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Optimization of vibration amplitude ratio of face mill tool of VMC and analysis with design expert to endorsing shim design

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Abstract

This paper presents the concept, design and development of shim (passive damper) to improve the stability for high spindle speed machine operation of face mill tool. The objective of this paper is to learning the dynamic behavior of a face mill tool on VMC with dissimilar types of shims which cover investigation of dynamic motion behavior of the face mill tool, the behavior of different types of shim design and behavior of vibration by using the amplitude ratio method and analysis by a Design Expert. Research work supported computational analysis with Ansys, 35 VMC experimental records and analyzed by ANOVA/Design Expert with different type of shims to observe a dynamic behavior of chatter. It include of the effect of process parameters like Cutting speed (250,200,150 m/min), feed per tooth (0.05, 0.1, 0.15mm/tooth), depth of cut (1.2 mm, 1.0 mm, 0.8 mm), and different types of materials (shims) for face mill tool on VMC, for analyzing the responses like amplitude ratio in X – direction, Y- direction with ANOVA and optimizing for AISI 2062 steel by Design Expert. An experimental methodology was developed using the DOE (Design of experiment) technique. The optimum factorial method was used to design an orthogonal array of four factors having three levels. Here, the main results are based on amplitude ratio, ANOVA analysis and optimization. ANOVA was used to decide the effects of the machining parameters on the vibration amplitude ratio in X; and vibration amplitude ratio in Y .This is useful for evaluating the stability of milling operations via time domain FFT and analyzed by ANOVA. Data are validated by 35 sets of VMC experiments. Physical 35 experiments may be not enough in a view of high level researchers, academicians and industrialist to conclude the use of shim and it need in face mill tool on VMC. Hence here optimization based on optimum factorial method is executed using Design Expert software in which 35experiments and its iterations with 70 populations were used to run the program. It is found that the most critical parameter in this study is the material of Shim. At high cutting parameters carbide shim , at low and medium cutting parameters SS shim are given better results by ANOVA and Optimization of Design Expert also validated by 35 sets of VMC experiments. Hence these shim designs endorse versatile solutions.

Keywords: Chatter frequency, ANOVA, Shim, Amplitude ratio, Optimization, Tooth passing frequency

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1. Introduction

Machining has noise and chatter is a major problem as VMC-vertical milling Centre causes more vibrations at maximum speed operation (Celikag et al., 2019; Yuan et al., 2019). Today accuracy and precision with top speed machining is important to scratch price and escalation production (Gandhi and Pandya, 2022). One of the biggest obstacles to fully automating machining processes including milling, drilling, boring, and turning is chatter (Eynian, 2019; Gandhi and Pandya 2022). Chatter in machining causes issues like poor surface smoothness, excessive noise, shorter tool life, and in the worst scenario, component breakdown, which lowers productivity (Yue et al., 2018; Liu et al., 2019; Wenish et al., 2019; Prajapati et al., 2020). Face milling is the most common milling process and can be accomplished using various wide range of different tools. Here Special Purpose two types of face mill with (TNMG) inserts, diameter Ø63mm and 5 inserts without shim and with shim is discussed (Gandhi and Pandya, 2022). Gandhi and Pandya (2022) had conducted computational analysis of the face mill tool utilizing the carbide shim, the SS-Stainless Steel shim, and the without shim face mill tool, followed by a harmonic analysis. The ANSYS workbench was used for computational analysis (FEA), and the calculated damping ratio was validated by experimental analysis for decreasing chatter by examining the operational and stationary properties of the cutting tools.

Rogov et al. (2017) examined the quality of the visible machine work and the effectiveness of the turning employing a shim by adding great restraint characteristics in the fastening of the insert. There are 5 planned shims, which will be prepared of granite, ceramic, chlorite schist, epoxy granite, and sandstone (Rogov et al., 2017). Experimental and computational research is provided to examine the stress-strain relationship in the insert's fastened set structure. Studying the static and operational characteristics of cutting tools with shims constructed of various materials (Rogov et al., 2017). Rubeo and Schmitz (2017) described a metric known as the amplitude ratio for assessing the stability of milling operations through time domain simulation (see also Rubeo and Schmitz, 2017). When creating contour diagrams to depict stability behavior across a variety of spindle speeds and axial depths of cut, the amplitude ratio is employed (Rubeo and Schmitz, 2017). Through comparison to results acquired using semi-analytical methods and independently published data, the applicability of the amplitude ratio stability metric is assessed (Rubeo and Schmitz, 2017). Moghaddam and Kolahan (2016) gave consideration to the impact of the machining parameters on the surface roughness. On AISI1045, nine trials were carried out, and the associated surface roughness values were recorded. Then, using MATLAB software, optimization based on PSO was carried out. The programme ran for 30 iterations with 50 populations. In a computer with a Core 2 Duo CPU, a single run of computation takes an average of 15 seconds to complete. Then, experiments were carried out once more using the PSO-recommended machining parameters. According to the results of the research, surface roughness decreases when cutting speed is increased and similarly when feed is decreased.

Our objective is to decrease chatter and to improve surface quality in VMC-Vertical Milling Centre (Gandhi and Pandya, 2022). An aim of research is not only to reduce chatter by using shim but also validates with ANOVA and makes it versatile and proven by optimization (Ambigai and Prabhu, 2019).

2. Experimental Methods

The experiment is done on VMC- with a CoCo 80 try axial dynamic signal analyzer to validate the ANOVA analysis. This setup is used for collecting vibration signals, as shown in Figure 1. Vibration signals are collected with use of a CoCo 80 try axial dynamic signal analyzer attached to a VMC- tool holder. Analyzer gives displacement data which helps to plot motion study graphs. The experiments were conducted on the CVM 640 (VMC) with two face milling tools, 1st is special purpose Kyocera make without shim face-milling and 2nd is with shim Kyocera make face milling tool both have Ø 63 mm with the 5 inserts as shown in Figure 2 (Gandhi and Pandya, 2022). Work piece Plate of 75*25*300 mm of 2062 mild steel 130 BH work material were used for the experiments. Machining was done using a TNMG 120412 (Carbide) insert. The experiments were conducted at 3 Cutting speed (250m/min, 200m/min, 150m/min), 3 Feed Per Tooth (0.15mm/tooth,0.1mm/tooth , 0.05mm/tooth), 3 Depth of cut (1.2 mm, 1.0 mm, 0.8 mm), and 4 Shim Material (SS- Stainless Steel, Carbide & Without shim face mill) are taken for the experiments. For experiments up milling process with a width of cut 64 mm is used. Surface roughness is measured using an SJ 210 surface roughness tester with measuring range -200 µm to 150 µm as shown in Figure 3.

Figure 1 CVM milling machine with CoCo80 Dynamic Signal analyzer with Try Axial Sensor

Figure 2 face milling tool 63 mm dia with shim and without shim face mill

Figure 3 surface roughness tester

The displacement information gathered with a dynamic analyzer CO CO80. Displacement Data is plotted using EDM software. The Fast Fourier Transformation (FFT) graphs are created using Matlab to determine how the face mill tool behaves. From FFT graphs we found Tooth-passing frequency, chatter frequency and amplitude ratio for the face mill tool.

3. Data Collection of Vibration and Dynamic Motion Behaviour Analysis

3.1 Data collection

Using a CoCo 80 dynamic signal analyzer, vibration signals from physical components are converted into numerical data that can be carefully studied and analyzed (Guo et al., 2021). Vibration signals are recorded with a double cut, under various cutting conditions, and with various shims in order to detect chatter (Fratila and Caizar, 2011; Zhou et al., 2018; Pimenov et al., 2019; Sambedana and Jagadeesha, 2019; Narooei and Ramli, 2022; Ma et al., 2022). EDM and MATLAB tools were used to create TDR (Time Displacement Response) and FFT (Fast Fourier Transformation) graphs. Tooth passing frequency, chatter frequency, amplitude ratio and Dynamic Motion Behavior for above conditions have been studied and analyzed by using TDR and FFT graphs.

Input Parameters: 1.Cutting speed in m/min, 2.Cutting speed in m/min, Depth of cut in mm, 3.Feed in mm/Tooth, 4.Shim (Without Shim, SS & Carbide)

Output Parameters: 1, Amplitude Ratio r_{amp}= A_{cf} (μm) / A_{tpf} (μm) in X, 2.Amplitude Ratio r_{amp}= A_{cf} (μm) / A_{tpf} (μm) in Y, 3. Surface roughness

3.2 Factors and Levels

The design of the DOE table was made possible by the right factor selection and their levels available by Design Expert software. In this paper, four factors with three levels were selected for DOE and are shown in Table 1.

Table 1 Factors and levels

Level	Cutting speed m/min	Depth of cut mm	Feed mm/Tooth	Shim
1	250	1.2	0.15	3
2	200	1.0	0.10	2
3	150	0.8	0.05	1

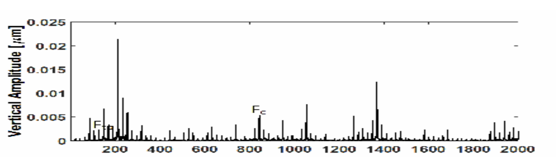
Note: 3-SS shim, 2-Carbide shim, 1-without shim

Based on the input parameters, a possible number of combinations are selected for experimental work. Experiments are carried out with a combination of without shim and with different shim materials, depth of cut, feed, and cutting speed, so 35 experiments are done. Model: Optimum Factorial model, run: 35, Level: 3, Factor: 4

3.3 Dynamic motion behavior analysis

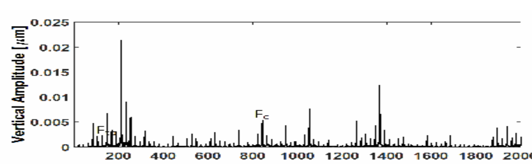
Different combinations of depth of cut, feed rate, and cutting speed for face mills without shims and with shims (made of carbide and stainless steel) were used in studies to determine the dynamics of motion. The results included TDR and FFT graphs. The FFT spectrum analyzer receives a time-varying signal as the input; FFT calculate the sine and cosine component magnitudes and shows the spectrum of these frequency components (Yuan et al., 2019; Prajapati et al., 2020; Gandhi and Pandya, 2022). This frequency versus amplitude plots for both the X-longitudinal and Y-cross feed directions . Thus, motion study is achieved using TDR and FFT graphs to assess the dynamics of motion and calculate chatter frequency and tooth-passing frequency. The dynamics of motion of FFT patterns that are discussed are investigated. Figure 4.[(a-b), (c-d), (e-f)] displays the different FFT graphs for without shim face mill tool, SS shim and carbide shim face mill tool with a cutting speed of 250 m/min, a depth of cut of 0.8 mm and a feed of 0.05 mm/tooth (Yuan et al., 2019; Prajapati et al., 2020; Gandhi and Pandya, 2022). By using Fig. 4-a to 4-f chatter frequency, the tooth- passing frequency, and amplitude ratio for without shim, SS shim and carbide shim are find out. Surface roughness for all shim is measure below 5 micron, so we conclude that VMC is working under standard conditions and it is not included here.

4-a



Without shim FFT in X-Longitudinal Feed

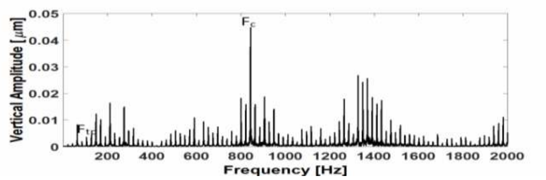
4-b



Without shim FFT in Y-Cross Feed

Figure 4-a FFT responses in the X direction **Figure 4-b** FFT responses in the Y direction for carbide shim with a cutting speed of 250 m/min , depth of cut 0.8 mm and feed 0.05mm/tooth

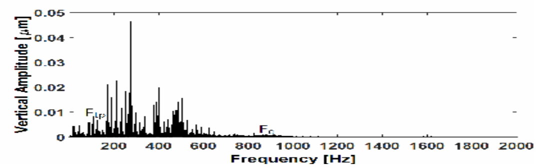
4-c



SS FFT In X-Longitudinal Feed

Figure 4-c FFT responses in the X direction

4-d

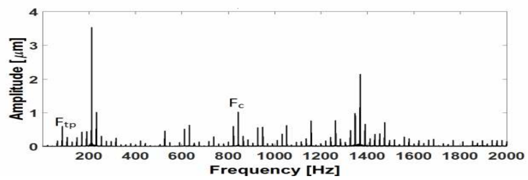


SS FFT in Y- Cross feed

Figure 4-d FFT responses in the Y direction

for SS shim with a cutting speed of 250 m/min , depth of cut 0.8 mm and feed 0.05mm/tooth

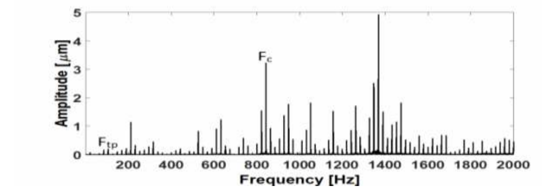
4-e



Carbide **shim FFT In X-Longitudinal Feed**

Figure 4-e FFT responses in the X direction

4-f



Carbide **shim FFT in Y- Cross feed**

Figure4-f FFT responses in the Y direction

for without shim with cutting speed 250 m/min, depth of cut 0.8 mm and feed 0.05mm/tooth

By observing above Figure 4.[(a-b), (c-d), (e-f)], it is clear that the amplitude ratio in X for carbide shim and the amplitude ratio in Y for SS shim are minimum, so both carbide shim and SS shim can give better results than a without shim face mill tool, irrespective of all cutting parameters. Without shim face mill on VMC, it gives chatter in crossover feed irrespective of its cutting parameters, which increases the probability of waviness and chatter. This is how the vertical milling center's face mill tool is currently operating. With SS shim face mill tool, vibration amplitude ratio was significantly damped out, 20 to 40% in crossover direction at medium and low cutting speeds, compared to without shim and carbide shim face mill tool. Hence the SS shim face mill tool is useful for reducing chatter at medium and lower cutting speeds. Carbide shim gives a 20 to 50% lesser vibration amplitude ratio compared with SS and without shim in all cutting conditions at a higher cutting speed of 250 m/min. Thus, the carbide shim vibration amplitude ratio was significantly damped out at a higher cutting speed. Hence carbide shim is useful for reducing chatter at high speed.

4. Findings of Experimental Analysis

4.1 Amplitude ratio diagram

In this study, under various machining settings, the dynamic behavior of the face mill tool with and without shims is examined (Gandhi and Pandya, 2022). The FFT graphs show the amplitude of chatter-frequency, tooth-passing frequency in X-longitudinal Feed and Y- cross feed of the face mill tool for different depths of cut (1.2mm, 1.0mm, 0.8mm) , cutting speeds (250, 200, 150 m/min) and feed (0.015, 0.01, and 0.05 mm/tooth). By using this value, the amplitude of chatter- frequency Fc (μm) divided by the amplitude of tooth- passing frequency Ftp (μm) is found out (Gandhi and Pandya, 2022). To observe the dynamic motion behavior of face mill tool of without shim and with shim face mill tool 3 graphs are generated as Figures 5a-5c for cutting speeds 250, 200 and 150 m/min respectively.

Figure 5a:1 for cutting speed 250 m/min

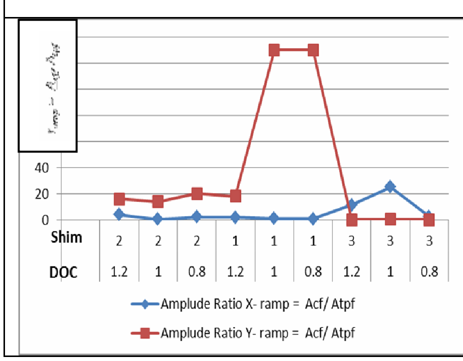


Figure 5b:1 for cutting speed 200 m/min

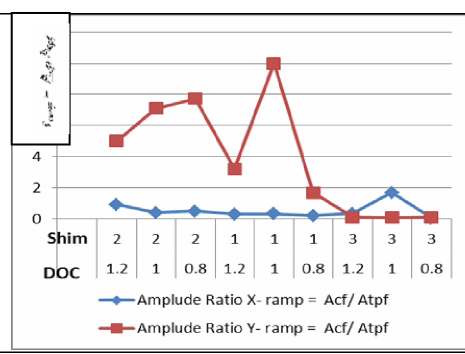
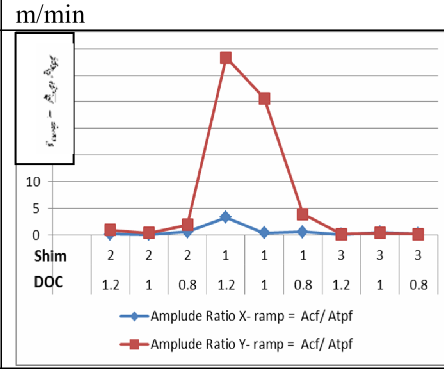


Figure 5c :1 for cutting speed 1500 m/min



By using Figures 5a to 5c of DOC Vs. amplitude ratio, It is evident that at a high cutting speed of 250 m/min, the carbide shim has the lowest amplitude ratio, which results in the lowest chatter. Because of this, using a carbide shim face mill tool can produce better results than using without shim and SS shim at high cutting parameters (Yuan et al., 2019; Prajapati et al., 2020; Gandhi and Pandya, 2022). While at medium 200 m/min and low 150 m/min cutting speed SS shim has a minimum amplitude ratio. Hence SS shim has minimum chatter; therefore SS shim face mill tool is useful for reducing chatter on VMC and it can give better results than without shim and carbide shim at medium and low cutting parameters.

5. ANOVA

To make a reliable and confident decision, we will require confirmation to support our approach. An ANOVA is a way to find out effectiveness and significance of experiment results (Ambigai and Prabhu, 2019; Pulido-González et al., 2020).

5.1 ANOVA for amplitude Ratio in X= R1 and Amplitude Ratio in Y= R2

Table 2 displays the findings of ANOVA for the face mill tool at R1 Amplitude Ratio in X and R2 Amplitude Ratio in Y. Additionally, the table displays the DF-degrees of freedom, SS- the sum of squares, MS-mean squares F-values, likelihood, and various interactions' P-values for each factor. The obtained models were reflected to be statistically substantial. That is desirable because it shows that the terms in the model have a significant impact on the response. A low p-value (<0.05) indicates statistical significance for the source on the corresponding response (i.e. P = 0.05, or 95% confidence level).

Table: 2 Analysis of variance (ANOVA) results of the quadratic model

R1 Amplitude Ratio in X						R2 Amplitude Ratio in Y						
Source of variance	Sum of squares	DF	Mean Squares	F Value	p-value Prob > F	Source of variance	Sum of squares	DF	Mean Squares	F Value	p-value Prob > F	
Model	5337000000	14	381214285.	34952.6	0.0005	Model	243700000	14	17407142.85	3192.03	< 0.0001	Significant
A-Cutting Speed	86950000	1	86950000	7972.23	0.0019	*A-Cutting Speed*	*4760000*	1	*4760000*	*872.86*	*< 0.0001*	Significant
B-DOC	73190000	1	73190000	6710.61	0.0022	*B-DOC*	*12330000*	1	*12330000*	*2261.016*	*< 0.0001*	Significant
C-Feed	115100000	1	115100000	10553.2	0.0014	*C-Feed*	*5716000*	1	*5716000*	*1048.17*	*< 0.0001*	Significant
D-Shim	469800000	1	469800000	43074.8	0.0003	*D-Shim*	*4501000*	1	*4501000*	*825.37*	*< 0.0001*	Significant
AB	203500000	1	203500000	18658	0.0016	*AB*	*14260000*	1	*14260000*	*2614.93*	*< 0.0001*	Significant
AC	415300000	1	415300000	38077.8	0.0008	*AC*	*25860000*	1	*25860000*	*4742.08*	*< 0.0001*	Significant
AD	546700000	1	546700000	50125.6	0.0006	*AD*	*61230000*	1	*61230000*	*11228.06*	*< 0.0001*	Significant
BC	255600000	1	255600000	2344.81	0.0013	*BC*	*26690000*	1	*26690000*	*4894.28*	*< 0.0001*	Significant
BD	508300000	1	508300000	46604.8	0.0006	*BD*	*58510000*	1	*58510000*	*10729.28*	*< 0.0001*	Significant
CD	257000000	1	257000000	23563.7	0.0013	*CD*	*50200000*	1	*50200000*	*9205.435*	*< 0.0001*	Significant
A^2	177010500	1	177010500	16229.6	0.054	A^2	13681030	1	13681030	2508.76	.0056	
B^2	187820400	1	187820400	17220.8	.0652	B^2	34750452	1	34750452	6372.37	0.065	
C^2	136810300	1	136810300	12543.7	.0723	C^2	17701050	1	17701050	3245.93	0.055	
D^2	347504520	1	347504520	31861.8	0.0521	D^2	34750452	1	34750452	6372.37	0.076	
Pure Error	163600	15	10906.6			Pure Error	81800	15	5453.3			
Cor Total	5337000000	29				Cor Total	24370000	29				

Model Summary Statistics Table 2

R1 Amplitude Ratio in X					R2 Amplitude Ratio in Y			
Std. Dev.	0.085563173	R-Squared(R^2)	0.999966194		Std. Dev.	0.7	R-Squared	0.9710
Mean	1.544418024	Adj R-Squared	0.999425303		Mean	876.85	Adj R-Squared	0.9600
C.V. %	5.540156354	Adeq Precision	157.8766565		C.V. %	0.08	Adeq Precision(S/N)	30.514

Table 2 represents the ANOVA and the factor values. The suggested model provided Adj-R2(R1=0.9994 and R2=0.960) values. They demonstrated the fair accuracy of the data and the model. The projected model's standard deviation R2 (R1=0.9999 and R2=0.9710) value, means that just one of the total variation was not described by the model. The model fineness can be determined by measuring the signal-to-noise ratio (Adeq. Precision), this should be more than 4. This study's figures (R1=156.77665 and R2=30.514). Also the adjusted R2 (R1=0.9994 and R2=0.960) value was close to the R2 (R1=0.9999 and R2=0.9710) values. This shows that the model efficiency was unaffected by the removal of non-significant components. According to the ANOVA results in Table 2, the coefficients of variation (R1=5.50 and R2=0.08). This shows the strong reliability and accuracy of the experiments. All parameters had a considerable impact on vibration amplitude, in both linearly and cross feed direction and the interactive effect was also significant (p = 0.05) on vibration amplitude with quadratic properties. Larger F values of AD (R1=50125.6, R2=11228.06) and BD (R1=46604.8, R2=10729.28) indicate that the variation of the corresponding process parameter makes a big change in the amplitude ratio. From the ANOVA analysis, as shown in Table 2, it can be conditional that the AD and BD have more impact than the AB, AC and BC. Use that graphs to best illustrate how the process behaves.

5.2 ANOVA Graphs for the face mill tool

The best approach when examining model graphs is to concentrate on the terms that have notable effects -higher F values. Use that graphs to best illustrate how the process behaves. As shown in Table 2, it can be conditional that the AD and BD have more impact than the AB, AC and BC. or the research's factor and response parameters, the analysis of variance was performed. F-Test was used in the ANOVA analysis to compare the model variance with the residual variance. According to F value highest was best for locating an essential input parameter if F value was nearing one, which indicates that both variances were equal.

5.2.1ANOVA graphs for face mill tool at R1 Amplitude Ratio in X for AD and BD

Figure 6. *Contour and 3D plots for AD DOC 1.2-mm Feed 0.05 mm/tooth at R1 Amplitude Ratio in X*

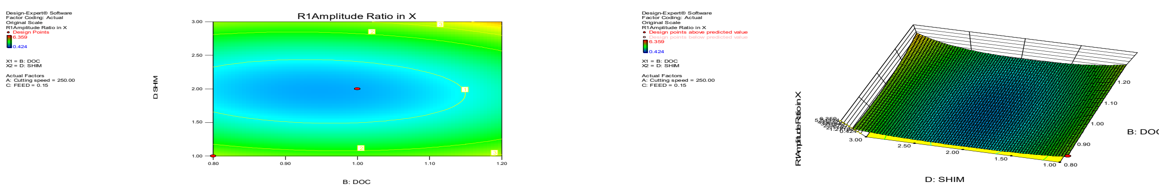


Figure 7. *Contour and 3D plots for BD Cutting Speed 250m/min Feed.15mm/tooth at R1 Amplitude Ratio in X*

Here from Figure 6 for AD, at 250m/min cutting speed has a minimum amplitude ratio and design points are available for shim 2(Carbide shim). At 200 and 150 m/min cutting speed has a minimum amplitude ratio and design points are available for shim 3 (SS shim). From Figure 7 for BD, at high-speed shim 2 (carbide shim) has given minimum Amplitude ratio in X, so carbide shim is better for face mill tool at high speed. SS shim can give better results for face mill to reducing chatter at medium and low cutting speed.

5.2.2 ANOVA Graphs for the face mill tool at R2 Amplitude Ratio in Y for AD and BD

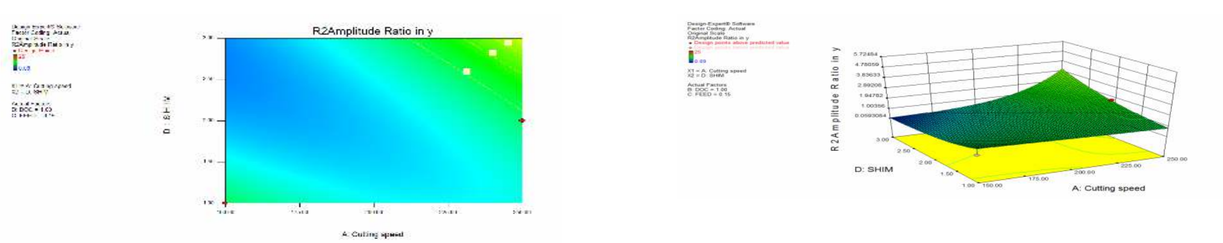


Figure 8. *Contour and 3D plots for AD DOC 1.2 mm Feed.15 mm/tooth at R2 Amplitude Ratio in Y*

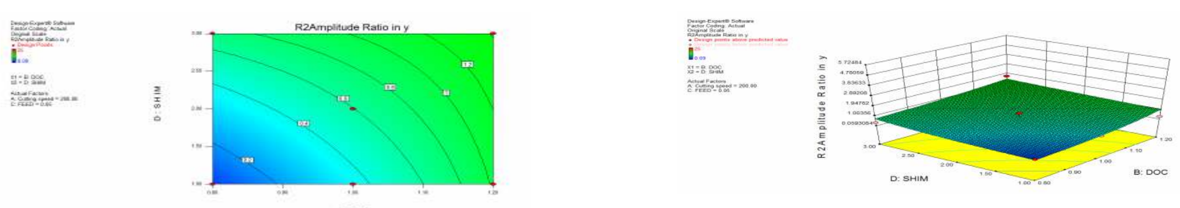
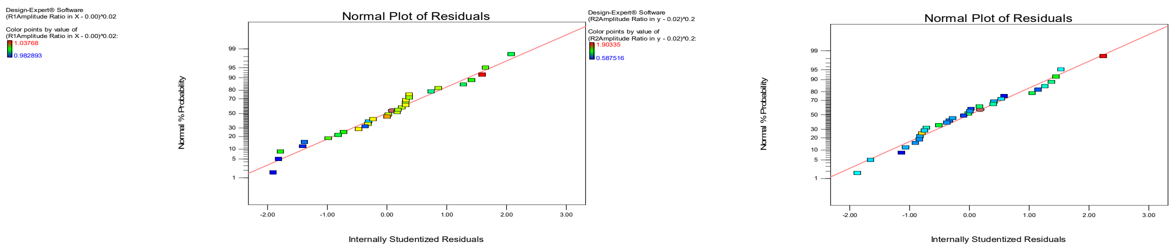


Figure 9. *Contour and 3D plots for BD Cutting Speed 200m/min Feed.05mm/tooth at R2 Amplitude Ratio in Y*

Here from Figure 8 for AD, at 250m/min cutting speed has a minimum amplitude ratio and design points are available for shim 2(Carbide shim). From Figure 9 for BD, at 250m/min shim 2 (carbide shim) has minimum amplitude ratio in X, so carbide shim is better for face mill tool at high speed. At 200 m/min cutting speed has a minimum amplitude ratio and design points are available for shim 3 (SS shim). Hence SS shim is better for face mill tool at medium and low cutting speed. Thus carbide shim is useful for reducing chatter at high cutting parameters and SS shim is at medium and low cutting parameters, which is validated with experimental analysis.

5.2.3 Diagnostic plots after ANOVA



Normal plot for R1 *Normal plot for R2*

Figure 10. Scatter plot of predicted value vs actual value from ANOVA design

Figure 10 indicates the validity of DOE method used for performing the experiment as the predicted values and the actual values are near to the average line shown in the Figure 10.

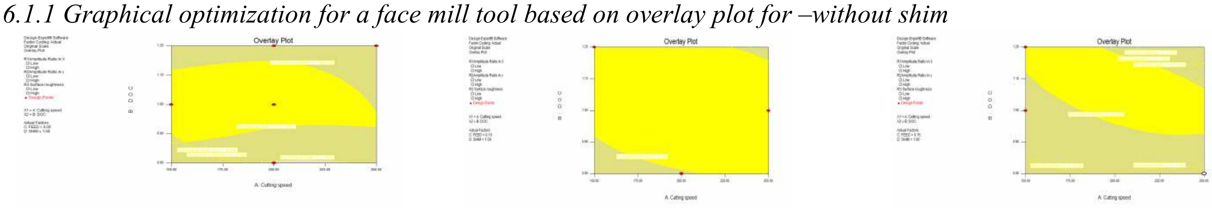
6. Optimization

Figure 10 indicates the validity of DOE method used for performing the optimization segment in Design Expert (Sharma et al., 2015). It examines a grouping of factor situations that concurrently satisfy the situations located on every one of the factors and responses.

6.1 Graphical Optimization

Graphical optimization uses the models to show the measures where suitable response results can be set up (Xaiyar et al., 2013; Moghaddam and Kolahan, 2016; Patil and Patil, 2020; Dinesh et al., 2021; Wang and Song, 2021). With multiple responses, regions where situations concurrently meet the critical properties are essential. On a plot of contour by overlapping unjustified response contours, the finest concern should be chosen. This optimization shows the area of accurate response values in the influence space. Here optimization based on optimum factorial method was executed using Design Expert software in which 35experiments and its iterations with 70 populations were used to run the program.

6.1.1 Graphical optimization for a face mill tool based on overlay plot for –without shim

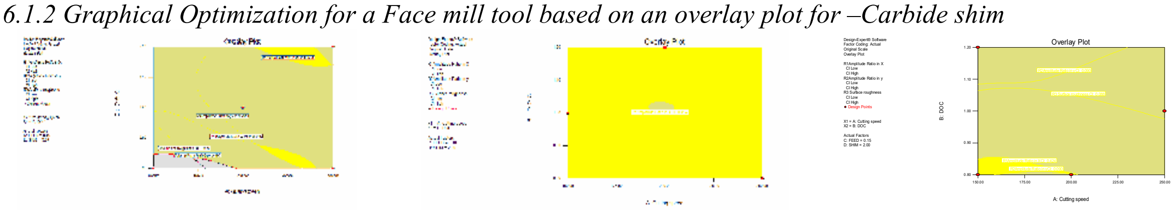


Shim 1 Feed 0.05 *Shim 1 Feed 0.1* *Shim 1 Feed 0.15*

Figure 11 *Graphical optimization for a face mill tool based on an overlay plot for shim (shim 1)*

From Figure 11, it is observed that for shim 1 (without shim) at high feed, total 2 design points available at 250 m/min cutting speed. No design points available at 150 and 200 m/min cutting speed; this is current scenario of VMC-Vertical Milling Centre operation of face mill tool.

6.1.2 Graphical Optimization for a Face mill tool based on an overlay plot for –Carbide shim

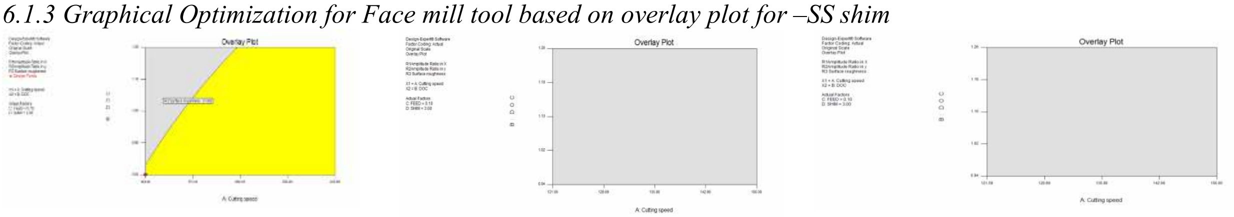


Shim 2 Feed = 0.05mm/tooth *Shim 2 Feed = 0.1 mm/tooth* *Shim 2 Feed = 0.15 mm/tooth*

Figure 12. *Graphical Optimization for a Face mill tool based on an overlay plot of carbide shim (shim 2)*

From Figure 12, it is observed that for shim 2(Carbide shim) Total 4 design points are available at 250m/min cutting speed, at high feed(0.15mm/Tooth) and no design points are available at 150 m/min, so, carbide shim is useful for reducing chatter at high cutting parameters, which is validated with experimental analysis.

6.1.3 Graphical Optimization for Face mill tool based on overlay plot for –SS shim



Shim 3 Feed = 0.05 mm/tooth *Shim 3 Feed = 0.1 mm/tooth* *Shim 3 Feed = 0.15 mm/tooth*

Figure 13. *Graphical Optimization for Face mill tool based on overlay plot for shim 3 –SS shim*

From Figure 13, it is observed that for (Shim 3) SS shim design points are available at cutting speeds of 150 and 200 m/min. Total 4 design points are available for SS shim at medium and low cutting parameters, SS shim is useful for low and medium cutting parameters, which is validated with experimental analysis. By graphical optimization Figures 11, 12 and 13, it is clear that carbide shim face mill tool is preferable for higher cutting parameters, while SS shim face mill tool is preferable for medium and lower cutting parameters. This is validated with experimental analysis and proven by optimization.

7. Conclusion

Physical 35 experiments may not be enough in a view of high level researchers academicians to conclude the use of shim and it need in face mill tool on VMC Hence here optimization based on optimum factorial method was executed using Design Expert software in which 35experiments and its iterations with 70 populations are used to run the program. To reduce chatter; the author came to the following major conclusions. Based on the computational and experimental analysis, with SS shim face mill tool vibration amplitude ratio was significantly damped out, 20 to 40% in crossover direction at medium and low cutting speeds, compared to without shim and carbide shim. Hence SS shim is useful for reducing chatter at medium and lower cutting parameters. With carbide shim face mill tool vibration amplitude ratio was significantly damped out, 20 to 50% compared to SS shim face mill tool and without shim face mill tool in all cutting conditions at a higher cutting parameters (Kull Neto et al., 2016). Hence at carbide shim is useful for reducing chatter, at higher cutting parameters. Hence carbide shim is useful for reducing chatter at high cutting parameters.

Based on the Design Expert ANOVA and the graphical optimization , For minimizing chatter carbide shim is preferable for higher cutting parameters while for lower and medium cutting parameters SS shim is preferable. This is validated with experimental analysis, hence these shim designs endorse versatile solutions and proven by optimization. Furthermore, the article may be useful to machining engineers. Here, we have develop the chatter and tool performance data base after analysing different machining parameters like Cutting speed (250,200,150 m/min), feed per tooth (0.05, 0.1, 0.15mm/tooth), depth of cut (1.2 mm, 1.0 mm, 0.8 mm), and shim (carbide, SS, without shim) which would useful for machining engineer. Besides, for the Design of experiment, the Design Expert is used and not another optimization tool because Design expert is a better choice when carrying out optimization of production process. Design expert is structured and more detailed than Minitab with regards to optimization process. Design Expert is more preferable than Minitab when carrying out optimization test. Design Expert is easy and reliable with reproducible results. Algorithm for both is same. Design Expert better in terms of interpretation and graphics for Optimization purposes. Easy to use without experience, clearly graphs etc. Also, although this tool is useful for continuous process and mass production, its limitation is that it is less useful for job or batch production.

Nomenclature

DOC	Depth of cut in mm	ANOVA	Analysis of variance
Fc	Chatter -frequency in Hz	A	Cutting speed in m/min
Ftp	Tooth -passing frequency in Hz	B	Depth of cut in mm
Acf	Amplitude of Chatter frequency in in µm	C	Feed in mm/Tooth
Atpf	Amplitude of tooth passing frequency in µm	D	SHIM
ramp	Amplitude Ratio	R1	Response 1, Amplitude Ratio in X
VMC	Vertical milling Centre	R2	Response 2, Amplitude Ratio in Y

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