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A Review Study of Analysis of Tool Chatter in Turning Operation and Control Methods

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Abstract – Machine tool chatter is one of the most significant bottlenecks in the turning operation. It's a self-excited vibration induced by the association of the machine tool/workpiece arrangement with the cutting mechanism dynamics. The nonlinearity of dry friction and the irregular interaction between the cutting instrument and the workpiece are the primary causes of frictional and effect chatter. There are a few ways to keep the chatter to a minimum. We will implement and compare some of these approaches in this article.

Keywords – Chatter, Machining, Turning Tool

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INTRODUCTION

For the manufacture of metallic parts and modules of desired dimensions, consistency, and form, traditional machining methods are widely used in industries. The aim of manufacturing industry is to produce high-quality goods at a faster rate. Higher metal removal rates will boost the productivity of these manufacturing industries (MRR). MRR can be improved by choosing the right machining parameters. These cutting criteria also have an effect on the finished product's surface appearance. As a result, when choosing these machining parameters for full MRR, the impact of these parameters on surface finish must be considered.

Turning is one of the most widely employed machining methods for producing a broad variety of higher MRR materials. Vibrations are generated by direct interaction between the tool and the workpiece during chip removal in various traditional machining processes. These sounds, also known as chatter vibrations or self-excited vibrations, have a number of drawbacks.

Chatter vibrations (tool chatter) are extremely important in machining and can occur in any cutting phase. Tool chatter causes unnecessary noise, poor product surface efficiency, tool wear, and other issues while spinning. Chatter has an effect on the output pace and machine tool assembly in addition to stock efficiency. As a result, analyzing chatter is important and necessary.

DIFFERENT TYPES OF CHATTER

A. Regenerative chatter

When cuts intersect, tiny waves in the substance are left behind that are regenerated with each subsequent tool pass, resulting in regenerative chatter. In turning operations, it is thought to be the most popular chatter mechanism.

A form of chatter known as multiple regenerative chatter happens when regenerative tool movements grow big enough that the tool loses touch with the workpiece. Shi and Tobias (1984), Kondo, Kawano, and Sato (1981), and Tlusty and Ismail (1981) have all studied this mechanism (1982).

B. Mode Coupling

When the relative vibration between the instrument and the workpiece appears in at least two directions in the plane of the cut, mode coupling happens. In this scenario, the tool follows an elliptic direction that changes the depth of cut in order to feed the coupled vibration modes. When chatter occurs in slender nearly symmetric instruments, such as dull bars, it is thought to be a cause. The mechanism of this mechanism and the phenomena of aero elastic flutter are strikingly identical. Other theories have been proposed. Arnold (1946) proposed that the cutting powers are inversely proportional to the velocity, resulting in negative damping. This chatter process is basically a frictional effect with identical properties to the well-known Rayleigh oscillator (Nayfeh and Mook, 1979).

C. Thermo mechanical

Thermomechanical chatter is caused by temperature fluctuations and the chip's temperature distortion. the first attempt to explain the thermo in detail. Hastings et al. produced mechanics (Jang and Tarng, 1999). Many of the above processes contribute to selfexcited oscillations. Rotating imbalance or misalignment of the workpiece is a typical cause of such vibrations in turning operations. Forced movements are often caused by tool wear and spindle mistakes. When the cutters rotate in and out of the workpiece during milling activities, these so-called "interrupted cuts" occur.

D. Interrupted cuts

Effect oscillations, a type of forced machine-tool vibration examined by Davies and Balachandran, are caused by interrupted cuts (1996).

Material removing in machining process

Material removal is a production method in which excess material is removed from a work surface in order to achieve the correct shape and scale. The processing of raw material into a final product is what the production method is all about. Initially, content removal was managed manually, which necessitated the use of experienced operators and a high level of focus.

Various sophisticated devices are present in the current situation, many of which are numerically operated by computers. Tool chatter can arise while operating these machines, though, and the variety of cutting parameters affects it. Machining operations are graded mostly based on the geometry and surface of the process:

- Turning
- Milling
- Drilling
- Boring
- Grinding

Turning is one of the most widely employed machining methods for producing a variety of materials. Orthogonal and oblique cuttings are two metal cutting methods used in spinning, according to various researchers. In an orthogonal cutting procedure, the tool's cutting edge is perpendicular to the tool's motion, while in an oblique cutting process, the tool's cutting edge is inclined to its motion.

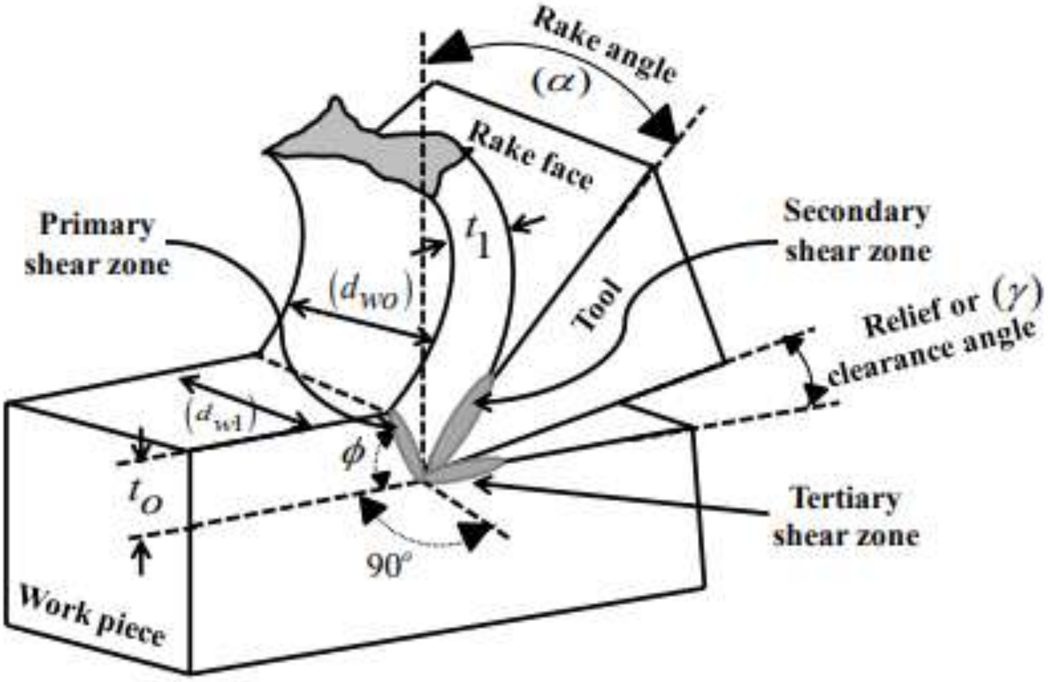

Figure 1: Geometry of orthogonal cutting process with three deformation zones

These two cutting methods have been presented in Figures 1 and 2, respectively. Where, α is rake angle, γ is clearance angle, ϕ shear angle, wo d chip width, w1 d uncut chip width, 1 t chip thickness and o t is uncut chip thickness.

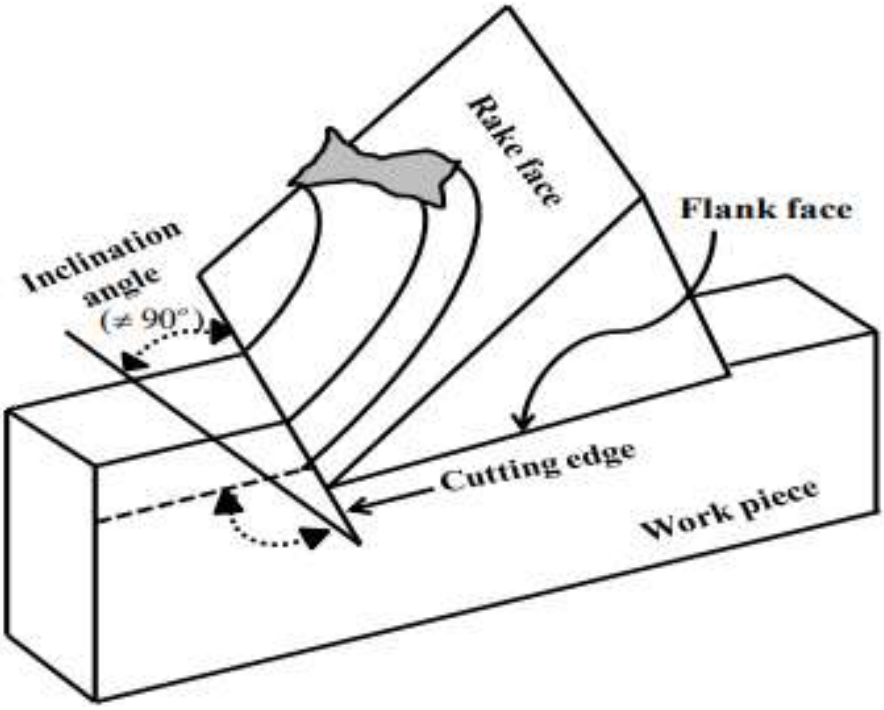

Figure 2: The geometry of oblique cutting

Cutting is essentially a plastic deformation mechanism in which the substance is permanently deformed and cannot be returned to its original shape and scale. In the cutting phase, three deformation shear zones grow, as seen in Figure 1. There are three zones: central, intermediate, and tertiary. These areas depict the progression of heat and temperature in the cutting field (work-piece, tool and chip). As the tool tip penetrates the workpiece during machining, the material being cut shears across the primary shear region. The substance is extracted in the form of chips in this method. In the primary zone, the most energy is converted to heat. Furthermore, using the chip-tool interface, the freshly formed chip runs around the face. In the chip-tool interface field, where heat is produced by rubbing motion, a secondary shear zone develops. Furthermore, the tool's flank face slides across the machined board, causing heat production due to friction. The tertiary shear zone is the region where the flank face meets the machined surface.

Chatter mechanism in turning

Regenerative chatter is caused by inexpedient vibration between the cutting instrument and the workpiece during the turning phase. Chatter shaking has a negative impact on product efficiency, resulting in inventory waste and lost processing time. Tool life and machining precision are often affected by chatter. Tool chatter is an unavoidable occurrence in the turning phase that is a significant impediment to achieving optimal metal removal rates (MRR). Chatter cannot be completely removed; however, it can be reduced to a minimum. The researchers have found it difficult to predict tool 5 chatter. Through several laborious experiments and studies, several facets of this area remain unexplored.

The improper rigidity of the lathe machine and cutting tool interface causes three types of vibrations in the turning process: free, coerced, and self-originating vibrations. Shifting of machine tool structures from their normal location, resulting in incorrect tool path movement, is an example of free vibration. External harmonic excitation (sinusoidal external force of a certain frequency), unbalanced bearing and gear assembly, and unbalanced spindle both triggers forced vibrations. These two sounds are clearly distinguishable and controllable.

The noisy movements at the work-piece-tool gui are referred to as chatter. Chatter, according to Yusoff and Sims, happens when the chip diameter is wide in comparison to the system's dynamic stiffness. Furthermore, Stephenson and Agapiou said that chatter in the machining phase is caused by differences in the workpiece's metallurgical properties and the creation of chips with a built-up edge. Cutting environments, according to Chae, are the most important factors affecting chatter vibration dynamics. This jarring shaking causes the machined workpiece's proportions to be off, as well as increased tool wear.

Figure 3 illustrates the mechanism of instrument chatter. The previous cutting surface had left a wavy surface on this cutting instrument. This lag between successive turning passes causes the instrument to jump from one profile to the next, resulting in regenerative chatter, or aggressive relative motion between the cutting tool and the workpiece. In Figure 3, V represents the work-piece cutting velocity, and qt () and qt ( ) represent the work-piece profiles produced during the current and previous turning passes, respectively.

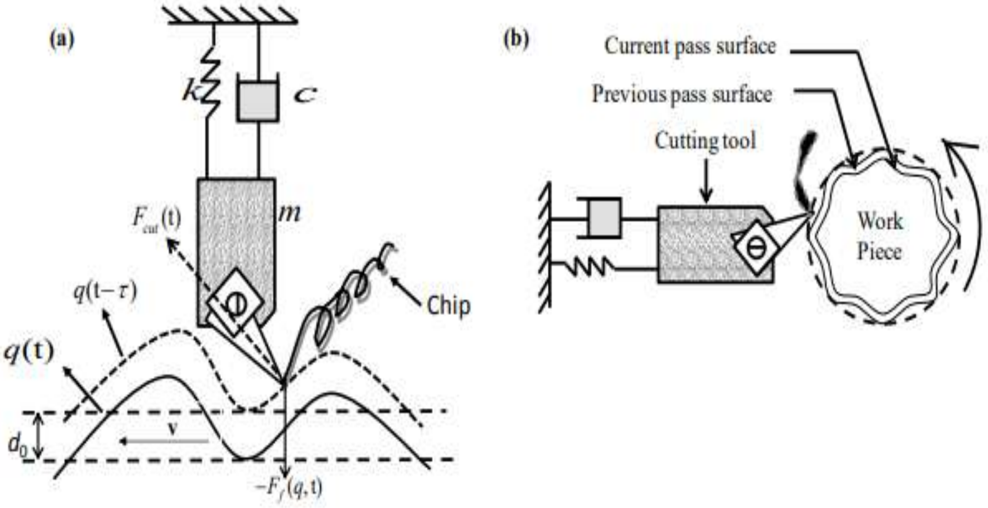

Figure 3: (a) Mechanism of regeneration (b) SDoF model for turning

Chatter Modelling Theory

Simulation of Tool motion in one direction

Assume that a lathe feeds a flat-faced orthogonal grooving instrument perpendicular to the axis of a cylindrical shaft kept between both the chuck and the tail stock center (see Fig4 and Fig5).

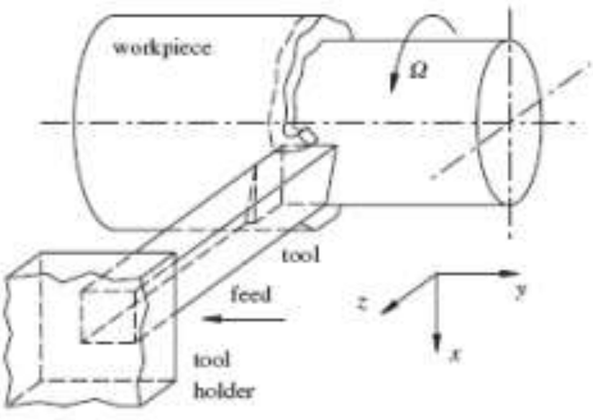

Figure 4: Turning Model

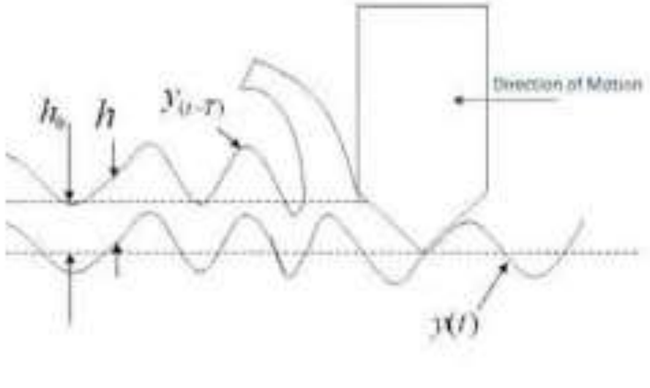

Figure 5: Chatter dynamics regenerative chatter vibration

The system's equations can be written as:

$$m_y\ddot{y}(t) + C_y\dot{y}(t) + K_y y(t) = F_f(t) = K_f.a.h(t) = K_f.a.h[h_0 + y(t - T) - y(t)]$$

The chatter vibration level remains similar to the structure's normal mode. In order to perform a crucial borderline stability study, $(s = jw_c)$, the characteristic function transforms into

$$1 + (1 - e^{-jw_cT})K_f.a_{lim}.Q(jw_c) = 0$$

Where a_{lim} For chatter vibration-free machine tools, is the ultimate bending depth of cut. Equating the actual component of the characteristic equation to zero yields the crucial axial depth of cut.:

$$1 + K_f.a_{lim}[G(1 - Cos(w_cT) - HSin(w_cT))] = 0$$

Or

$$a_{lim} = \frac{1}{K_f[G(1 - Cos(w_cT) - (^H/_G)Sin(w_cT))]}$$

Substituting $^H/_G = {}^{Sin(w_cT)}/_{(1 - Cos(w_cT)}$ This equation can be reorganized to generate

$$a_{lim} = \frac{-1}{2K_f.G(w_c)}$$

The dysfunctional area is represented by the stability lobes, while the stable region is represented by the points under the lobes. Chatter control strategies aim to transfer the lobes above or delete the unstable region.

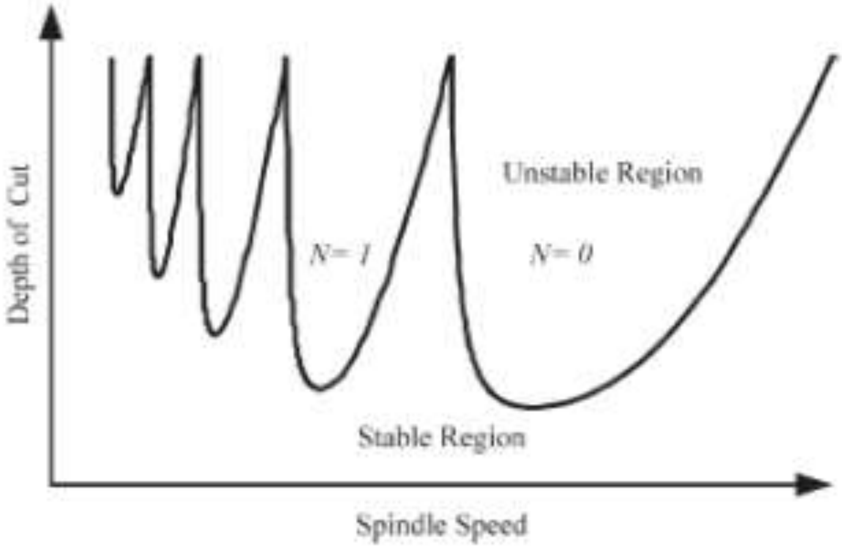

Figure 6: Typical stability lobe diagram

Tool motion simulation in two different directions

The instrument is supposed to be flexible and stretch in the x and y directions, while the workpiece is assumed to be rigid. As seen in Fig. 6, the structure can be modeled as a two-dimensional oscillator excited by the cutting power.

The governing equations read:

$$m_x\ddot{x}(t) + C_x\dot{x}(t) + K_x x(t) = F_x$$

$$m_y\ddot{y}(t) + C_y\dot{y}(t) + K_y y(t) = F_y$$

Where m, C_x, C_y, K_x and K_y in the x and y directions, are the mode shape mass, damping, and stiffness parameters, however.

The cutting force is expressed as

$$F_x = K_x w h^q$$

$$F_y = K_y w h^q$$

Where K_x and K_y w is the depth of cut, h is the chip thickness, and q is an exponent (q = 0.75 is a common analytical value for this parameter).

This model assumes that the tool never leaves the workpiece during the cutting operation, that is, h>0.

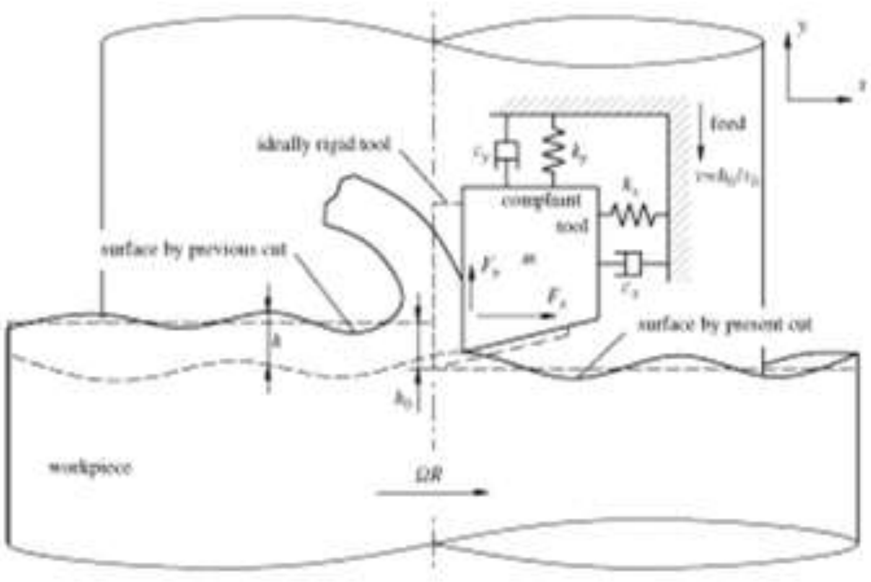

Figure 7: Regeneration Model in turning

The chip thickness would be a constant if the instrument were static. $h = h_0$. This is just the innovative feed. However, the tool feels movements that change its cutting depth in realistic cases and the tool cuts this wavy surface after a revolution of the workpiece. This renders the chip thickness during machining inconstant due to the regenerative impact. The chip thickness may be determined while the regenerative delay is present:

$$h = \begin{cases} v\tau + y(t-\tau) - y(t) & \text{if } y(t) - y(t-\tau) \le v\tau \\ 0 & \text{if } y(t) - y(t-\tau) > v\tau \end{cases}$$

Where v The feed's velocity. The case here $y(t)-y(t-\tau)>v\tau$ The lack of touch between the workpiece and the instrument correlates. In the present paper the effects of touch losses are only studied local bifurcations. Therefore, we conclude that in the following analysis $y(t)-y(t-\tau)\leq v\tau$ during machining. The delay in time is not equivalent to the rotational length of the piece, though, since the tool often feels vibration in the direction of x:

$$R\Omega\tau = 2R\pi + x(t) - x(t-\tau)$$

Here Ω is the pace of the spindle (rad/s) and R is the workpiece radius. The regenerative time is therefore a state-based delay, because both current (x(t) and delayed are dependent on the state $(x(t-\tau))$. We would then use the mark $\tau(x_t)$, where $x_t(s)=x(t+s), s\in[-r,0], r\in R^+$ The history of the state is defined.

We presume the tool is symmetrical in order to minimize the amount of parameters, i.e., $C_x = C_y = C,\ K_x = K_y = K.$

The normal angular frequency is the appropriate $w_n = \sqrt{K/m}$ and the ammunition ratio $\xi = C/2mw_n$

On the basis of the analysis model established by Alintas and Budak, the machining stability for the vertical grinder can be predicted. In their approach, Fourier-series components have approximated the time varied force coefficient of the complex milling process model. The stability of the chat-free axial cutting depths is the consequences (Z_{min}) And the end-mill process spindle speed(n) was obtained as follows from Gagnol et al.

The speed-dependent feature of the transformation of the displacement Fourier $x(jw)$ on the complex cutting force tip of the tool $F(jw)$ can be defined as:

$$H(jw) = \frac{X(jw)}{F(jw)} = R_e(w) + jI_m(w)$$

$$Z_{min} = \frac{-1}{NK_tK_rR_e(w)}$$

$$\varphi = \pi - 2\tan^{-1}\frac{I_m(w)}{R_e(w)}$$

$$n = \frac{60w_c}{N(2k\pi+\varphi)}, \qquad k = \text{lobes } (0,1,2,\ldots)$$

In the above equations, R_e and I_m are the actual and imaginary component of the spindle tool tip transition mechanism. K_t and K_r The resistor coefficients for the cutting are both tangential and radial against the cutter. N is the sum and k are the number of the lobe.

A two-tooth carbide cutter for machining the material from Al7075 was used to estimate machining stability. The coefficients of cutting strength were calibrated as $K_t = 796\ N/mm^2$ and $K_r = 0.21$

CONCLUSION

The findings achieved in this paper are true under persistent cuts and machining conditions. It is important to mention that. Additional changes in any conditions of trimming and working can modify the performance results. This analysis allows the researchers to understand the exact essence of the tool chatter and apply the principle to choose the optimal machining parameters and to operate stably with the maximum metal removal rate.

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