shows the analysis of the interaction plot:

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➢ When cutting speed changes from 19 to 22 m/s, variation in cycle time doesn't depend on feed rate as the respective plots are parallel.

➢ Decrease in cycle time when cutting speed changes from 16 to 19 m/s depends on feedrate because respective plots depart from being parallel. When feed rate is low (55) change in cycle time is very less with change in cutting speed (from 16 to 19). Whereas reduction in cycle time is maximum with change in cutting speed (from 16 to 19) when feed rate is high (140)

➢ The best combinations of cutting speed and feedrate values from the interaction plot are

Feed rate = 140mm/rev and cutting speed = 19m/s

Feed rate = 140mm/rev and cutting speed = 22m/s

C) Flute Polish

Table 2 Flute polish

Operation	cutting speed	feed rate	Fluting cycle time				
Flute polish	18	120	1:52	1:50	1:51	1:52	1:51
		160	1:42	1:42	1:43	1:44	1:43
		170	1:30	1:32	1:30	1:31	1:32
	20	120	1:48	1:46	1:46	1:47	1:48
		160	1:39	1:42	1:40	1:39	1:41
		170	1:30	1:34	1:36	1:33	1:32
	22	120	1:42	1:44	1:43	1:44	1:42
		160	1:30	1:33	1:32	1:30	1:30
		170	1:26	1:28	1:26	1:28	1:27

For flute polish operation data, the figure 6 shows the main effects of flute polish operation, the plots of the fitted means indicate the following:

- **Cutting Speed:** Treatment value of 22m/s resulted in lesser cycle time than 18 and 20 m/s.
- **Feed Rate:** 170 mm/rev resulted in least cycle time than 120and 160mm/rev.

The grand mean reference line is drawn at 1.3833min.

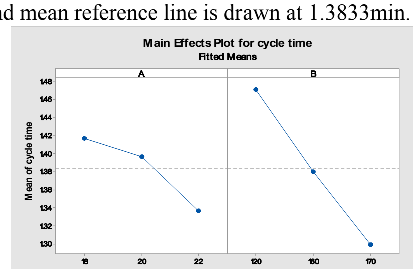


Figure 6 main effect of flute polish

- Based on comparison of the Slopes of the lines on the plots it is concluded that feed rate has the larger effect followed by cutting speed on response variable cycle time.

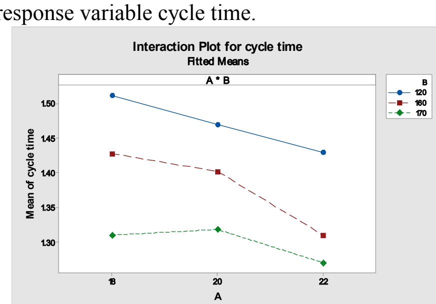


Figure 7 interaction effect of flute polish

Figure 7 shows the interaction effect of the flute polish below shows the analysis of the interaction plot:

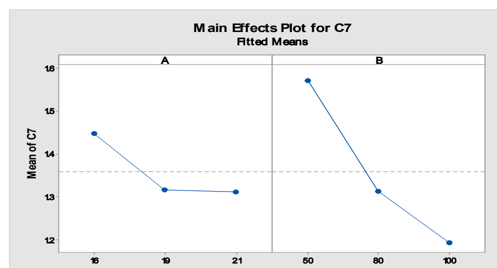
- Decrease in cycle time when cutting speed changes from 18 to 22 m/s depends on feedrate because respective plots depart from being parallel.
- When feed rate is low (120) change in cycle time is high with increase in cutting speed (from 18 to 22).
- When feed rate is 160there is slight change in cycle time with increase in cutting speed from 18 to 20, but change is high when cutting speed changes from 20 to 22 m/s.
- When feed rate is high (170) there is slight increase in cycle time with increase in cutting speed from 18 to 20, but later it decreases when cutting speed changes from 20 to 22 m/s.
- The best combinations of cutting speed and feedrate values from the interaction plot are Feedrate = 170mm/rev and cutting speed = 22m/s.

D) End Face Gash

operation	cutting speed	feed rate	Fluting cycle time				
Endface gash	16	50	1:58	1:58	1:59	2:00	1:59
		80	1:38	1:40	1:41	1:38	1:40
		100	1:27	1:30	1:29	1:27	1:28
	19	50	1:52	1:54	1:53	1:53	1:52
		80	1:28	1:30	1:27	1:27	1:27
		100	1:14	1:16	1:15	1:14	1:14
	21	50	1:50	1:52	1:54	1:50	1:52
		80	1:26	1:28	1:29	1:26	1:25
		100	1:14	1:18	1:16	1:14	1:15

Table 3 End face gash

Figure 8 and 9 shows the main effect plot and interaction effect plot of the end face gash operation.



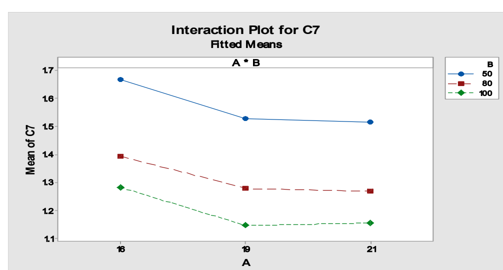


Figure 8 main effect of end face gash

Figure 9 interaction effect of end face gash

In ANOVA table 'P' value is equal to 0 for interaction. Statistically as already mentioned, if P value is greater than 0.05 then that particular factor or interaction is not significant. Hence there is no need to analyze interaction plot. It can be concluded that there is no combined effect of cutting speed and feed rate on cycle time reduction.

E) End Face Finish

Table 4 end face finish

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operation	cutting speed	feed rate	Fluting cycle time				
End face finish	24	120	1:15	1:17	1:18	1:15	1:16
		130	1:12	1:14	1:12	1:13	1:13
		150	1:08	1:10	1:09	1:08	1:09
	26	120	1:18	1:14	1:13	1:12	1:14
		130	1:09	1:09	1:10	1:09	1:10
		150	1:02	1:02	1:02	1:04	1:04
	28	120	1:12	1:12	1:14	1:15	1:16
		130	1:09	1:10	1:09	1:10	1:11
		150	1:01	1:02	1:02	1:04	1:05

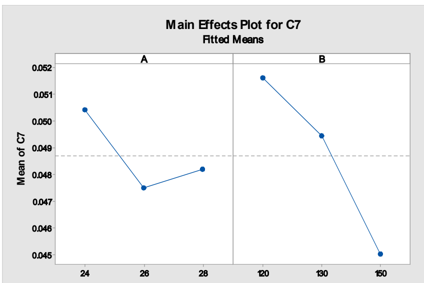


Figure 10 Main effect of end face finish

For end face finish operation data, figure 10 shows the main effect the plots of the fitted means indicate the following:

- **Cutting Speed:** Treatment value of 26 m/s resulted in lesser cycle time than 24 and 28 m/s.
- **Feed Rate:** 150mm/rev resulted in least cycle time than 120and 130mm/rev.
- The grand mean reference line is drawn at 0.04704 min.
- Based on comparison of the Slopes of the lines on the plots it is concluded that feed rate has the larger effect followed by cutting speed on response variable cycle time.

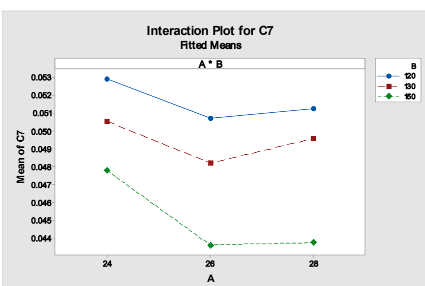


Figure 11 interaction effect of end face finish

Figure 11 shows the interaction effect of the flute polish below shows the analysis of the interaction plot:

➢ Table (ANOVA), indicate that the interaction of cutting speed (A) by feed rate (B) has a P value of 0.054. This means that the interaction is almost significant at 0.05 α-level. The interaction plot in Figure indicates that

➢ There is no interaction between cutting speed and feedrate when cutting speed changes from 24 to 26 m/s and feed rate is low(120 and 130mm/rev).

➢ Reduction in cycle time is high when cutting speed changes from 24 to 26m/s and when feed rate is high(150mm/rev).

➢ Again, there is no interaction between cutting speed and feedrate when cutting speed changes from 26 to 28 m/s and feed rate is low and high(120 and 150mm/rev).

➢ But cycle time increases when cutting speed changes from 26 to 28m/s and when feed rate is moderate(130mm/rev).

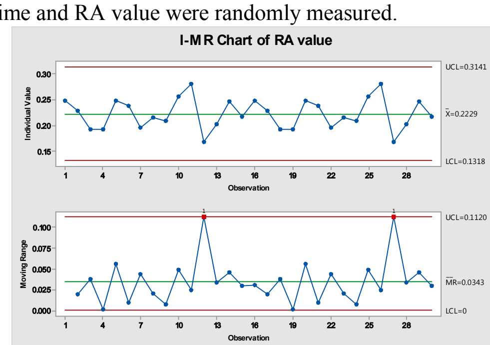
➢ The best combinations of cutting speed and feedrate values from the interaction plot are

Feedrate = 150mm/rev and cutting speed = 26m/s.

Feedrate = 150mm/rev and cutting speed = 28m/s.

F) Baseline Measurement

The baseline measurements were taken to compute process stability for end mill grinding. This ensures the stability of grinding process after the study. During the general long production run, cycle time and RA value were randomly measured.



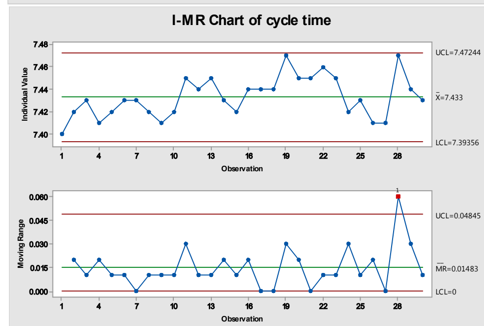


Figure 12 I-MR chart of RA value

Figure 13 I-MR chart of cycle time

The I-MR (Individual-Moving Range) chart shows in Figure 12 and 13 have almost all measurements within the control limits. Hence grinding process is found to be stable with respect to both the output parameter RA value and cycle time.

V. CONCLUSION

Following conclusions are drawn from above study:

➢ Cutting speed and feedrate are the major parameters affecting the cycle time of grinding operation in end mill manufacturing.

➢ Reducing cycle time is the main objective with quality issues keeping intact. From the experimentation the best optimum combination of the parameters:

- Flute from solid is cutting speed 19m/s and feed rate 140mm/rev.
- Flute polish is cutting speed 22m/s and feed rate 170mm/rev.
- End face gash is cutting speed 19m/s and feed rate 100mm/rev.
- End face finish is cutting speed 26m/s and feed rate 150mm/rev.
- OD finish is cutting speed 26m/s and feed rate 140mm/rev.

➢ The parametric improvement relatively is 60% in flute from solid, 30% in flute polish, 50% in end face gashing, 20% in end face finish and 14% in OD eccentric.

➢ On comparing the cycle time before and after optimization it was found that there is 40% reduction in grinding cycle time.

➢ There is increase in daily output of end mill manufacturing from 112pcs to 187pcs.

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