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Prediction of Chatter Vibration in Vertical Milling Center Using FRF

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Abstract:-Productivity of high speed milling operations can be seriously limited by chatter occurrences. Chatter is a self-excited vibration that occurs during the machining operations. Chatter occurrence is strongly affected by dynamic response of the whole system. It can imprint poor surface on the work piece and bifurcation happen. The main dynamic problem is self-excited vibration called regenerative chatter. A stability lobe can be used to predict the chatter vibration. This method can be highly sensible to the dynamic properties. Chatter identification technique is based on analytical-experimental and numerical method. A stability lobe diagram is formed by a series of intersected scallop-shaped borderlines of stability. There are various algorithms which can be applied in optimization of machining process. The critical cutting speed and axial flow of depth of cut are analytically determined by Eigen values of the domain. Numerical method, dynamics of milling process is described by the discontinuous differential equations. Frequency response function is positioned in tool position. Time varying dynamic cutting force coefficients is approximated by Fourier series. By comparing the results of both analytical & numerical methods they can easily predict the chatter vibration. Mat lab, spreadsheet is the software used for the simulation.

I. INTRODUCTION

High speed milling operations are mainly used in manufacturing systems for increased production and high precision manufacturing. During high speed milling machining operations, dynamic problems have been introduced. The main dynamic problem is self-excited vibration called regenerative chatter.

Chatter vibrations can create a poor surface finish on the work piece and this damages the cutting tool and the machine. It is strongly affected by the dynamic response of the whole system. Chatter is a self-excited vibration and it can occur during machining operations and becomes a common limitation to productivity and part quality and it has a several negative effects such as poor surface quality, less accuracy excessive noise and tool wear, machine tool damage, reduced Material Removal rate (MRR), increased costs in terms of time, materials and energy.

Regenerative chatter is the most common form of self-excited vibrations. It can occur often because most operations involve overlapping cuts which can be a source of vibrations amplification. The cutter vibrations leave a wavy surface. When milling, the next tooth attacks this wavy surface and generates a new wavy surface.

Many researchers has been made in the field of chatter. It presented various techniques including analytical as well as experimental to avoid chatter and to select machining parameters, viz., depth of cut and spindle speed to achieve maximum chatter free MRR.

A stability lobe diagram can be created for the prediction of chatter vibration. It is based on regenerative chatter theory. This stability lobe diagram creates an effective tool to predict & control chatter. This method can be highly sensitive to the dynamic properties of the milling machine, especially to the damping properties (1), this formed a series of scallop-shaped borderlines of stability. This lobe denotes stable cuts at various ranges of spindle speed. These optimum depths of cut have been found by graphical solution from the stability lobe diagram. This process requires a lengthy procedures & calculations. Different paper presents a different method for the prediction of chatter vibration. Simple method to calculate optimum depth of cut & to determine corresponding spindle speeds (2). This can be analyzed in different software like mat lab & spreadsheet. It helps to understand the theory of machine chattering

A. Self-Excitation Mechanisms

Chatter is broadly classified in to 2 categories namely primary & secondary. Primary chatter is caused by friction between the tool & the work piece itself by thermo-mechanical effects on the chip formation. Secondary chatter is based on regeneration waviness of the work piece (18). It is the most important cause for the chatter. It is the most common form of self excited vibration. While operation it produces wavy surface on the work piece. A great danger is due to inner interactions in the MWTH system, and the tool path regeneration phenomenon. Vibration observed in the machine-work piece-tool-holder (MWTH) system. This system is based on mass-spring-damping system (3).

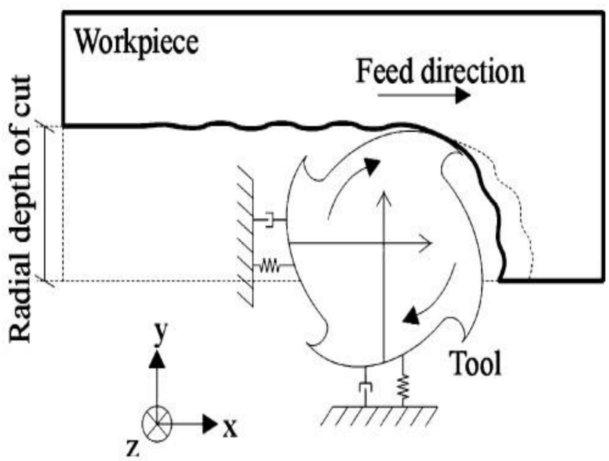

Fig.1: Dynamics of Milling Model

Fig1 shows the dynamic milling force model showing the undulation on machined surface and each tooth removes the undulation caused by the previous tooth. Based on this model, equations were arrived to find the chatter free axial depth of cut.

II. ANALYTICAL METHOD

Machine tool dynamics have been important issue of interest amongst the machining community due to its significant role in the stability. This machine tool chatter vibration occurs due to self-excitation mechanisms in the generation of chip thickness during machining operations. Chatter free axial depth of cuts & spindle speeds has been calculated. Analytical stability lobes have been calculated in this paper (5) and this stability lobe has been compared with the lobes generated by the lobes created by time domain process. This time domain is approximated by the Fourier series components. Many industries said that chatter is the one of the major limitations in metal cutting process, from the last 60years many proposed different methods for the prediction of this issue but it is still one of the major limitations for a manufacturing industries(6).This paper presents a critical review of the different chatter techniques,. They replaced a cutting tool materials,HSS tool cut four times faster than the carbon steels replaced carbide tools replaced HSS tools in metal removal process & it is 3-5 times faster than HSS tools and they also thought that there is a limitations in the design procedure so, they used Finite Element Method (FEM) this can provide dynamic frequency like natural frequency but after using this method they face a difficult to estimate a damping(reduction in amplitude of an oscillation) as a result energy is being drained from the system to overcome some of the forces like frictional this leads to accuracy problem. For increasing the accuracy they uses low friction guiding system, the first machine tool which provide this method has relatively high damping resistance. Varying dynamic process is due to metal removing process is also modelled by means of (FEM) method (8).

Roller bearings or aerostatic guiding system are also used for high (precision & speeds). Robust stability prediction method also uses the same method, cutting coefficient & natural frequency for creating stability lobe diagram (9) to minimize the vibrations.

While machining they also calculated the cutting speed i.e., spindle speed. Position of the unstable position is defined by the ratio k, between chatter frequency (fc) and the tooth passing frequency (fz).

$$K = f_c/f_z = 60f_c/ZN$$

Where:

Z= number of teeth on the tool

N= speed in rpm

They classified this method in 3 different zones like,

Zone A: (k >10) process damping source

High increase in stability is obtained due to increase in flank & wavy surface. In this zone lower spindle speed, higher the stability boundary.

Zone B: (10 > k > 3) intermediate zone

In this zone stability limit is close to absolute stability in the whole spindle speed region. Especially true for high damping values.

Zone C: (3 > k > 5) high speed zone

Stability can be increased by selection of spindle speed coincides with one of the stability pocket.

Zone D: (0.5 > k) ultra-high speed zone

Stability can be improved by increasing the spindle speed.

This paper (9) (10) presents the new analytical method, single frequency or Zero Order Approximation (ZOA) which is to solve the inaccuracy in milling process. It is the fast estimation of the stability & can be fed directly to the FRF. It is precise for most of the process only when highly interrupted cutting process are considered. Sometimes chatter may also occur in the line contact with the unstable region. It is also an important index for the chatter vibration.

This can be calculated by the form of design index, (a_p/a_{lim}), a_p is the distance between 2 adjacent regenerative effect cancellation lines & a_{lim} is the asymptotic stability limit (11). This was considered only to design the helix angle difference of a tool & in several conditions.

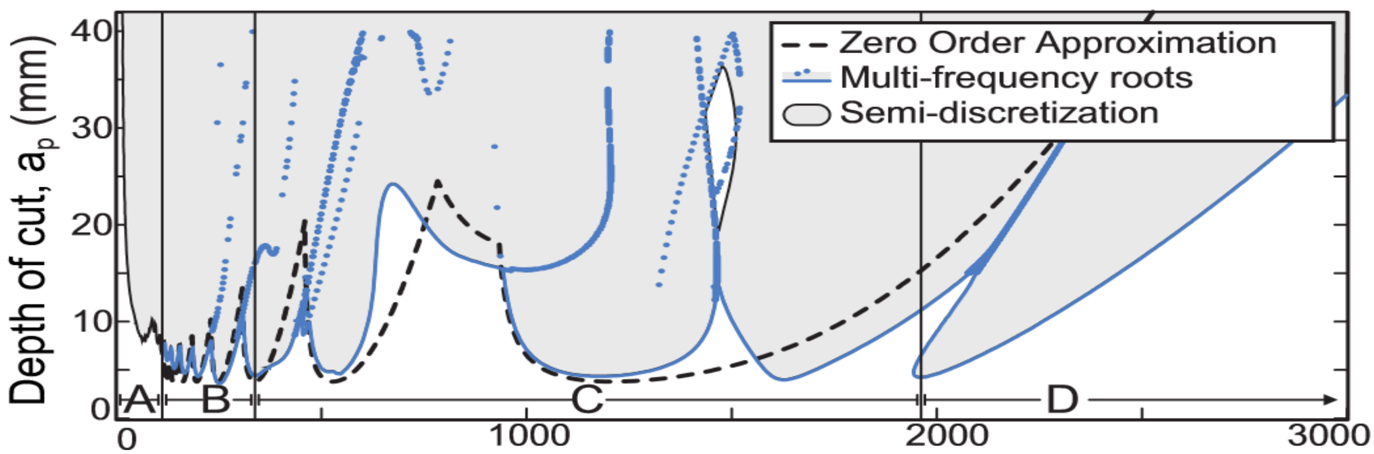

Fig. 2: Zero Order Approximation

Fig2 shows that the zero order approximation, an approximation of function by constant and it determines a formula to fit the multiple data points. X-axis represents the cutting speed and y-axis represents the axial depth of cut in the machining process.it clearly shows the variation in the surface of machining. ZOA is simply the level of precision used to represent the quantity which are not perfectly known (10)

While machining an important factor that chatter has to be monitored, for this sensors has been used to monitor the defects, acceleration sensors are generally used. It results in low reliability of the machine tools(13). It does not require any additional sensors it only uses the servo information of the spindle control system. Self excited & forced chatter vibration has been detected.Some of the methods that has been used to monitor the process some of them are,.

Fig.3 tells the about the average T method, can measure the angular velocity with a higher accuracy than the conventional M and T methods. It affords a better estimation of the accuracy of the estimation of the disturbance torque.

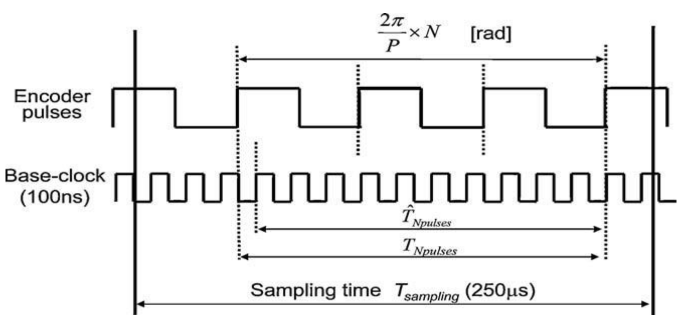

Fig.3: Average T Method

The proposed disturbance observer can detect the chatter vibrations. The waveform of the measured disturbance torque changes according to the type of chatter vibrations. FFT analysis of the disturbance torque shows that the behavior of the chatter vibrations up to 2 kHz becomes remarkable when the axial cutting depth increases.

The discrimination method using digital filtering is proposed to separately detect the self-excited and forced types. The type of chatter discriminated from the dominant component corresponds to the alignment of the chatter mark left on the machined surface.

Milling test is also carried out that is used to measure the resonance frequency of the spindle together with the end mill cutter, an impulse force response test was carried out. The result shows that the resonance frequencies are 835 Hz and 2300 Hz.

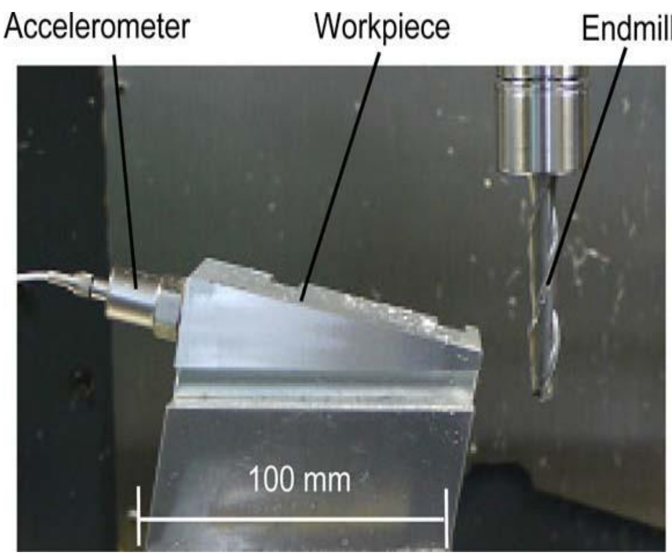

Fig.4: Schematic Digram of Milling

Fig4 shows schematic diagram of milling, impulse force response test was carried out is used tomeasure the resonance frequency of the spindle. A digital microscope is used, revealed that chatter marks on the machined surface when the cutting height exceeded a certain value (13)

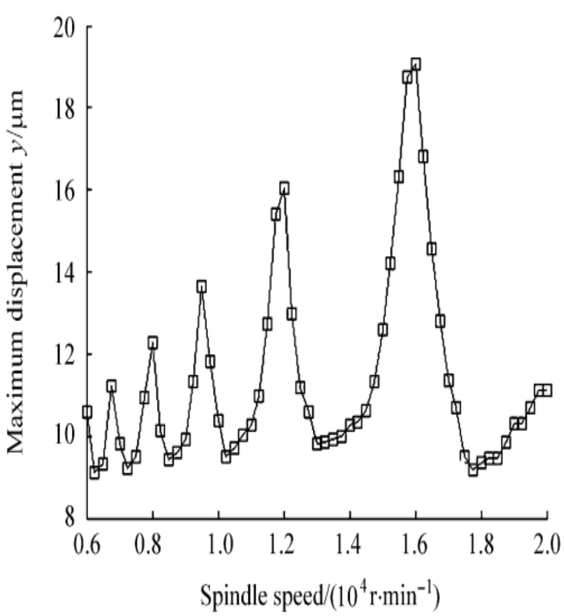

Fig.5: Stability Lobe Diagram

Fig5 shows the stability diagram, x- axis represents the spindle speed and the y-axis represents the max. depth of cut. From this diagram a graph has been derived. From this graph,the stable & unstable areas are separated by the critical cutting parameter plotted against cutting speed.

III. NUMERICAL METHOD

It is one of the method for the prediction of chatter vibration, achieving high performance in machining process. It is used to solve the differential equations(15) which governs the dynamics of milling system.several chatter detection creteria is applied to the simulated signals & the stability dig, is obtained in time-domain.By simulating the chatter stability lobes in the time-domain & analyzing the influences of different spindle speeds on the vibration amplitudes of the tool under a fixed chip-load condition(14).floquet's theorem & fourier series are used to formulate the milling stability and this is numerically solved by Nyquist creterion.

Diffrential equations describing the dynamics of the system is represented as:

$$m_1\ddot{x}_1(t)+c_1\dot{x}_1(t)+k_1x_1(t)+k_{11}x_1(t)^3=\sum_{p=1}^{z}F_p(t)$$

$$m_2\ddot{x}_2(t)+c_2\dot{x}_2(t)+k_2x_2(t)+k_{21}x_2(t)^3=-\sum_{p=1}^{z}F_p(t)$$

Where,

m_1- substitute mass of the tool

c_1- damping of the tool,

k_1, k_{11} - linear & nonlinear stiffness of the tool,

m_2- substitute mass of the work piece,

c_2- damping of the work piece,

k_2, k_{21}- linear & nonlinear stiffness of the work piece

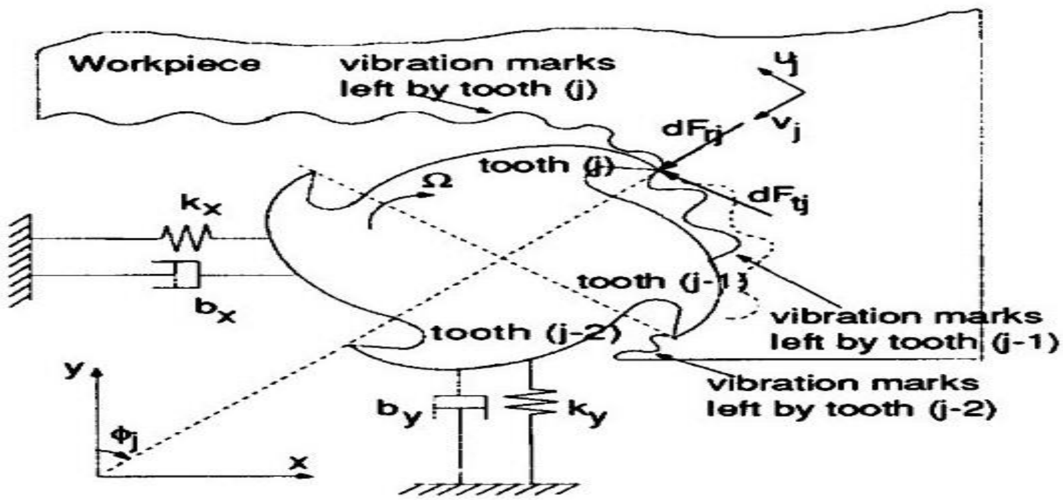

Fig.6: Dynamic Model of Milling with 2DOF

Fig. 6 shows how the cutting force causes both the cutter and the work piece to vibrate on the cutting surface. Each vibration cutting tooth removes the wavy surface left by the previous tooth results in modulated chip thickness.

The time-domain model is used to predict the cutting forces, the torques, the power, the dimensional surface finish, the amplitude & the frequency of vibration in milling operations.Dynamics of milling sytem is predicted by differential equations. It is an approximate solutions, in which the continuous time variable tis replaced by discrete time variable. Thus the differential equations are solved by time increment, starting with initial conditions. The time-domain chatter stability diagram is obtained by applying the mentioned chatter detectin criteria synthetically to the stimulated data. Varification test has also been tested for confirming the time-domain chatter stability diagram. Thus this paper finally concluded that, in rough milling highert machining efficiency can be achieved by selecting a spindle speed & the depth of cut like that low surface roughness can be achieved by selecting a spindle speed beyond the resonating frequency of the milling system.

Thus the dynamics of the milling process is easily described by the discontinuous differential equations with a time delay which will cause instability in various parameters.so, the stability lobes is determined numerically(15). In order to reduce the harmful vibrations piezo-elements is being used and thus the work shows numerical results of chatter control in both open & the closed system.

IV. SIMULATIONS

Simulations are verified by experimental tests and confirms the efficiency of the proposed approach in providing a reliable tool for prediction of chatter in machining(16). Spreadsheet, mat lab software is used to create the stability lobe diagram. Non-linear differential equations of motions were solved by using mat lab Simulink to generate the stability lobe diagram (15). This helps to solve the limitations in work piece manufacturing to reduce chatter.

V. CONCLUSIONS

Thus the stability of milling is currently well understood and predicted at high speeds by the frequency and time domain solutions first, confirms what kind of problem i.e., is analyzed, chatter vibration, second measure the chatter frequency. Third, evaluate the position of stability lobe (k), fourth, dynamic stiffness and cutting speed & the free axial depth of cut. Helix angle is also used to increase the process damping(7). And finally SLD (stability Lobe Diagram) has been created and it is sometime analyzed by software like MATLAB. Thus the dynamic properties of a work piece can have a significant impact on the stability chart(8). The modelling of process damping physics is still a research challenge, but once modelled current stability laws can be used to predict the chatter stability lobes at low speeds as well(5). Also it should be noted that successful results in scope of chatter suppression have been obtained.By comparing the results of both analytical & numerical methods they can easily predict the chatter vibration.

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