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Experimental Research and Optimization of Cutting Parameters for High Speed Machining

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Abstract: High Speed machining has captured popularity over last few years; Due to technological enhancements its implementation was successful. Because of progressive growth in machine tools and cutting too technology, HSM has proved itself an economic manufacturing process for manufacturing parts with high fidelity and surface quality. In recent times, with the progress of cutting tool technologies, HSM has also been used for machining alloy steels for preparing molds/dies employed in the manufacturing of a broad collection of automotive components, and also for plastic molding parts. This mechanization was effectively used with some advancement in machine tools, controllers and spindles. [1, 2]. The goal of this research is to develop mathematical models, in terms of the High-speed Milling operation input parameters. These models will assist engineers and technologists to achieve desirable machining conditions. This approach will assure the highest Depth of Cut, and assist in lowering machining time. Furthermore, it will reduce the numbers of experiments without any significant loss in the accuracy of the models developed.

Keywords: Depth of cut, High speed milling, Machining time,

I. INTRODUCTION

High Speed machining has captured popularity over last few years; Due to technological enhancements its implementation was successful. Because of progressive growth in machine tools and cutting too technology, HSM has proved itself an economic manufacturing process for manufacturing parts with high fidelity and surface quality. In recent times, with the progress of cutting tool technologies, HSM has also been used for machining alloy steels for preparing molds/dies employed in the manufacturing of a broad collection of automotive components, and also for plastic molding parts.

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This mechanization was effectively This technology was successfully used with some advancements in machine tools, controllers and spindles. [1, 2]. HSM processes enable high material removal rates, low cutting forces, reduced lead times and improved part precision [4]. The distinction between conventional and high-speed machining is based on the work piece material being machined, type of cutting operation, and the cutting tool used [5].
High speed dynamic milling tool paths employs the complete range of their cutting tools to gain huge efficiency in milling. They are intended to make the most of material removal while reducing tool wear. Supplementary advantages of using high speed dynamic milling tool paths consist of:

1. Tool burial avoidance
2. Minimum heat build up
3. Better chip evacuation

Following are high speed dynamic milling tool paths existing in Mastercam.

A. Dynamic Area Mill—Machines pockets using more than one chains to drive the tool path. The chain that encompasses the largest 2D area contains the tool path; all subsequent chains are considered islands. Utilize Dynamic Area Mill for parts which are generally can be machined with a Pocket tool path. Fig 1.1shows Dynamic Area Mill

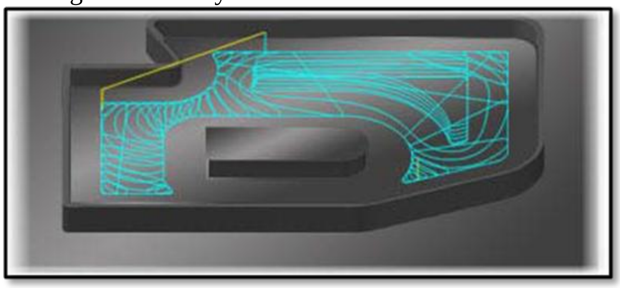

Fig. 1.1 Dynamic Area Mill, Mastercam

Dynamic Core Mill: Machines open pocket shapes or standing core shapes using the outmost chain as the stock boundary. The tool moves freely outside of this area. Use Dynamic Core Mill on parts where you need to face an area, generally on the outside of a part. Please refer fig 1.2 for Dynamic Core Mill.

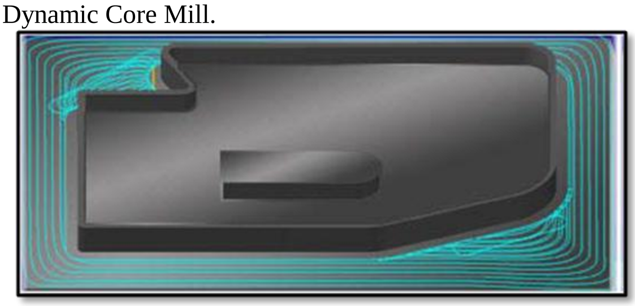

Fig. 1.2 Dynamic Core Mill, Mastercam

Dynamic Contour: The tool motion converts to dynamic in areas where the tool would bind or encounter too much material. Use on walls or contours that contain small radii. Fig 1.3 shows Dynamic Contour tool path.

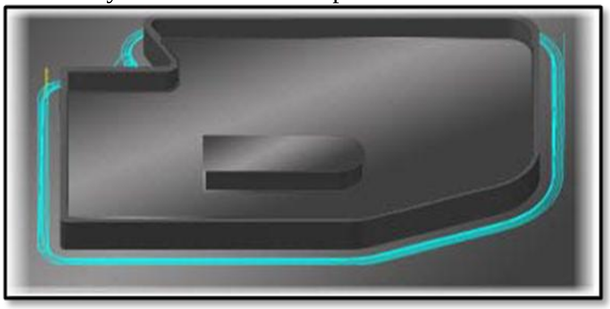

Fig. 1.3 Dynamic Contour, Mastercam

Dynamic Rest Mill: As shown in Fig1.4 Dynamic Rest Mill targets material left from previous operations. Dynamic motions used to rapidly remove material left by previous operations or by a specified tool size. Use Dynamic Rest Mill when the roughing tools used leave material in corners or narrow part areas. Please refer below fig. for Dynamic Rest Mill.

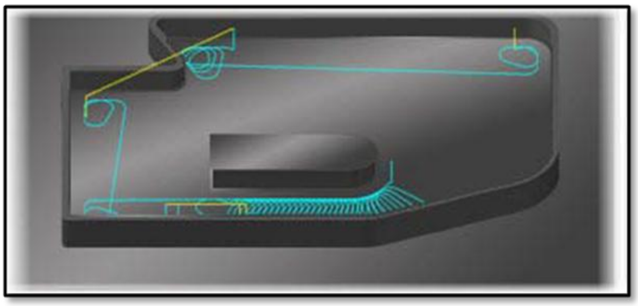

Fig. 1.4 Dynamic Rest Mill, Mastercam

The goal of work is to develop mathematical models, in terms of the High-speed Milling operation input parameters. These models will assist engineers and technologists to achieve desirable machining conditions. This approach will assure the highest Depth of Cut, and assist in lowering machining time. Furthermore, it will reduce the numbers of experiments without any significant loss in the accuracy of the models developed.

II. LITERATURE SURVEY

The duration of interest, for this literature survey, begins in 2003 to 2015. An exploration was made of the keyword indices on the Elsevier,SCOPUS, Springer link, IEEE Explore, EBSCO and Wiley Inderscience online database, for article abstracts containing the key words like, ‘‘optimisation of machining conditions, DoE, ANN, RSM, GA, Milling, Cutting conditions, High-speed machining for the period from 1996 to 2015.As found in the literature survey all four optimisation/modelling techniques were reviewed presented below.

Chang et. al.(2007) Using Taguchi method an experimental outcome were evaluated, which progressed recognition of best possible machining conditions. As per the conclusion rotational speed, with a contribution percentage as high as 42.68%, had the most superior effect on LAM system performance, followed by pulsed frequency, depth of cut, and feed [20].

Aggarwal et. al. (2008) The contribution shows the conclusion of an experimental examination into the effects of feed rate , cutting speed, nose radius and cutting environment in CNC turning of AISI P-20 tool steel. Design of experiment techniques, i.e. Taguchi’s technique and response surface methodology (RSM), have been used to achieve the objective of the experimental study. Although both the methods predicted nearly same results, RSM techniques are more superior to Taguchi’s technique [29].

Ginta et. al. (2008) This paper contributes to an approach to establish models and the struggle in optimization of surface roughness and tool life in end milling of titanium alloy Ti–6Al– 4V using uncoated WCCo inserts under dry conditions coupled with small central composite design (CCD) is adhered to Response surface methodology was used in budding the surface roughness and tool life models in context to primary cutting parameters such as cutting speed, axial depth of cut and feed. [24].

Davimet. al.(2008) examined the usage of ANN model in effect of cutting conditions on surface roughness in turning of free machining steel. Study reflects usage of artificial neural network (ANN) for development of Surface roughness prediction models. This is done in order to investigate the effects of cutting conditions during turning of free machiningsteel,9SMnPb28k(DIN). The ANN model of surface roughness parameters is developed with the cutting conditions such as depth of cut, feed rate and cutting speed as depending process parameters. [11].

Muthukrishnan et. al.(2009) investigated the optimization of machining parameters of Al/SiC-MMC with ANN analysis and ANOVA. The surface roughness of Al–SiC (20 p) has been studied in this paper by turning the composite bars using coarse grade polycrystalline diamond (PCD) insert under different cutting conditions. The data collected from experimentation are tested with artificial neural network (ANN) techniques and analysis of variance (ANOVA) [12].

Zain et. al.(2012) practiced done ANN models and regression for calculating minimum value of machining performance.To forecast the minimum Ra value, the process of modeling is considered in this study. The outcome demonstrates that ANN models and regression have reduced the minimum Ra value of real experimental data by about 1.57% and 1.05%, respectively [9].

III. EXPERIMENTAL SETUP

A. Selection of Material

The workpiece material for machiningisTi-6Al-4V bar of diameter25mm, fig.1.1shows titanium bar for cutting on milling machine.

Fig. 1.1Titanium bar for Cutting on Machine

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Ti-6Al-4Vis the most widely used metal in the Aerospace industry but its Machinability is less. Titanium grade 5 is selected for test because the use of grade 5 is 50 % of total use of Titanium in industry.

Mechanical properties of Ti-6Al-4V are as given below.

Table 1.1Titanium bar: Workpiece material properties

Physical properties	Titanium Ti-6Al-AV (Grade 5)UNS R56400	
Density	4.43 g/cc	0.16lb/in^3
Hardness, Brinell	379	379
Tensilestrength, ultimate	1170Mpa	170000psi
Tensilestrength, yield	1100Mpa	160000psi
Elongation of beam	10%	10%
Modulus of elasticity	110 Gpa	16500ksi
Compressive yieldstrength	1070Mpa	155000psi

B. *Job Setup on Machine*

Round bar held in Four Jawchuck on Table as shownbelow. X and Y zeroat center of Bar and Z0 at top of Bar.Pleaserefer fig.1.2 and 1.3.

Fig. 1.2 Job Setup on Machine

Fig. 1.3 Job Setup with Tool on Machine

C. Machining Strategy: Dynamic Cutting Strategy from Mastercam software.

Mastercam's Dynamic Motion tool-paths convey these powerful benefits while helping you get the most out of any machine – old or new. Tool wear and Cycle time are shops' constant concerns. Mastercam's dynamic milling is developed to improve both with a single powerful technique.

Mastercam's Dynamic Milling tool-paths create constantly adapting motion providing smoother, safer cuts. The concerned motion is easier on machine and can efficiently use the full flute length, eliminating the need for multiple depth cuts and greatly extending cutter life. Fig 1.2 and 1.3 shows toolpath generated in Mastercam.

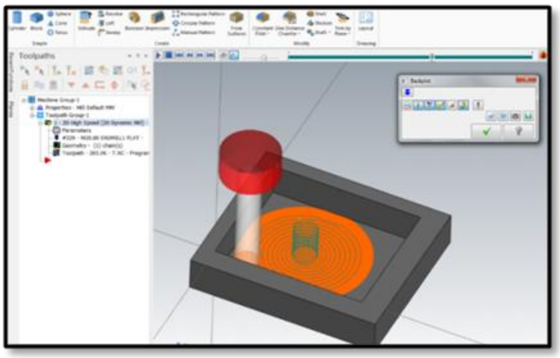

Fig. 1.3 High speed Toolpath in Mastercam

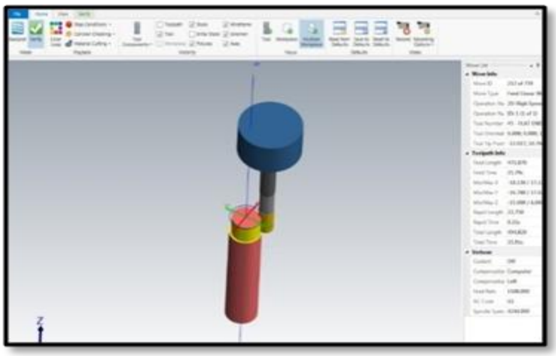

Fig.1.4 3D Simulation in Mastercam

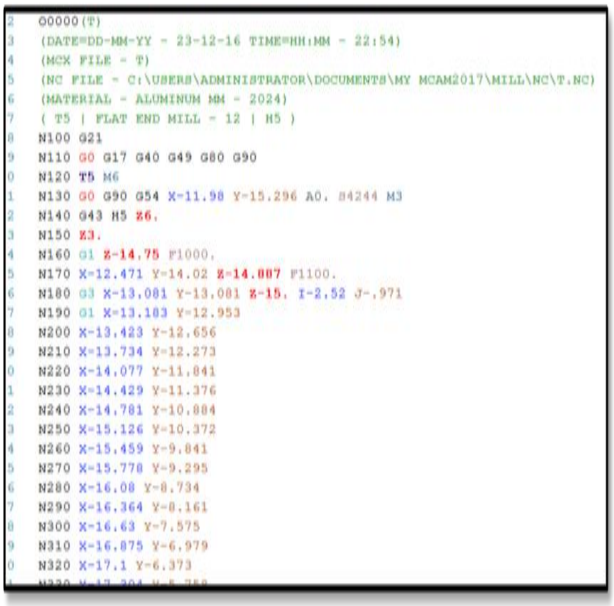

Fig. 1.5 NC program generated by Mastercam

D. SELECTION OF PARAMETERS

For High speed machining Feed, spindle speed, stop over, depth of cut, coolant speed, clamping, cutting tool, tool holder, material hardness and tool diameter can be treated as machining variables.

But for DOE experimentation four variables Feed, Spindle speed, Stopover, Depth of Cut are identified and other parameters as treated as constant. Out of type of parameters process parameters were taken as variables and technical and geometrical parameters are treated as constant, so equation can be written as

Y= f (Feed, Spindle speed, Stopover, Depth of Cut) + e.

E. DESIGN EXPERT 10 SOFTEWARE AND RUN

TABLE:

The software used for the project is Design Expert 10. Design–Expert is a statistical software package from Stat-Ease Inc. that is specifically dedicated to performing design of experiments (DOE). Graphical tools help identify the impact of each factor on the desired outcomes and reveal abnormalities in the data.

Design of experiments is a method by which you make purposeful changes to input factors of your process to observe the effects on the output. DOE's can and have been performed in virtually every industry on the planet—agriculture, chemical, pharmaceutical, electronics, automotive, hard goods manufacturing, etc. Traditionally, experimentation has been done in a haphazard one factor at a time (OFAT) manner. This method is inefficient and very often yields misleading results. On the other hand, factorial designs are a very basic type of DOE, require only a minimal number of runs, yet they allow you to identify interactions in your process. This information leads you to breakthroughs in process understanding, thus reducing costs, increasing profits, improving quality, and .Central Composite Designs (CCD): Standard (axial levels (α) for "star points" are set for rateability) Good design properties, little co linearity, orthogonal blocks, rotatable, , insensitive to outliers and missing data. Each factor has five levels. Region of operability must be greater than region of interest to accommodate axial runs. For 5 or more factors, change factorial core of CCD to: o Standard Resolution V fractional design, or o Min-run Res V.

For Experimentation 5 level of each of the four variables are selected and CCD type RSM design is done. Fig 1.6 shows summery of design planned. From design expert software a run sheet was generated which shows 25 experiments to be conducted for each tensile and impact responses.

Design Summary

File Version 10.0.3.0

Design Wizar Screening > Factorial / RSM > HTC > All Numeric

Study Type	Response Surface		Subtype	Randomized	
Design Type	*I-optimal*	Coordinate Exc	Runs	25	
Design Mode	Quadratic		Blocks	No Blocks	Build Time (r 390.00

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	FEED	MM/MIN	Numeric	Discrete	636	1188	-1.000=636	1.000=1188	917.52	223.515
B	SPEED	RPM	Numeric	Discrete	3183	4244	-1.000=3183	1.000=4244	3713.6	433.177
C	DEPTH OF CUT	MM	Numeric	Discrete	5	15	-1.000=5	1.000=15	10.2	4.07738
D	STEP OVER	MM	Numeric	Discrete	0.84	1.2	-1.000=0.84	1.000=1.2	1.0092	0.143059

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	SPINDLE LOAD	%	25	Polynomial	3	13	6.56	2.88791	4.33333	None	Quadratic
R2	CYCLE TIME	SEC	25	Polynomial	31	68	46.04	12.1294	2.19355	None	Linear

Fig. 1.6 Input Parameters that are to be Varied and Range

Table 1.3 Run Sheet from Design Expert 10 Software

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Run	A:FEED	B:SPEED	C:DEPTH OF CUT	D:STEP OVER	SPINDLE LOAD	CYCLE TIME
	MM/MIN	RPM	MM	MM	%	SEC
1	1188	3714	5	0.84	5	35
2	912	3714	5	1.02	5	47
3	636	3714	10	0.84	3	66
4	1050	3448	10	1.11	8	34
5	1188	3183	5	1.2	5	31
6	1050	3448	10	1.11	6	39
7	636	3183	15	1.2	5	56
8	912	3183	7.5	0.84	3	48
9	1050	3448	10	1.11	8	35
10	636	3183	15	0.84	6	68
11	1188	4244	15	0.84	10	39
12	1188	3183	15	0.84	10	38
13	912	4244	7.5	0.93	5	45
14	912	3183	7.5	0.84	3	52
15	912	3714	15	1.02	10	43
16	636	4244	15	1.2	10	59
17	1188	4244	10	1.02	8	33
18	1188	4244	10	1.02	8	33
19	912	4244	5	1.2	6	36
20	912	3714	15	1.02	10	43
21	636	3183	5	1.02	3	57
22	636	4244	15	0.93	8	62
23	1188	3979	15	1.2	13	31
24	636	4244	5	0.84	3	67
25	636	3714	7.5	1.2	3	54

Experiements were carried out as per the run table as shown in table 1.3 and responces after milling machining are noted. The same are entered in the run sheet and results were ploted from Design expert software.

IV. RESULTS

A. RESULT FROM RSM

Polynomial equations were obtained from Design expert software is as below.

SPINDLE LOAD = -27.4439 + 0.00442822 * FEED + 0.00418649 * SPEED + -1.22797 * DEPTH OF CUT + 38.7282 * STEP OVER + -3.14585e-006 * FEED * SPEED + 0.000311904 * FEED * DEPTH OF CUT + 0.00592746 * FEED * STEP OVER + 3.6155e-005 * SPEED * DEPTH OF CUT + 0.00763851 * SPEED * STEP OVER + 0.171155 * DEPTH OF CUT * STEP OVER + 2.39261e-006 * FEED^2 + -1.06803e-006 * SPEED^2 + 0.0564184 * DEPTH OF CUT^2 + -34.291 * STEP OVER^2

CYCLE TIME= 117.381 + -0.0497481 * FEED + -0.000181085 * SPEED + 0.186781 * DEPTH OF CUT + -26.6832 * STEP OVER

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B. RESULTS FOR SPINDLE LOAD

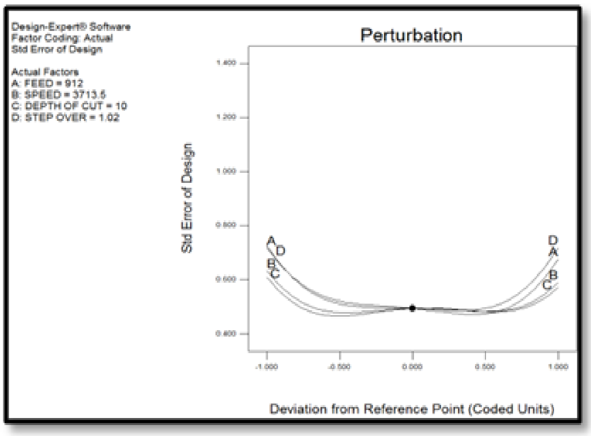


Fig. 1.7 Perturbation Plot for Spindle Load

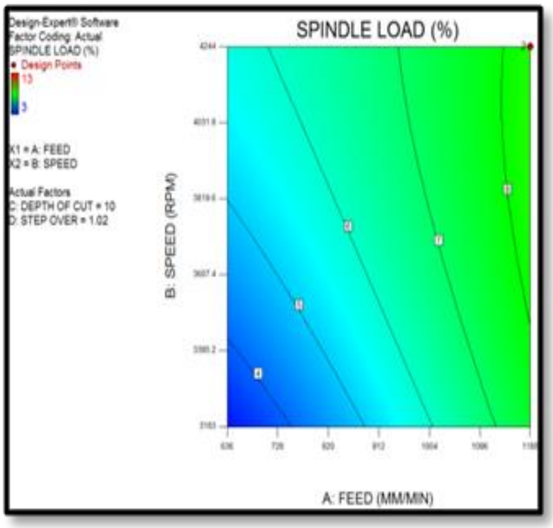


Fig. 1.8 Contour Graph for Spindle Load

In the subsequent headings, whenever a comparison between any two input parameters is being discussed the third parameter would be on its center level. It is seen from the results that all the process input parameters have a significant effect on Spindle Load during machining. However, Fig. 1.7 is a perturbation plot which shows the effect of the machining parameters on the Spindle Load and Fig. 1.8 is a contours graph demonstrating the effect of the spindle speed and Feed on the Spindle Load.

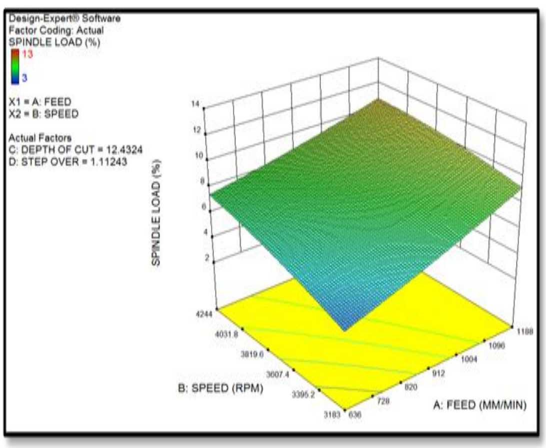


Fig. 1.9 Response Surface for Spindle Load

It is observed from Fig. 1.9 that both the step over and Depth of Cut have a faintly positive effect on the Spindle Load. Also, with respect to the Feed the result demonstrate that increasing the spindle speed and Feed would result in increased the spindle load, the Spindle load then starts to increase as the Feed tends to amplify over the center limit. Such performance could be attributable to one of the following reasons. In general, as the consequences indicate, it is not advised that very low or very high feed should be used.
In terms of the interaction effect between the spindle speed and Feed, it is evident that by using high Feed Spindle load and high spindle speeds, have a tendancy to increase.

C. RESULTS FOR CYCLE TIME

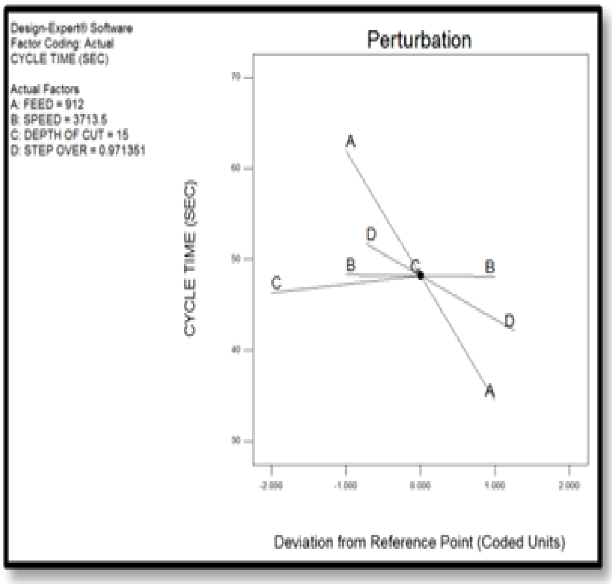
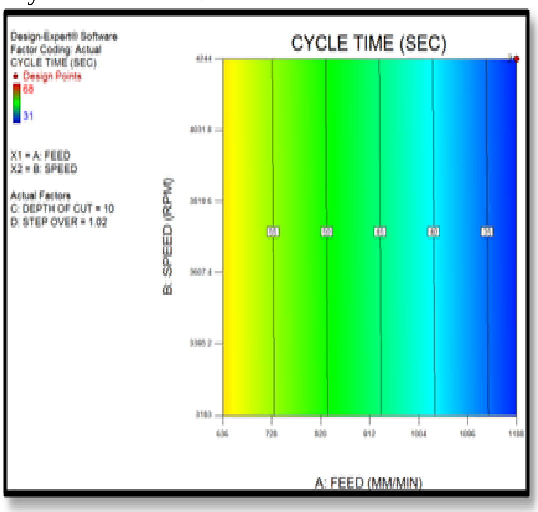


Fig. 1.10 Perturbation Plot for Cycle Time

A reduction is the most important criteria in the Machining Cycle Time. This is mandatory in order to reduce cost per component, For that reason, the relationship between the cycle time and machining input parameters must be highlighted. The result showss that Fig 1.10 all the input parameters have a significant effect on the cycle time during machining. Significant interaction effect was found in the case of the cycle time model.



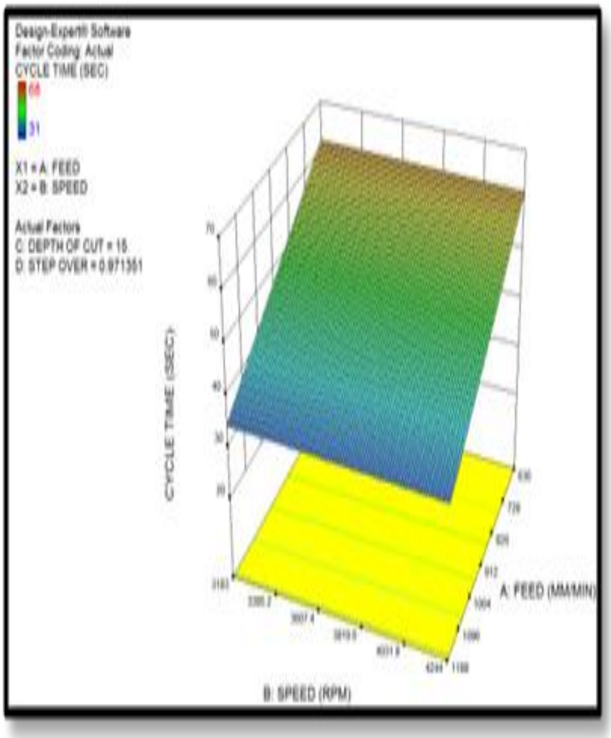


Fig. 1.11 Contour for Cycle TimeFig. 1.12 Response Surface for Cycle Time

Fig. 1.10 demonstrates a perturbation plot to compare the effect of different machining factors at a point (midpoint by default) in the design space.

From this figure, it can be observed with the increase of feed the cycle time decreases This is because the tool will move fast and travel the feed distance in less time. Fig. 1.11 and 1.12 shows the effect of spindle speed and feed on the cycle time at Depth of Cut of 10 mm and stop over at 1.02mm. The outcome demonstrates that the cycle time would be reduced, if the spindle load increases. This is essential in the optimization of the machining process.

V. CONCLUSIONS & FUTURE IMPROVEMENTS

A. CONCLUSION

1. To optimize the High-speed machining process and to obtain the best cycle time of the component RSM is correct method.
2. Spindle load goes on increasing as feed increases. Optimum parameters for Spindle load can be found out at Feed= **912 mm/min, Speed = 3713.5 rpm ,Depth of Cut = 12.43 mm, Step over = 1.11 mm**

Spindle load = 7.99 % for Cycle Time = 44 Secs

3. It is not desirable to have machining with very low spindle speed and very high feed or with high spindle speeds and very low feed.
4. Cycle time has less effect of spindle speed. Cycle time decreases as the feed increases.

Optimum parameters for cycle time can be found out at

Depth of Cut = 15 mm, Step over = 0.9713 mm, Feed = 912 mm/min, Speed = 3713.5 rpm

Cycle Time = 48.25 for SpindleLoad= 9.85%

B. FUTURE IMPROVEMENTS

1. An expert system can be developed for decision making for selection of input parameters based on required levels of output parameters.
2. Also we can use one of the optimization techniques to develop expert systems like ANN, GA.
3. Other variables can also be analyzed as output responses like machine vibrations and Tool Life.
4. Could integrate features like predictive and adaptive control of highspeed machining with expert system.
5. Could look for feasibility of real time monitoring of machining process used in aerospace industry.

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