Optimization of Milling Parameters in Face Milling

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***Abstract*–The objective of this paper is to optimize milling process parameter in case of face milling - Metal removal rate on 6061-T6 Aluminium work-piece using Design of Experiments (DOE) and Response Surface Methodology (RSM) and by taking into consideration feed rate, depth of cut and spindle speed as input parameters.**

***Keywords*–Face milling, Response Surface Methodology, Feed rate, depth of cut, spindle speed.**

I. INTRODUCTION

In this paper we are discussing about the various process parameters for the face milling operation on 6061-T6 Aluminium using Design of Experiment software and Response Surface Methodology with the tool specification: Φ 60 mm four-flute face-milling cutter with grade 1C28M40 inserts..

II. DESIGN OF EXPERIMENTS

DOE is a formal mathematical method for systematically conducting and planning scientific studies that change experimental variables together in order to determine their effect of a given response. It makes controlled changes to input variables in order to gain maximum amounts of information on effect and cause relationships with a minimum sample size. It is more efficient that a standard approach of changing "one attribute at a time" in order to observe the attribute's impact on a given response. It generates information on the effect various factors have on a response attribute and in some cases may be able to determine optimal settings for those factors It encourages "brainstorming" activities associated with discussing key factors that may affect a given response and allows the experimenter to identify the "key" factors for future studies.

To analyze the data set, statistical tool DESIGN EXPERT-8 (Software) had been used to reduce the manipulation and help to arrive at proper improvement plan of the Manufacturing process and Techniques.

II. LATEST TECHNIQUES

The latest techniques for optimization include fuzzy logic, scatter search technique, genetic algorithm, and Taguchi technique and response surface methodology.

A. Fuzzy logic: Fuzzy logic has great capability to capture human common-sense reasoning, decision-making and other aspects of human cognition. Kosko (1997) shows that it over comes the limitations of classic logical systems, which imposes inherent restrictions on representation of imprecise concepts. Vagueness in the coefficients and constraints may be naturally modeled by fuzzy logic. Modeling by fuzzy logic opens up a new way to optimize cutting conditions and also tool selection.

B. Genetic algorithm (GA): These are the algorithms based on mechanics of natural selection and natural genetics, which are more robust and more likely to locate global optimum. It is because of this feature that GA goes through solution space starting from a group of points and not from a single point. The cutting conditions are encoded as genes by binary encoding to apply GA in optimization of machining parameters. A set of genes is combined together to form chromosomes, used to perform the basic mechanisms in GA, such as crossover and mutation.

Crossover is the operation to exchange some part of two chromosomes to generate new offspring, which is important when exploring the whole search space rapidly. Mutation is applied after crossover to provide a small randomness to the new chromosomes. To evaluate each individual or chromosome, the encoded cutting conditions are decoded from the chromosomes and are used to predict machining performance measures. Fitness or objective function is a function needed in the optimization process and selection of next generation in genetic algorithm. Optimum results of cutting conditions are obtained by comparison of values of objective functions among all individuals after a number of iterations. Besides weighting factors and constraints, suitable parameters of GA are required to operate efficiently. GA optimization methodology is based on machining performance predictions models developed from a comprehensive system of theoretical analysis, experimental data base and numerical methods. The GA parameters along with relevant objective functions and set of machining performance constraints are imposed on GA optimization methodology to provide optimum cutting conditions.

C. Scatter search technique (SS): This technique originates from strategies for combining decision rules and surrogate constraints. SS is completely generalized and problem-independent since it has no restrictive assumptions about objective function, parameter set and constraint set. It can be easily modified to optimize machining operation under various economic criteria and numerous practical constraints. It can obtain near-optimal solutions within reasonable execution time on PC. Potentially, it can be extended as a nonline quality control strategy for optimizing machining parameters based on signals from sensors. Chen & Chen (2003) have done extensive work on this technique.

D. Response surface methodology (RSM): Experimentation and making inferences are the twin features of general scientific methodology. Statistics as a scientific discipline is mainly designed to achieve these objectives. Planning of experiments is particularly very useful in deriving clear and accurate conclusions from the experimental observations, on the basis of which inferences can be made in the best possible manner. The methodology for making inferences has three main aspects. First, it establishes methods for drawing inferences from observations when these are not exact but subject to variation, because inferences are not exact but probabilistic in nature. Second, it specifies methods for collection of data appropriately, so that assumptions for the application of appropriate statistical methods to them are satisfied. Lastly, techniques for proper interpretation of results are devised. The advantages of design of experiments as reported by Adler et al (1975) and Johnston (1964) are as follows.

- Numbers of trials are reduced.
- Optimum values of parameters can be determined.
- Assessment of experimental error can be made.
- Qualitative estimation of parameters can be made.
- Inference regarding the effect of parameters on the characteristics of the process can be made.

Cochran & Cox (1962) quoted Box and Wilson as having proposed response surface methodology for the optimization of experiments. In many experimental situations, it is possible to represent independent factors in quantitative form. Then these factors can be thought of as having a functional relationship or response: $Y = \varphi (X_1, X_2, \ldots Xk) \pm er$, between the response Y and X_1 , X_2 , . . . Xk of k quantitative factors. The function φ is called response surface or response function. The residual er measures the experimental error. For a given set of independent variables, a characteristic surface responds. When the mathematical form of φ is not known, it can be approximated satisfactorily within the experimental region by a polynomial. The higher the degree of the polynomial the better is the correlation, though at the same time the costs of experimentation become higher.

III. TRADITIONAL APPROACH TO EXPERIMENTATION

- Study one factor at a time (OFAT), holding all other variables constant
- Simple process, but doesn't account for interactions
- It is inefficient (serial processing)

Design of Experiment Approach:

- Study multiple factors changing at once (parallel processing)
- Accounts for interactions between attribute
- Maximize information with minimum runs

Constraints

The restrictions that must be satisfied to produce an acceptable design are collectively called design constraints. Constraints represent the limitations on the behavior or performance of the system is termed behavior or functional constraints. They represent physical limitations on design variables, such as availability, fabric ability, and transportability, are known as side constraints or geometric.

The constraints or process parameters selected for the present work are:

Spindle speed – (A); Feed – (B); Depth of cut – (C)

And the environment chosen for work is dry.

The ranges of the selected process parameters were ascertained by conducting some preliminary experiments using one variable at a time approach. It was also decided to study the interactions among the parameters. The selected interactions were-spindle speed and feed (A x B); feed and depth of cut (B x C); spindle speed and depth of cut (A x C)

It was also decided to study each selected parameter at three levels. This is due to the reason that non – linear behavior, if any, of the parameters of a process can only be revealed if more than two levels are used. It is also necessary that the interval between the levels in multilevel experiment must be equal.

A. Spindle speed: The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (RPM). The preferred speed is determined by working backward from the desired surface speed (sfm or m/min) and incorporating the diameter (of work-piece or cutter).

- Excessive spindle speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct spindle speed for the material and tools will greatly enhance tool life and the quality of the surface finish.
- For a given machining operation, the spindle speed will remain constant for most situations; therefore the spindle speed will also remain constant.
- Spindle speed becomes important in the operation of routers, spindle moulders or shapers, milling machines and drills.

Formula to determine Spindle Speed

$$\textbf{RPM} = \frac{\text{Cutting Speed X 12}}{\pi \text{ X Diameter}} \qquad \ldots (1.1)$$

B. Feed: Feed rate (also often styled as a solid compound, feed-rate, or called simply feed) is the relative velocity at which the cutter is advanced along the work-piece; its vector is perpendicular to the vector of cutting speed. Feed rate units depend on the motion of the tool and work-piece; in rotating systems (e.g., turning and boring), the units are almost always distance per spindle revolution (inches per revolution [in/rev or ipr] or millimeters per revolution [mm/rev]). In linear systems (e.g., milling), the units are typically distance per time (inches per minute [in/min or ipm] or millimeters per minute [mm/min]), although distance per revolution or per cutter tooth are also sometimes used.

Feed-rate is dependent on the:

- Type of tool (a small drill or a large drill, high speed or carbide, a box tool or recess, a thin form tool or wide form tool, a slide knurl or a turret straddle knurl).
- Surface finish desired.
- Power available at the spindle (to prevent stalling of the cutter or work-piece).
- Rigidity of the machine and tooling setup (ability to withstand vibration or chatter).
- Strength of the work-piece (high feed rates will collapse thin wall tubing)
- Characteristics of the material being cut, chip flow depends on material type and feed rate. The ideal chip shape is small and breaks free early, carrying heat away from the tool and work.
- Threads per inch (TPI) for taps die heads and threading tools.

When deciding what feed rate to use for a certain cutting operation, the calculation is fairly straightforward for single-point cutting tools, because all of the cutting work is done at one point (done by "one tooth", as it were). With a milling machine or jointer, where multi-tipped/multi-fluted cutting tools are involved, then the desirable feed rate becomes dependent on the number of teeth on the cutter, as well as the desired amount of material per tooth to cut (expressed as chip load). The greater the number of cutting edges, the higher the feed rate permissible: for a cutting edge to work efficiently it must remove sufficient material to cut rather than rub; it also must do its fair share of work.

The ratio of the spindle speed and the feed rate controls how aggressive the cut is, and the nature of the sward formed.

(a). Formula to determine feed rate

This formula can be used to figure out the feed rate that the cutter travels into or around the work. This would apply to cutters on a milling machine, drill press and a number of other machine tools. This is not to be used on the lathe for turning operations, as the feed rate on a lathe is given as feed per revolution.

$$FR = RPM \times T \times CL \quad \text{…. (1.2)}$$

Where:

- FR = the calculated feed rate (in/ min) or (mm/min).
- RPM = the calculated speed for the cutter.
- T = Number of teeth on the cutter.
- CL = the chip load or feed per tooth. This is the size of chip that each tooth of the cutter takes.

C. Depth of Cut: The depth of cut, DOC is the depth that the tool penetrates into the surface of the work-piece. The DOC is half of the difference in the initial and final diameters.

Cutting speed and feed rate come together with depth of cut to determine the material removal rate, which is the volume of work-piece material (metal, wood, plastic, etc.) that can be removed per time unit.

IV. RESPONSE

A Response is the term denoting either an exit or changes which exit a system and which activate/modify a process.

A. Material Removal Rate:

Material Removal Rate (MRR) is the volume of material removed from the work piece in one minute.

$$MRR = F \times D \times d \quad \text{…. (3.3)}$$

Where,

MRR = Cubic inches or millimeter removed per minute,
F = Feed in mm/min,
d = Depth of Cut in mm
D = Tool diameter

Practically MRR is measured by weighing the work-piece before and then after the machining process with the help of digital weighing machine, noting the machining time with the help of a stopwatch and finally dividing the weight removed during machining by machining time.

V. EXPERIMENTATION

A. Inputs required:

- CNC milling machine
- Aluminium work-piece
- Milling tools
- Digital weighing machine
- Stopwatch
- Design expert software

B. Experimental set-up

The experiments have been carried out on a 1.5HP CNC vertical milling center equipped with an φ 60 mm four-flute face-milling cutter with grade 1C28M40 inserts. The work-piece material used in these tests was 6061-T6 Aluminium.

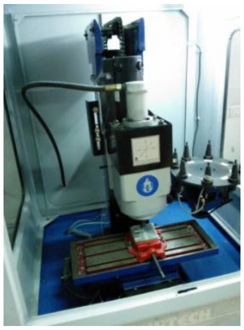

Fig.1.1: CNC Milling Machine

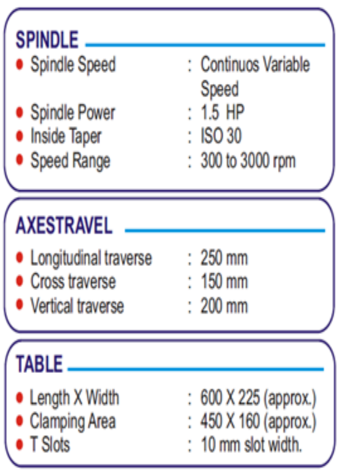

Fig.1. 2
Specifications of CNC Milling M/C used

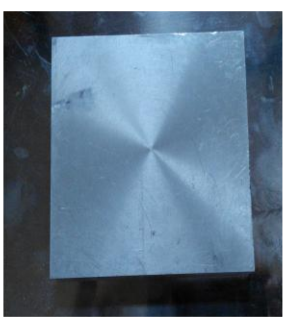

Fig. 1.3:
Work-piece

Fig.1.4
Digital Weighing machine

C. Experimental procedure:

- A part program having the experimental values of feed rate, spindle speed and depth of cut is prepared and entered.

One of the Part Program used in the experiment:

```
+9(TOOL/MILL, 6, 0, 50)
(STOCK/BLOCK, 100, 100, 10, 0, 0, 10)
M03 S2500
N01 G00 X70.0 Y30.0 Z10.0
N02 G01 Z-0.5 F15
N03 G01 X80.0
N07 G01 F50
N10 G01 Z10.0
N20 M30
```

- Weight of the work-piece is measured by making use of Digital weighing machine.
- Work-piece is clamped on the CNC Milling Machine.
- Machine is started.
- Machining time is noted with the help of a stopwatch.
- After machining work-piece is taken out and weighed again.
- MRR is obtained by dividing the weight removed during machining by machining time.
- The process is repeated 26 times by making necessary changes in the values of feed rate, spindle speed and depth of cut in the part program.

To investigate how process parameters effect on process state variables MRR, several experiments were conducted. A design including three levels of factors for face milling operations was used. The feed rate, spindle speed and depth of cut considered as independent input variables. Linear and second order polynomials were fitted to the experimental data for obtaining the regression equations. The lack of fit test, variance test and other adequacy measures were used in selecting optimum models. Table 1 shows milling machine input variables and experiment levels.

Table 1.1: Process variable and experimental levels

S.No	Parameter	Unit	Low	Medium	High
1	Spindle speed, S	RPM	2500	2700	2800
2	Feed rate, f	mm/min	15	20	25
3	Depth of cut, D	Mm	0.5	0.75	1

Once the cutting operations are accomplished, Material removal rate is calculated practically by weighing the work-piece after each experiment and then dividing the amount of metal removed by machining time for each experiment. The experimental results thus obtained are tabulated.

Table 1.2: Experimental results

TEST	F *(mm/min)*	D *(mm)*	S *(RPM)*	Weight removed *(gm)*	Time *(s)*	MRR *(gm/sec)*
1.	15	0.5	2500	0.202	43.28	0.004667
2.	15	0.5	2700	0.302	43.14	0.007004

3.	15	0.5	2800	0.105	42.99	0.002442
4.	15	0.75	2500	0.102	43.67	0.0023356
5.	15	0.75	2700	0.102	42.06	0.002425
6.	15	0.75	2800	0.202	43.80	0.004611
7.	15	1	2500	0.402	48.12	0.008354
8.	15	1	2700	0.199	46.35	0.004293
9.	15	1	2800	0.401	47.05	0.0085228
10.	20	0.5	2500	0.21	33.80	0.005946
11.	20	0.5	2700	0.201	34.62	0.005805
12.	20	0.5	2800	0.1	16.54	0.006045
13.	20	0.75	2500	0.053	17.12	0.003095
14.	20	0.75	2700	0.052	17.70	0.002937
15.	20	0.75	2800	0.156	17.20	0.009069
16.	20	1	2500	0.052	17.85	0.002913
17.	20	1	2700	0.101	17.09	0.005909
18.	20	1	2800	0.031	17.75	0.001746
19.	25	0.5	2500	0.041	13.39	0.003061
20.	25	0.5	2700	0.03	13.47	0.002227
21.	25	0.5	2800	0.061	13.14	0.0046423
22.	25	0.75	2500	0.041	13.13	0.0031226
23.	25	0.75	2700	0.103	14.20	0.007253
24.	25	0.75	2800	0.303	14.44	0.002098
25.	25	1	2500	0.104	17.66	0.005889
26.	25	1	2700	0.103	16.20	0.006358
27.	25	1	2800	0.202	15.94	0.012609

Fig. 1.5: Work-piece after 27 experiments

Fig. 1.6: Digital weighing m/c indicating
Reduced weight of the work-piece

VI. RESULTS AND DISCUSSION

Behalf on the conducted experiments and accomplished analysis, the following conclusions can be made:

- The Material removal rates affected by all the process parameters viz. spindle speed, depth of cut and feed rate.
- The MRR is increased by increasing any of the process parameters.

A. *Effect of Spindle Speed*

First it is increased from 2500 RPM to 2700 RPM and then 2800 RPM. Due to increase in Spindle the MRR is increased. This is attributed to the fact that the required time for the metal removal decreases. It could not possible to perform the cutting beyond N > 5000 rpm beyond this spindle speed the tool failure take place.

B. Effect of Depth of Cut

With increase in depth of cut from 0.5mm to 0.75mm and finally 1mm by the MRR is increased. The MRR goes on increasing because the increase in depth of cut removes the large amount of material by the specimen. Very high depth of cut like 50 mm causes the tool failure because of high temperature.

C. Effect of Feed Rate (f)

With increase in feed rate from 15 mm/min to 20 mm/min and then 25 mm/min the MRR is increased. The increasing feed rate decrease the processing time thereby increasing the MRR. Beyond f=100 mm/min. it is not possible to continue machining as the tool failure occurs as it results in wear.

- The depth of cut and spindle speed and their interaction are more significant i.e. the effect of variation in depth of cut and spindle speed is more as compared to feed rate.

- By calculating the slope of Fig: of each input parameter vs response it is concluded that the contribution of

  Feed Rate is **12.51307%**
  Spindle Speed is **38.42653%**
  Depth of cut is **49.141601%**

- RSM technique has the advantage of investigating the influence of each machining variable on the values of technological parameters.
- The Analysis of Variance (ANOVA) is helpful in determining which control factor has how much importance in the determination of the results obtained from the experimental study.
- Model Adequacy checking ensures that predicted model is adequate.
- The maximum value of MRR is **0.012609 gm/sec**
- The Optimum value of input factors for maximum MRR are:

  Feed Rate - **25 mm/min**
  Spindle Speed - **2800 RPM**
  Depth of Cut - **1 mm**

VII. CONCLUSIONS AND SCOPE FOR THE FUTURE WORK

- The experimental investigation established that the MRR can be optimized by the proper settings of machining parameters. High MRR can also result in better production rate and machine ability. Design Expert provides an easy, accurate and cheap procedure for optimization. RSM is one of the most important tools in developing new processes and optimizing their performance. This procedure utilizes data gathered from process through statistically design of experiments method. Optimization provides a number of solutions which can be further judge for the best one depending upon the available resources and present constraints over the process system. Thus, employment of this optimization procedure over the manufacturing systems is simple and economically viable. In addition, the proposed procedure can be implemented easily by using ready-made standard statistical packages.
- In future, the process of optimization can be further apply to a number of manufacturing processes like milling, drilling, grinding and many more with the use of different range of materials and tools. The material selection can range from soft to hard and tough materials. These materials can be metals, non-metals and alloys. Cutting tools can include various ranges of HSS tools, carbide tools, CBN and ceramic tools and many more.
- Response Surface Methodology is a better tool to provide a good practical insight into developing new optimizing and process them. This methodology could help engineers to provide a mathematical model to represent the behaviour of system as a convincing function of process parameters. This methodology can be applied to a number of processes to achieve accurate results comparative to other methods.
- More accurate MRR measurement techniques can also be employed over MRR dependent processes to achieve more accurate optimization results..
- Advance versions of Design Expert can be used to get some more analysis and optimization tools for further detailed explanations.

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