Influence of Tooth Passing Frequency, Chatter Frequency, Depth of Cut and Amplitude Ratio on Chatter Reduction and Stability Analysis of Face Mill Tool for Carbide Shim, Without Shim and No Load Condition

*N.B.Gandhi[1] , *D.H.Pandya[2]

[1], Research Scholar, Department of Mechanical Engineering, LDRP ITR, KSV University, Gandhinagar, Gujarat, India
[2],Professor and Head, Department of Mechanical Engineering, LDRP ITR, KSV University, Gandhinagar, Gujarat, India

Abstract **: The purpose of this research is to find a distinct boundary between steady and unsteady machining behavior using FFT- Frequency response curve in form of frequency- Amplitude to establish a new stability metric of cutting condition (carbide shim, without shim and no load condition) and Amplitude Ratio. For this purpose machine tool chatter has been studied which involves amplitude ratio calculations based on face mill tool FFT which produce the stability diagram using frequency domain approaches. We have used experimental approach to analysis stability of face milling is based on FFT of the system obtained by Vibration signals which are taken with use of Try axial sensor attached to VMC- Vertical Milling Centre. Vibration signals are obtained in time domain and using MATLAB software to generate FFT. Here to study stability analysis Carbide shim, without shim and No load conditions are considered. Machine spindle frequency, Tooth passing frequency, Chatter frequency and depth of cut are used to generate graph of Amplitude Ratio to find stability of face mill tool. This experimental research tries to found that how we can use face mill different cutting conditions to restrict chatter in VMC operation.**

Keywords**: Machine tool chatter, FFT, Vertical Milling Centre, Tooth passing frequency, stability graph**

1. Introduction

K Kolluru[8] emphasized that Chatter is created due to regenerative vibration on work piece. Chatter is a serious problem in machining. It can become quite violent and generate a distinctive loud noise. Chatter in machining is very bad for tool life, restricts with the accuracy of the machining operation, higher energy consumption and will shorten the life of machine tool, ultimately it reduce productivity. Hence analyzing chatter is most favorite research topic for academicians and CNC professionals. Regenerative chatter is a so-called self-excited oscillation because the vibration itself generates the energy that again creates the vibration.[8]. MOU Wenping observed[1] that In the past few decades, lots of studies have been conducted to avoid the chatter in machining. Most commonly, for a certain spindle-tool combination, machining tests can be conducted to find the stability range of the cutting parameters. But in practice, a large number of machining test is time consuming and waste of materials. In recent years, along with the development of intelligent manufacturing, online chatter monitoring became a topic of huge interest. Monitoring and precise detection of the chatter is critical during machining. To figure out such problem, lots of signal processing methods need to applied, such as moving average filter, multiband resonance filtering, comb filter, Wiener filter, fast Fourier transform (FFT), power spectral density (PSD), short-time Fourier transform (STFT), wavelet transform, wavelet package transform (WPT), Hilbert–Huang transform (HHT), empirical mode decomposition (EMD), ensemble empirical mode decomposition (EEMD), variational mode decomposition (VMD), synchro squeezing transform (SST), envelope analysis, singular spectrum analysis (SSA), singular value decomposition (SVD), estimation of signal parameters via rotational invariance techniques (ESPRIT), Poincare and cyclostationary method. And lots of indicators were established to distinguish stable and chatter, such as statistical indexes, scalar descriptors, various variations and ratios, C0 complexity, power spectral entropy, energy entropy, singular value entropy (SVE), fractal dimension, first-order singular value, regression coefficient, minimum quantization error (MQE) and synchronous angular statistic parameters. Some intelligence algorithms were also adopted to classify the unstable and stable, such as artificial neural networks (ANN), hidden Markov model (HMM), support vector machine (SVM), and simulated annealing (SA) algorithm. All methods based on EMD need to strength their theoretical basis, and although EMD can effectively decompose the non-stationary signal using sum of Amplitude-Modulated-Frequency-Modulated (AM-FM) signal, EMD cannot be analyzed from the theory and performance evaluation.26 VMD was introduced in the framework of a variational problem by Dragomiretskiy and

Zosso.40 Wang, et al.41[1]Ozturk, E. , Budak, [18] presented The application of stability diagrams is an efficient tool to predict chatter free cutting conditions. Although several stability models have been developed for milling operations, they are limited to 3 axis milling applications. In an earlier study by the authors, a stability model for 5 axis milling was presented using single frequency solution. Due to the time varying nature of the milling dynamics, a multi frequency system response may be obtained for cases where radial depth of cut is small. These frequencies show up in the system response in the form of addition and subtraction of the chatter frequency and harmonics of the tooth passing frequency. In the present study, dynamics of 5-axis milling is modeled analytically considering multi-frequency effects. The existence of multi frequency response is demonstrated.[18]

Y Liu, Z Liu examined[15] that the dynamics behavior of CLD tool holder is first considered to be influenced by the chatter frequency due to the viscoelastic material. The mechanical properties of viscoelastic materials are determined by the testing frequency. Analytical models are built to calculate the modal parameters such as damping ratio. The chatter frequency Dependence further increases the critical depth of cuts in stability lobes. Then, dimensions of the CLD structure are simulated and selected to increase damping where the chatter frequency is assumed to approximate the natural frequency, after that the developed CLD tool holder is manufactured. Lastly, modal tests and cutting experiments are performed for verification. The damping ratio of developed CLD tool holder is increased by 99% compared to that of conventional steel tool holder using experiments and numerical solutions. The effect of multi frequency dynamics on the stability diagrams are shown by the analytical solutions and time domain simulations.[15]HK Neto [10] examined that the tool is usually long with a small diameter, and therefore vibrates easily. Its trajectory must follow the surface shape, causing its effective diameter in contact with the workpiece to change as the cutter travels along the surface. Consequently, cutting speed also varies, which may affect tool life and surface roughness. Since the tool is not rigid, the tooth passing frequency, which is the main frequency of the cutting forces, may be close to the natural frequency of the tool, often leading to high vibration and even chatter.

Xu, T Zhou[12], Indicated that Chatters generated during Cutting is vicious self-excited vibration between tool and work piece, which will seriously degrade the machining surface quality and health of machine tool. Online monitoring of chatter phenomenon can feed back the control system to adjust processing parameters dynamically for chatter suppression. In this paper, short-time difference spectrum analysis (STDSA) is proposed for early chatter identification, which can recognize chatter frequency and track its amplitude from low SNR vibration signal at early stage. The method is verified by both simulated vibration signals and machining vibration signals collected FFT from an axle lathe. Comparison between classic variational mode decomposition (VMD) and STDSA is given to illustrate its performance. The results indicate that the method is robust to noise and has little warning time delay, which makes it suitable for the online monitoring of cutting chatter in industrial production environment.[12]

Our goal is to measure the limit of stable and unstable condition in VMC-Vertical Milling Centre with face mill tool. This kind of experimental work is initiated and introduced by this research paper where stability diagram is used to fix stable and unstable vibration and chatter in VMC using face mill tool. MA Rubeo[16] stated that Study of the vibration frequencies at different cutting conditions is an alternative to the use of impact hammer test for identifications of natural frequencies/ chatter frequencies of the machining structure and calculation of stability lobe diagrams. Vibration frequencies not only depend on the natural frequencies of the structure, but also they are depends on the spindle speed, frequency amplitude ratio (chatter frequency to tooth passing frequency) of the structure and the depth of cut. In this study, method is used to investigate the effects of different depth of cut and frequency amplitude ratio (tooth passing frequency to chatter frequency) of the structure on chatter for carbide shim, without shim and no load condition. The quality of frequency prediction is obtained by FFT of linear and nonlinear time domain signals of machining experiments.

2. Experimental methodology and results

Experiments are carried out on VMC- Vertical Milling Centre with CoCo 80 dynamic signal analyzer and surface roughness tester (-200 µm to 150µm) to analyze Depth of cut- Amplitude ratio also Depth of cut- frequency ratio and evaluate Stability diagram. This Setup used for the collection of vibration signals is as shown in the Fig.1 (a). Vibration signals are taken with use of Try axial sensor attached to VMC- Vertical Milling Centre tool holder. Analyzer gives the displacement-time, velocity-time, acceleration-time and frequency-amplitude relations in reference to each other which help to plot motion study graphs. The experiments were carried out on the CVM 640

(VMC- Vertical Milling Centre) Milling machine with two face milling tool, 1st is special purpose Kyocera make face milling tool Ø 63 mm with 5 inserts cutting tool and 2nd is Kyocera make face milling tool Ø 63 mm with 5 inserts and with shim as shown in Fig 1 (b), work piece Plate of 75*25*300 mm of 2062 mild steel 130 BH were used for the experiments. The machining was done using TNMG 120412 (Carbide) insert. The experiments were conducted at 1 Cutting speed (250m/min), 1 Feed Per Tooth (0.05mm/tooth), 3 Depth of cut (1.2 mm, 1.0 mm, 0.8 mm), and Carbide shim , Without shim and No Load face mill cutting condition are taken for experiments as shows in table Ⅳ.I, Ⅳ.II and Ⅳ.III . Here for Finding Spindle rotational frequency, tooth passing frequency and chatter frequency (system natural frequency) and its amplitude three cutting condition (Carbide shim, without shim and no load cutting condition) with Cutting speed 250m/min and depth of cut 1.2 mm, 1.0 mm, 0.8 mm are taken as shows in table Ⅳ.I, Ⅳ.II and Ⅳ.III .

The displacement data collected using CO CO80 dynamic signal analyser. EDM software is used to plot displacement data. MATLAB is used to generate The Fast Fourier Transformation (FFT) graphs to find the dynamic behavior of face mill tool. From FFT graphs we found Rotational frequency, tooth passing frequency, chatter frequency and its amplitude as shown in Fig Fig. 2.[(a-b), (c-d), (e-f)].

Fig. 1.(a) *CVM milling Machine with CoCo80 Dynamic Signal analyser with Try Axial Sensor*

Fig. 1.(b) *face milling tool 63 mm dia with shim and Without shim face mill*

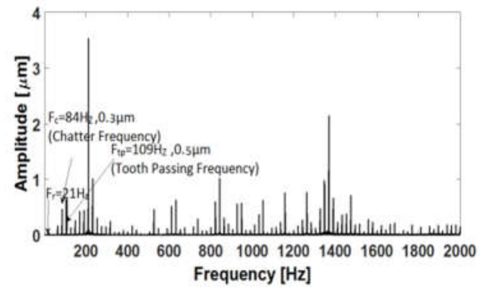
3. Data collection of vibration and dynamic motion behavior analysis

3.1 Data collection

Data collection is the process of converting the vibration signals of physical Components-(CoCo 80 dynamic signal analyser) into the numerical data which can be precisely studied and analyzed. To find out chatter, vibration signals are taken with different depth of cut cut(1.2 mm, 1.0 mm, 0.8 mm), with different cutting condition(carbide shim , without shim and No load) at 250m/m cutting speed. TDR (Time Displacement Response) and FFT (Fast Fourier Transformation) graphs were generated with the help of EDM and MATLAB software. Rotational frequency, Chatter frequency and Dynamic Motion Behavior for above conditions have been studied and analyzed by using TDR and FFT graphs.

The signal is sampled at 2 kHz, and a length of 10 s signal is considered. Due to the low amplitude of chatter vibration and interferences of other components, it is hard to find chatter vibration in time domain. Hence FFT graphs were generated with the help of EDM and MATLAB software. These FFT graphs are Amplitude vs. Frequency (Hz). This graph consists of X- longitudinal feed direction and Y-cross feed direction. As Fig. 2.[(a-b), (c-d), (e-f)] shows the different FFT graphs for carbide shim , without shim and No load face mill tool with cutting speed 250 m/min , Depth of cut 1.2 mm and feed 0.05mm/tooth. It shows the frequency spectrum of the different signal. Although the chatter vibration can be identified in frequency domain, chatter frequency is normally unknown for the cutting process because it is a dynamic parameter of complex cutting system. Without the prior knowledge of chatter frequency, reason of chatter cannot be understand and explain. So amplitude ratio method and frequency ratio method is used to process the signals and their results are compared.

a



b

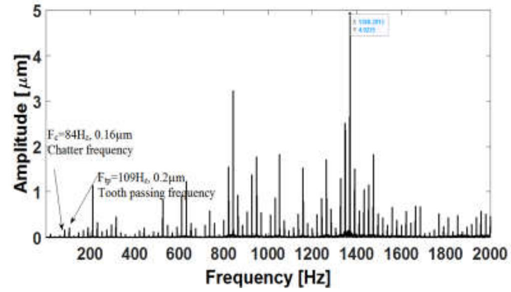
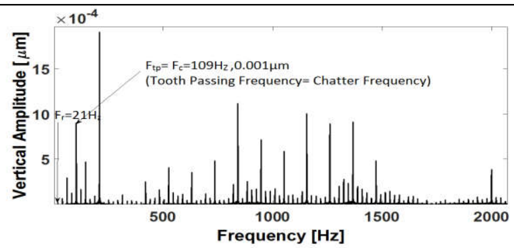


Fig. 2.(a-b): ***Experimental result: shows the different FFT graphs, for the dynamic motion behavior analysis for X direction- longitudinal and Y direction- Cross Feed for Carbide Shim face mll(a-b) That shows that Chatter frequency is lower than tooth passing frequency in X direction in Y direction for Carbide shim with Cutting speed 250 m/min , Depth of cut 1.2 mm and feed 0.05mm/tooth***

c



d

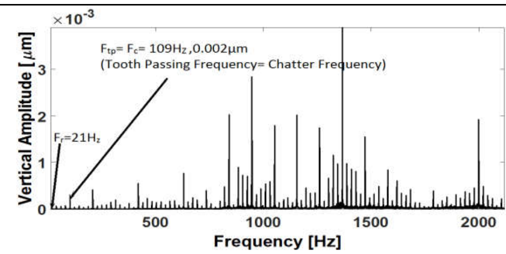
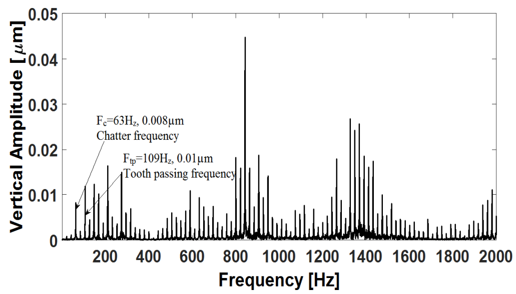


Fig. 2.(c-d): *Experimental result: shows the different FFT graphs, for the dynamic motion behavior analysis for X direction- longitudinal and Y direction- Cross Feed for without Shim face mll (c-d) That shows that Chatter frequency is equal to tooth passing frequency in X direction and in Y direction with Cutting speed 250 m/min , Depth of cut 1.2 mm and feed 0.05mm/tooth*

e



f

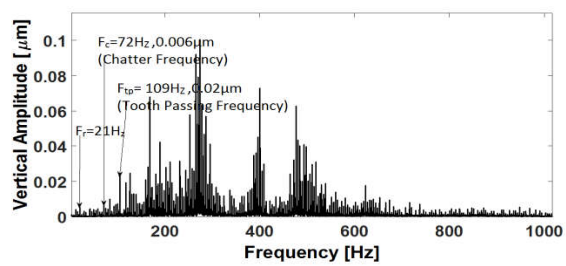


Fig. 2.(e-f): *Experimental result: shows the different FFT graphs, for the dynamic motion behaviour analysis for X direction- longitudinal and Y direction- Cross Feed for No load face mill (c-d) That shows that Chatter frequency is 0.8 to tooth passing frequency in X direction and Chatter frequency is 0.3 than tooth passing frequency in Y direction with Cutting speed 250 m/min , Depth of cut 1.2 mm and feed 0.05mm/tooth*

4. Result and findings of experimental analysis

In this paper, the face mill tool behavior is observed for different machining conditions are as given in Table IV.I. The result of FFT graphs shows Chatter frequency, tooth passing frequency and amplitude of Chatter frequency, tooth passing frequency of face mill tool for different depth of cut (1.2mm,1.0mm,0.8mm) with Cutting speed 250 m/min and feed 0.05 mm/tooth. Table IV.I shows X-longitudinal feed and Y-cross feed of FFT graphs, frequency in Hz and amplitude in (µm) by using this value the ratio of Chatter frequency Fc(Hz) to Tooth passing frequency (Hz) and its amplitude(µm) ratio is calculated. To find out the effect of (depth of cut)DOC- Amplitude ratio and (depth of cut)DOC- Frequency ratio on face mill cutting condition , Table IV.I is used and graph is generated from it which shows in Graph: 1 and Graph: 2.

Sr.No	Cut. Speed (m/min), Doc(mm), Feed(mm/ tooth)	Face mill cutting condition	Tooth passing frequency F_{tp}(109H_z) and Amp(µm) A_{tp}				Amp(µm)Chatter frequency F_c(H_z) and Amp(µm) A_{cf}				Frequency Ratio and Amplitude Ratio F_c (H_z)and Amp(µm) A_{cf} / F_{tp} (H_z) and Amp(µm) A_{tp}			
			X		Y		X		Y		X		Y	
			(H_z)	A_{tp} (µm)	(H_z)	A_{tp} (µm)	(H_z)	A_{cf} (µm)	(H_z)	A_{cf} (µm)	f_c //f_{tp}	r_{amp} = A_{cf} /A_{tp}	f_c /f_{tp}	r_{amp} = A_{cf}/A_{tp}
1	250/1.2/0.05	Carbide	109	0.5	109	0.2	84	0.3	84	0.16	0.77	0.6	0.77	0.8
2	250/01/0.05	Carbide	109	0.6	109	0.5	84	0.5	109	0.5	0.77	0.83	1.0	0.83
3	250/0.8/0.05	Carbide	109	0.045	109	0.9	84	0.04	109	0.9	0.77	0.88	1.0	1
4	250/1.2/0.05	w/o Shim	109	0.001	109	0.004	109	0.001	109	0.004	1.00	1	1.00	1
5	250/01/0.05	w/o Shim	109	0.002	109	.00009	63	0.0023	147	0.0001	0.58	1.15	1.35	1.1
6	250/0.8/0.05	w/o Shim	109	0.004	109	.00008	109	0.0045	210	0.0001	1.00	1.125	1.93	1.2
7	250/1.2/0.05	No Load	109	0.01	109	0.02	63	0.008	72	0.006	0.58	0.8	0.66	0.3
8	250/01/0.05	No Load	109	0.001	109	0.008	63	0.0001	42	0.002	0.58	0.1	0.39	0.25
9	250/0.8/0.05	No Load	109	0.008	109	0.008	84	0.005	42	0.004	0.77	0.7	0.39	0.5

Table IV.I. *Face mill Frequency Ratio and Amplitude Ratio of Chatter frequency V/S Tooth passing frequency*

Table IV.I shows that in case of carbide shim frequency ratio (F_c/F_{tp}<<1) is remain constant as 0.77 for all (depth of cut) DOC(1.2mm,1.0mm,0.8mm). and Amplitude ratio ($r_{amp} = A_{cf}/ A_{tpf}$) is minimum(0.6 in x feed and 0.8 in y feed) for maximum depth of cut (1.2mm) and Amplitude ratio ($r_{amp} = A_{cf}/ A_{tpf}$) maximum(0.88 in x feed and y feed) for minimum depth of cut(0.8mm). in case of without Shim frequency ratio(F_c/F_{tp}<<1) is (1.0 in x feed y feed) for maximum depth of cut (1.2mm) and Amplitude ratio($r_{amp} = A_{cf}/ A_{tpf}$) is minimum(1.0 in x feed y feed) and for minimum depth of cut (0.8mm) Amplitude ratio($r_{amp} = A_{cf}/ A_{tpf}$) is maximum(1.125 in x feed and 1.2 in y feed) with Cutting speed 250 m/min and 0.05 mm/tooth feed in x feed. in case of No Load condition frequency ratio(F_c/F_{tp}<<1) is 0.580,0.58,0.77 and Amplitude ratio($r_{amp} = A_{cf}/ A_{tpf}$) is 0.8,0.1,0.7 for doc (1.2mm,1.0mm,0.8mm) respectively in x feed and frequency ratio(F_c/F_{tp}<<1) is 0.66,0.39,0.39 and Amplitude ratio($r_{amp} = A_{cf}/ A_{tpf}$) is 0.3,0.25,0.5 for doc (1.2mm,1.0mm,0.8mm) respectively in y feed.

5. Amplitude Ratio Diagram

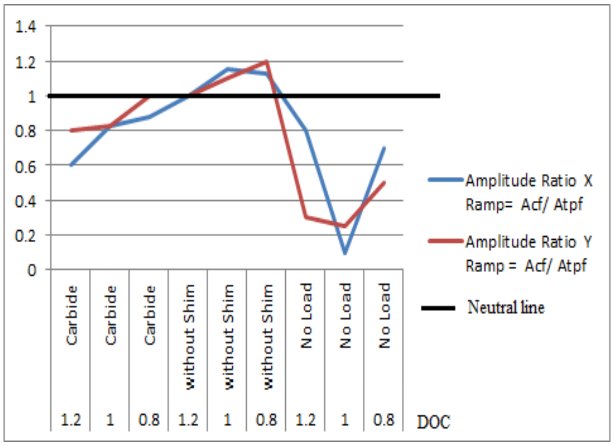
Purpose of this research is to find out a distinct boundary between stable and unstable machining behavior using FFT(Frequency response curve) in form of frequency - amplitude which used to establish a new steadiness metric with help of generating Graphs of DOC(depth of cut) V/S Amplitude Ratio ($r_{amp} = A_{cf}/ A_{tpf}$)and DOC(depth of cut) V/S Frequency Ratio Fc/Ftp . The amplitude ratio stability metric provides a quantitative measure of the occurrence and severity of chatter. The outcome of frequency domain FFT contains specific information as Frequency Ratio (F_c/F_{tp}<<1)and Amplitude Ratio ($r_{amp} = A_{cf}/ A_{tpf}$)combinations as shown in Table IV.I . This comprises the instantaneous cutting forces and tool / workpiece deflections, velocities, and accelerations which can be denoted in the frequency domain of Table IV.I. The frequency of the milling signals contains the tooth passing frequency, spindle rotational frequency, Chatter frequency and their multiples (or harmonics). Therefore, stable cuts may be described as having a “synchronization of chatter frequency with the tooth passing frequency”. Unstable cuts also contain these frequency components, however, they also exhibit “a chatter frequency which results in a asynchronous with the tooth passing frequency” This chatter frequency is typically close to the natural frequency of the most flexible structure in the machine-tool workpiece system. Since chatter can be identified by the display of a chatter frequency and the severity of chatter can be forecast by the ratio of amplitude of the chatter frequency relative to amplitude of the tooth passing frequency. [16]

DOC-Amplitude ratio Graph: 1 derived from Table IV.II. which derived from Table IV.I. further DOC-frequency ratio Graph: 2 derived from Table IV.III. which derived from Table IV.I. are generated through FFT with parameters given in Table IV.II. and Table IV.III. Finally for each combination of cutting condition and axial depth of cut the amplitude ratios are plotted as a Graph: 1 and frequency ratios plotted as a Graph: 2.

The amplitude ratio, ramp, is calculated as:

$$r_{amp} = A_{cf}/ A_{tpf}$$

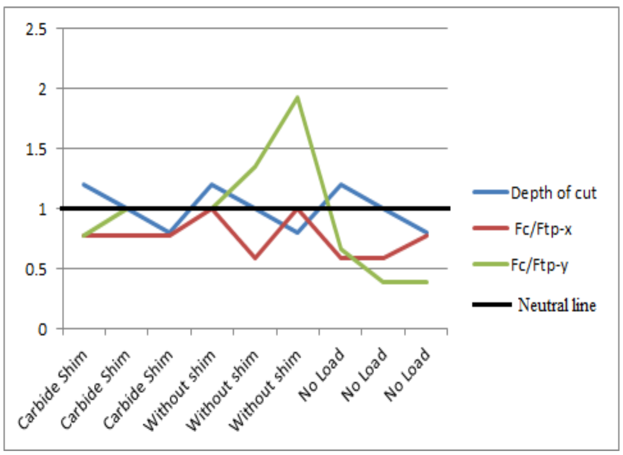
where A_{cf} is the amplitude of the chatter frequency and A_{tpf} is the maximum amplitude of the tooth passing frequency (and harmonics) in a given milling signal. An illustrative example of an amplitude ratio diagram is displayed in Graph: 1. This diagrams provide global stability information over a 250m/min spindle speeds and axial depths of cut 1.2mm,1.0mm,0.8mm. Large stable regions are evident that are predicted to contain no chatter frequency below the neutral line . Further, the severity of chatter is evident by value of the amplitude ratio. It may be the case that a small chatter frequency (r_{amp} <<1)is acceptable for most machine shop applications. However, as the amplitude ratio becomes larger chatter becomes increasingly severe.[16] It is validated with DOC-frequency ratio Graph: 2 derived from Table IV.III.



Graph: 1 *DOC- Amplitude Ratio A_{cf}/ A_{tpf} (stability diagram)*

Doc (mm)	Face mill cutting condition	Amplude Ratio X- r_{amp} = A_{cf}/ A_{tpf}	Amplude Ratio Y- r_{amp} = A_{cf}/ A_{tpf}
1.2	Carbide	0.6	0.8
1	Carbide	0.83	0.83
0.8	Carbide	0.88	1
1.2	without Shim	1	1
1	without Shim	1.15	1.1
0.8	without Shim	1.125	1.2
1.2	No Load	0.8	0.3
1	No Load	0.1	0.25
0.8	No Load	0.7	0.5

Table IV.II. *DOC- Amplitude Ratio r_{amp} = A_{cf}/ A_{tpf}*



Graph: 2 *DOC- Frequency Ratio F_c/F_{tp}(stability diagram)*

Doc (mm)	Face mill cutting condition	Frequency Ratio-X F_c/F_{tp}	Frequency Ratio-Y F_c/F_{tp}
1.2	Carbide	0.77	0.77
1	Carbide	0.77	1.0
0.8	Carbide	0.77	1.0
1.2	without Shim	1.00	1.00
1	without Shim	0.58	1.35
0.8	without Shim	1.00	1.93
1.2	No Load	0.58	0.66
1	No Load	0.58	0.39
0.8	No Load	0.77	0.39

Table IV.III. *DOC- Frequency Ratio= Fc/Ftp*

From table **IV**.II and Graph: 1 shows that neutral line is the limit of stable and unstable for all cutting condition. For carbide shim using maximum depth of cut Amplitude Ratio (r_{amp} = A_{cf}/ A_{tpf})is minimum. And with decrease of depth of cut, Amplitude Ratio (r_{amp} = A_{cf}/ A_{tpf})is increasing. It is below the neutral line with high doc (1.2mm and 1mm)0.66 to 0.88 (r_{amp} <1) hence it is stable for high doc. For minimum 0.8mm doc Amplitude Ratio (r_{amp} = A_{cf}/ A_{tpf})is on neutral line s(r_{amp} = A_{cf}/ A_{tpf})in y feed, and 0.88(r_{amp} = A_{cf}/ A_{tpf})in x feed hence it is uncertain or stable for 0.8 mm doc. Amplitude Ratio (r_{amp} = A_{cf}/ A_{tpf})is maximum for without shim in X-feed And Y-feed for all cutting condition (1.2mm and 1mm and 0.8mm) 1to 1.2(r_{amp} >/=1) it is not below the neutral line so it is uncertain or unstable cutting condition. Amplitude Ratio (r_{amp} = A_{cf}/ A_{tpf})is minimum 0. 1to 0.8(r_{amp} <<1) with No load condition and it is below the neutral line so it is stable cutting condition in X-feed And Y-feed for all cutting condition (1.2mm and 1mm and 0.8mm).
Above all parameters are validated by Graph: 2 DOC- Frequency Ratio (F_c/F_{tp}<<1)and Table IV.III.

6. Results

The stability diagram obtained using the DOC- Amplitude Ratio(r_{amp} = A_{cf}/ A_{tpf})is displayed in Graph: 1 and Doc-Frequency Ratio(F_c/F_{tp}<<1) in Graph: 2 by using Table IV.II and Table IV.III respectvely. (r_{amp} >/=1) shows unstable vibration / chatter and (r_{amp} = A_{cf}/ A_{tpf}<1) shows stable vibration / chatter in stability diagram. Thus it show the boundary between the chatter and no chatter region and identifying the stable and unstable cutting zone.

The stability diagram obtained using the DOC- amplitude ratio Graph: 1 is derived from Table IV.II.Furter DOC-Frequency Ratio (F_c/F_{tp}<<1)Graph: 2 is derived from Table IV.III. The horizontal axis is expressed as different cutting condition and doc and the on vertical axis is expressed as amplitude ratio of the chatter frequency to the tooth passing frequency ($r_{amp} = A_{cf}/ A_{tpf} < 1$). In most machine shop applications (r_{amp} <<1) and chatter frequency is ideal condition. .However, as the amplitude ratio(r_{amp} >>1) becomes larger, chatter becomes increasingly severe and damaging. From table IV.II and Graph: 1 and also From table IV.III and Graph: 2 shows that neutral line (ramp =1) between stable and unstable cutting condition. In case of without shim Amplitude Ratio(A_{cf}/ A_{tpf})and Frequency Ratio (F_c/F_{tp}) is maximum in X-feed And Y-feed for all cutting condition and above or equal to the neutral line, so it is unstable cutting condition. In case of No load condition Amplitude Ratio(A_{cf}/ A_{tpf}<<1) and Frequency Ratio(F_c/F_{tp}<<1) is minimum and it is below the neutral line so it is stable cutting condition. In case of carbide shim for maximum depth of cut DOC (1.2mm and 1mm) Amplitude Ratio (A_{cf}/ A_{tpf}<<1) and Frequency Ratio (F_c/F_{tp}<<1) is minimum and below the neutral line so it is stable condition and decrease of depth of cut (0.8mm) Amplitude Ratio ($r_{amp} = A_{cf}/ A_{tpf} =1$) and Frequency Ratio ($F_c/F_{tp}$<<1) is equal to the neutral line so it is uncertain.

As find out by author N.B.Gandhi[19] Table IV. IV. Damping Ratio for Different Shim material using computational analysis.

Shim	Natural Frequency Fr (Hz)	Max amplitude (mm)	Half power point	F1(Hz)	F2(Hz)	Damping Ratio
Carbide	6392.2	1.21E-02	8.55E-03	6356.812	6437.238	**0.0063**
Without shim	8700.3	1.298E+08	9.17E+7	8655.81	8756.435	**0.0057**

Table IV.IV *Damping Ratio for Different Shim material*

Above Table IV. IV. gives following conclusion from the computational analysis - harmonic analysis. Carbide has higher value for damping ratio than Without shim face mill tool.

7. Conclusion

Table IV.II and Graph: 1[DOC v/s amplitude ratio(A_{cf}/ A_{tpf})] gives following conclusion

- Before initiating operation there is minimum vibration and no chatter which recognize as no load condition to compare with without shim face mill and carbide shim face mill tool.
- Without shim face mill on VMC gives unstable cutting condition as show in Graph: 1 which is current scenario of VMC-Vertical Milling Centre operation of face mill as per experimental data. Without shim face mill damping ratio is lower than carbide shim material using computational analysis.
- Carbide shim face mill on VMC gives stable cutting condition with maximum depth of cut compare to without shim face mill as per experimental data and new findings which is useful to reduce vibration and chatter. Carbide shim has higher damping ratio than without shim face mill tool using computational analysis done by author.

Table IV.III and Graph: 2 [DOC v/s Frequency Ratio (F_c/F_{tp}<<1)] shows that conclusion of Table IV.II and Graph:1[DOC v/s amplitude ratio(Acf/ Atpf)] is validated as following.

- Without shim face mill on VMC gives unstable cutting condition as show in Graph: 2. But Frequency Ratio (F_c/F_{tp}<<1) is lower than amplitude ratio(A_{cf}/ A_{tpf}) in x-Feed and higher than amplitude ratio(A_{cf}/ A_{tpf}) in y-Feed
- Carbide shim face mill on VMC gives stable cutting condition with maximum depth of cut compare to without shim face mill as per experimental data and new findings which is useful to reduce vibration and chatter. But Frequency Ratio (F_c/F_{tp}<<1) is remain constant as 0.77 in x-feed.

Thus results are much closer to each other in face mill on VMC In this paper. Above Conclusions Is validate with table IV.III and Graph: 2 also with damping ratio table IV.III.

Acknowledgements-

Authors would like to acknowledge the support received by Green KSV Skill Development Centre, LDRP-ITR campus, Gandhinagar, GUJARAT

References

1. MOU Wenping, ZHU Shaowei, Z JIANG, S Ge Vibration signal-based chatter identification for milling of thin-walled structure - Chinese Journal of …, 2020 - Elsevier
2. Y Guo, H Dong, G Wang, Y Ke Vibration analysis and suppression in robotic boring process - International Journal of Machine Tools and …, 2016 - Elsevier
3. Y Mohammadi, M Azvar, E BudakSuppressing vibration modes of spindle-holder-tool assembly through FRF modification for enhanced chatter stability - Cirp Annals, 2018 - Elsevier
4. B Powałka, K Jemielniak Stability analysis in milling of flexible parts based on operational modal analysis - CIRP Journal of Manufacturing Science and …, 2015 - Elsevier
5. B Powałka, K Jemielniak Stability analysis in milling of flexible parts based on operational modal analysis. CIRP J Manuf Sci Technol 9: 125–135 - 2015
6. M Eynian Prediction of vibration frequencies in milling using modified Nyquist method - CIRP Journal of Manufacturing Science and …, 2015 - Elsevier
7. X Wang, Q Song, Z Liu Precise chatter monitoring of thin-walled component milling process based on parametric time-frequency transform method - Journal of Materials Processing Technology, 2020 - Elsevier
8. K Kolluru, D Axinte, A Becker A solution for minimising vibrations in milling of thin walled casings by applying dampers to workpiece surface - CIRP Annals, 2013 - Elsevier
9. L Yuan, S Sun, Z Pan, D Ding, O Gienke, W LiMode coupling chatter suppression for robotic machining using semi-active magnetorheological elastomers absorber - Mechanical Systems and …, 2019 - Elsevier
10. HK Neto, AE Diniz, R Pederiva Influence of tooth passing frequency, feed direction, and tool overhang on the surface roughness of curved surfaces of hardened steel - The International Journal of Advanced …, 2016 - Springer
11. MM da Silva, GS Venter, PS Varoto, RT Coelho Experimental results on chatter reduction in turning through embedded piezoelectric material and passive shunt circuits - Mechatronics, 2015 - Elsevier
12. X Xu, T Zhou, H Hu, Y Hu Chatter Frequency Identification and Amplitude Tracking Using Short-Time Difference Spectrum Analysis - IEEE Transactions on …, 2020 - ieeexplore.ieee.org
13. Y Shi, F Mahr, U von Wagner, E Uhlmann Chatter frequencies of micromilling processes: Influencing factors and online detection via piezoactuators - International Journal of Machine …, 2012 - Elsevier
14. MK Dikshit, AB Puri, A Maity Chatter and dynamic cutting force prediction in high-speed ball end milling - Machining Science and Technology, 2017 - Taylor & Francis
15. Y Liu, Z Liu, Q Song, B Wang Analysis and implementation of chatter frequency dependent constrained layer damping tool holder for stability improvement in turning process - Journal of Materials Processing Technology, 2019 - Elsevier
16. MA Rubeo, TL SchmitzAmplitude ratio: a new metric for milling stability identification - Procedia Manufacturing, 2017 - Elsevier
17. YUE Caixu, GAO Haining, LIU Xianli, SY Liang… A review of chatter vibration research in milling - Chinese Journal of …, 2019 – Elsevier
18. Solution Ozturk, E. , Budak, E Chatter Stability of 5-Axis Milling Using Multi-Frequency.*Manufacturing Research Laboratory, Sabanci University, Istanbul, Turkey

19. N.B.Gandhi and D.H.Pandya Computational Investigation of Chatter for Face Mill Tool on VMC using Different Shim Material with Experimental Validation , LDRP Institute of Technology& Research, KSV University, Gandhinagar, Gujarat, India