Chatter Reduction in Milling Process: A Review

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Abstract:- Chatter is a self-energized vibration that can happen amid machining operations and turn into a typical restriction to profitability and part quality. Consequently, it has been a point of mechanical and scholarly enthusiasm for the assembling area for a long time. A lot of researches have been carried out to take care of the issue and researchers have studied how to distinguish, recognize, avoid, forestall, lessen, control, or suppress chatter. This paper audits the condition of research on the chatter issue and characterizes the current techniques created to guarantee stable cutting into those that utilization the heaving impact, out-of-process or in-process, furthermore, those that, passively or actively, alter the system conduct.

I. INTRODUCTION

A. Generalities

High speed milling operations are mostly utilized as a part of manufacturing systems for expanded production and high accuracy producing. During high speed milling operations, dynamic issues have been presented. The fundamental dynamic issue is self-energized vibration called regenerative chatter.

Chatter vibrations can make a poor surface finish on the work piece and this harms the cutting tool and the machine. It is unequivocally influenced by the dynamic reaction of the entire system. Chatter is a self-energized vibration and it can happen amid machining operations and turns into a typical constraint to profitability and part quality and it has a few negative impacts, for example, poor surface quality, less exactness over the top clamour and device wear, machine instrument harm, lessened Material Removal rate (MRR), expanded expenses as far as time, materials and vitality.

Regenerative chatter is simply the most widely recognized form of self-energized vibrations. It can happen regularly on the grounds that most operations include overlapping cuts which can be a wellspring of vibrations enhancement. The cutter vibrations leave a wavy surface. When milling, the following tooth assaults this wavy surface and produces another wavy surface.

Numerous specialists have been made in the field of chatter. It introduced different strategies including analytical as well as experimental to keep away from chatter and to choose machining parameters, viz., depth of cut and axle speed to accomplish greatest chatter free MRR.

A stability lobe diagram can be made for the expectation of chatter vibration. It depends on Regenerative Chatter Theory. This stability lobe diagram makes a powerful apparatus to foresee and control chatter. This technique can be highly sensitive to the dynamic properties of the milling machine, particularly to the damping properties; this framed a progression of scallop-shaped borderlines of stability. This projection indicates stable cuts at different scopes of axle speed. These ideal depth of cut have been found by graphical arrangement from the stability lobe diagram. This process requires a protracted methodology and figuring. Diverse paper exhibits a distinctive technique for the prediction of chatter vibration. Simple technique to compute ideal depth of cut and to decide corresponding spindle speeds. This can be investigated in various programming projects like MatLab and spreadsheet. It comprehends the hypothesis of machine chattering.

B. Self Excitation Mechanisms

Self-energized systems start to vibrate voluntarily suddenly, the amplitude increases until the point that some nonlinear impact restricts any further increment. The energy providing these vibrations is obtained from a uniform source of energy related with the system which, because of some mechanism inherent in the system, offers ascend to oscillating forces. The force following up on a vibrating object is generally external to the system and free of the movement.

- Frictional chatter happens when rubbing on the clearance face energizes vibration toward the cutting force and restrains in the thrust force direction.
- Thermo-mechanical chatter happens because of the temperature and strain rate in the plastic distortion zone.
- Mode coupling chatter exists if vibration in the thrust force direction produces vibration in the cutting force direction and the other way around. These outcomes in concurrent vibration in the cutting and thrust force headings. Physically, it is caused by various sources, for example, friction on the rake and clearance surfaces, chip thickness variety, shear angle oscillations and regeneration impact.
- Regenerative chatter is caused by the regeneration of waviness of the surface of the work piece. This so-called regenerative chatter is considered to be one of the most important causes of instability in the cutting process. This type of chatter will be considered in this paper.
C. Stability Lobe Diagram

Machine tool chatter causes machining instability, surface roughness, and tool wear in metal cutting processes. A lobe diagram based on regenerative chatter hypothesis is a compelling instrument to foresee and control chatter. Stability diagrams can be applied in machining processes to advance the most extreme depth of cut at the highest accessible spindle speed, in this way enhancing the material expulsion rate and expanding productivity and profitability. A stability lobe graph is framed by a progression of met scallop-shaped lines of stability. The crossing points of the projections indicate the deepest stable cuts at different range of spindle speed. These ideal depth of cut have generally been found by graphical arrangement from the stability lobe chart. The production of a stability lobe diagram requires long strategies and computations.

In the accompanying segments the proposed chatter research lines are displayed in more detail. At times, researchers combine or consolidate distinctive techniques into a solitary approach.

Fig. 1: Regeneration of Waviness in A Milling Model with Two Degrees of Freedom. Source: [9].

Fig. 2: Stability Lobe Diagram. Source [22]
II. STRATEGIES REDUCING CHATTER IN MILLING PROCESS

There are many methods for controlling chatter in milling operations. The main method used is creating Stability lobe diagrams for various model parameters of a milling machine and predicting chatter and influencing the results real time.

The following are the methods to create a Stability Lobe Diagram. Stability Lobe diagrams can be obtained by performing Numerical Simulations in MatLab. The Non-Linear differential equations of motion are solved by using fourth order Ruge-Kutta method [1].

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\[ m_1 \ddot{x}_1(t) + c_1 \dot{x}_1(t) + k_1 x_1(t) + k_{11} x_i(t)^3 = \sum_{p=1}^{n} F_p(t) \]
\[ m_2 \ddot{x}_2(t) + c_2 \dot{x}_2(t) + k_2 x_2(t) + k_{21} x_2(t)^3 = -\sum_{p=1}^{n} F_p(t) \]

Fig. 3: Non-Linear Differential Equation of Motion. Source

Real and imaginary parts of the characteristic equation of frequency response function are used in Subdivision method to attain Stability Lobe Diagram [2].

\[ D(\Omega, \omega, \omega_n, \omega_0) = \sum_{i=1}^{n} \left( \frac{T_i^2(s)}{s^2 + \omega_n^2} + i \omega_0 T_i^2(s) \right) \left( 1 - e^{i\omega t} \right) = 0 \]

Fig. 4: Characteristic Equation of FRF. Source [2]

By estimating parameters of milling system using frequency response function, the stability lobe diagram can be plotted directly by using tool tip’s frequency response function [7].

The non-linear differential equations of motion can be solved analytically and stability lobe diagrams for linear oscillator with time delay is determined. The delayed displacement feedback is influenced on duffing oscillator thereby reducing chatter [8].

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Periodic Operations of milling operation [8]. Milling stability can be predicted by creating a stability lobe diagram at different cutter positions [11].
The above are some of the methods of chatter prediction by creating a stability lobe diagram. But many of the traditional models that are used to create stability lobe diagrams are based on some assumptions like keeping the parameters such as natural frequency, stiffness and cutting coefficient constant. But in real time those parameters vary and affect the chatter stability. To avoid this, the uncertainty in those parameters is taken into considerations by using robust stability theory into two degrees of freedom milling model. By using edge theorem and zero exclusion condition a new stable model is developed [3].

Interaction between tool and thin-walled work piece can be modelled at discrete nodes along axial depth of cut and an efficient method based on structural dynamic modification scheme is developed to characterize the effect of material removal upon work piece dynamics and the method is performed in FEM modal [12].
Interference between tool flank face and machined surface causes damping. Using frequency method to solve the stability of the cutting chatter, by this it can be noticed that damping can improve the stability of low speed region [6].

Fig. 7: Varying Workpiece Dynamics: (A) The first Modes for the Initial and In-Process Workpieces; (B) Dynamic Displacements of Second Mode Shape At Different Tool Positions; And (C) Varying Dynamic Displacements of Second Mode Shape along the Tool Axis. Source [12].

Fig. 8: Two Orthogonal Direction FRFS Measured At the Tool Tip and Workpiece. Source [6].
Variable pitch and helix tools help suppressing chatter even at low cutting speeds. If properly designed, those tools may offer high productivity [10].

Chatter can be reduced by considering process stability of combined mode end milling with combination of both up-milling and down-milling [5].

To reduce chatter, instantaneous change in spindle speed taken as control command and the method of vibration surveillance by the spindle speed optimal linear control is developed. By using this method some cutting models can be created [4].

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**Fig.9:** Comparison of FFT in the X-Axis, Tool, Workpiece, and Relative. Source [6].

**Fig.10:** Combined-Mode Milling. Source [5].

**Fig.11:** A trial spindle speed programme generated for optimal-linear control at energy performance index and restriction on maximum spindle speed. Source [4].
Hybrid experimental-analytical approach can be used to identify tool-tip frequency response function during cutting operations. By using some cutting test and a microphone speed-dependent chatter stability is identified without use of frequency response function [13].
In flexible peripheral milling, to compensate workpiece deformations which is induced by cutting forces, a system is formed which consists of flexure hinge based worktable which is moved by piezoelectric actuator [14].
In milling to reduce the chatter vibration active structural methods are used which contains an active system that is integrated into a spindle unit and two different optimal control strategies are examined [15].

Dynamic analysis is made for milling process, comparing the results with energy performance index a control law is derived. This control law is applied to reduce chatter [16].

To suppress regenerative chatter linear and non-linear vibration absorbers are produced which leads to good surface finish in micro-milling process. These absorbers composed of mass, spring and dashpot elements in two directions [17].

Retrofittable intelligent active fixture is monitor the process and produces required counter-excitations to overcome chatter vibrations [18].

Milling chatter is mitigated by immersing the milling system in viscous fluid which increases milling efficiency under viscous fluid condition [19].

Conservative Congruence Transformation method is used avoid mode coupling chatter without changing the direction of tool feed in Robotic milling [20].

In ball end milling, to reduce vibrations optimal spindle speed is determined; this procedure is based on Liao-Young criterion [21].
II. SIMULATION:

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 [1]. This helps to solve the limitations in work piece manufacturing to reduce chatter.

IV. CONCLUSION

Vibrations in machining result from the absence of dynamic stiffness of some segment of the machine apparatus tool holder cutting tool workpiece framework. They are partitioned into free, constrained and self-energized vibrations. In the event that the system is very much well balanced, the second sort of vibration is because of variable chip thickness and the interfered with nature of the process. That implies that they are continuously present. Subsequently, to anticipate harm, the vibration level must be controlled. The most widely recognized self-energized vibration is regenerative chatter. A lot of research has been completed on the chatter issue since the late 1950s [25]. Not only the above seen techniques but other large number of experimental analysis are made to solve the chatter problem like, milling chatter is mitigated by immersing the milling system in viscous fluid which increases milling efficiency under viscous fluid condition [19]. Bunches of huge progresses have been made throughout the years. Advances in PCs, sensors and actuators have expanded comprehension of the chatter, and created and enhanced procedures to comprehend the issue. This paper audits the immense measure of literature with respect to chatter issue and characterizes a few strategies created to guarantee stable cutting.

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