Chatter Improvement in Hard Turning by Using Different Shim Material

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Abstract*- The machine tool structure loose stability due to the dynamic forces which arise during the cutting operation. Due to this self-excited vibrations occurs which is known as chatter. Chatter is a so-called self-excited oscillation because the vibration itself generates the energy that again creates the vibration. The single degree of freedom chatter theory has been considered for only those cases where rigidity of the tool and support is relatively small in one direction which may allow the tool to vibrate in that direction. Otherwise, the tool motion will not be straight and two degree of freedom theory will have to be used for analysing the problem. An analytical model is simulated using MATLAB. The model proposed in this work is an analytical model used for the prediction of stability limit for hard turning systems during cutting process by using various modes, speeds, width of cut, damping ratios and stiffness.*

Hard turning creates high pulsating pressures on the insert seat and shim. The shim acts as a shock absorber for the insert and work piece. The shim protects both insert and tool holder from damage due to high cutting forces. In the present work, the carbide shim is replaced with brass and aluminium cutting tests are conducted to find out the improvement in surface finish and there by chatter reduction.

Keywords- Chatter, Stabillity, Stiffness, Damping ratio, Single point cutting tool, Stabillity Analysis.

I. INTRODUCTION

With the modern trend of machine tool development, accuracy and reliability are gradually becoming more prominent. To achieve higher accuracy and productivity it is not enough to design the machine tools from static considerations without considering the dynamic instability of the machine tools. If there are any relative vibratory motion present between the cutting tool and the job, it is obvious that the performance of the machine tool will not be satisfactory. Moreover, machine tool vibration has a detrimental effect on tool life, which in turn, lowers down the productivity and increases the cost of production.

II. MATHEMATICAL MODELING: STABILITY OF CUTTING TOOL SYSTEM [1]

Basic and important concepts and equations of the structural dynamics, which are used in the following sections, which are used to develop matlab program, with the discussion of a single degree of freedom system. A viscously damped single degree of freedom system model is shown in Figure 1. Assuming that, any increment of force (P) due to regeneration effect occurring in y direction continues to act in β–direction and that is the only force acting on the system.

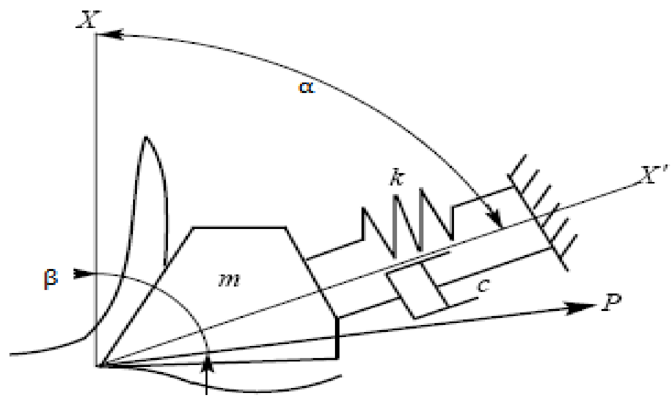

FIG 1: Single Degree of Freedom turning operation[15]

If the principal mode (x) is inclined to an angle α to the direction of normal (y) and to the generated surface, the motion along y is related to motion along x by,

$$y = x\cos\alpha$$

Hence, the chip-thickness variation is

$$y = y(t) - y(t-T)$$

$$y = [x(t)] - x(t-T)]\cos\alpha \quad \text{.......(1)}$$

The equation of motion along x is:

$$m\ddot{x} + c\dot{x} + kx = P_x(t) = P(t)\cos(\alpha - \beta)$$

Where,
m = Mass
c = Damping coefficient
k = Stiffness (k = P / x)

III. EFFECT OF MODE ORIENTATION ANGLE ON STABILITY

From the equation , the effect of mode orientation angle α on cross receptance is simulated with the help of software MATLAB program. The function u (coupling coefficient) for β = 60° is plotted in Figure 2.

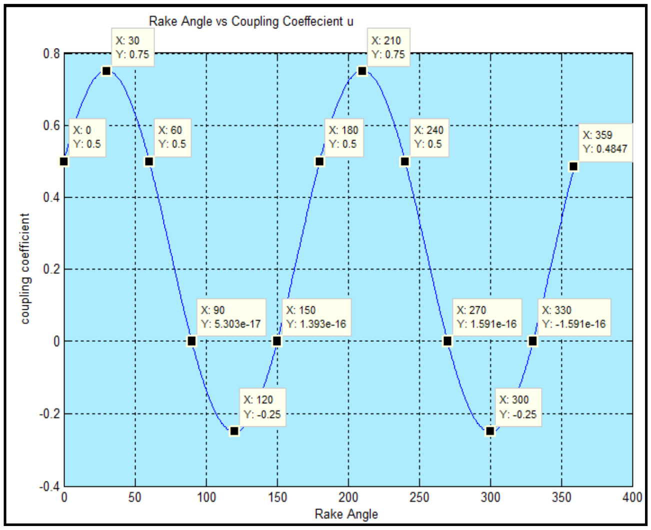

FIG 2: Effect of mode-coupling coefficient u on mode coupling angle α

From Figure 2, it is observed that for α= (β/2) and α= [(π/2) + β], the coupling coefficient, u becomes zero and an unconditional stability is achieved. This is also clearly shown in Figure 5. where a stability plot for different values of α keeping β invariant shows that the stability limits is affected by the mode orientation angle α.

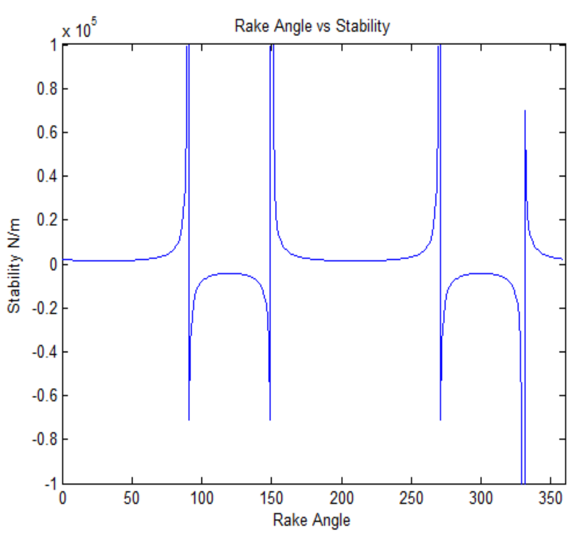

FIG 3: Variation of stability as a function of α

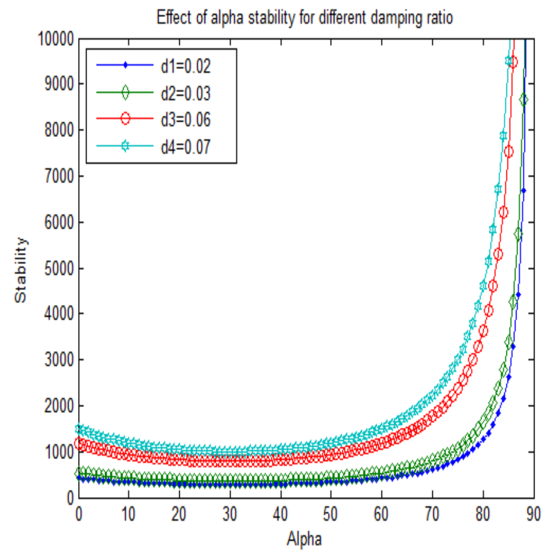

FIG 4: Effect of α on stability for different damping ratio

The limit of stability, connoted by coupling coefficient, r*, is minimum for α= (β /2). From the Figures 5 and 6, it is indicated that the permissible stability value r* is minimum at α_1= 30°. Figure 6 shows the effect of mode coupling angle α on stability limit for finding various damping ratio and keeping β invariant. The higher damping ratio has then higher stability region. The stability limit is increased when the damping ratios increase.

IV. EFFECT OF CUTTING SPEED ON STABILITY FOR VARIOUS DAMPING RATIOS

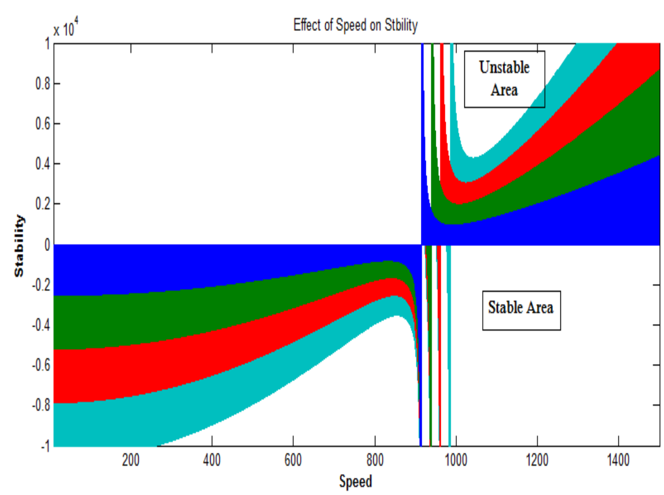

FIG 5: Effect of speed on system stability for different damping ratio

From the equation , it is indicated that the effect of speed on stability is simulated with the help of software MATLAB program. Figure 5 shows the stability plot of conventional characteristic equation method. The stability plot is based on the approximated values of mass and damping, the plot shows the effect of the variation of stability with the change in speed by keeping the stiffness and mass of the system constant with different values of damping ratio. The chatter frequency is greater than the resonant frequency. Hence, the stability plot should be discussed after the resonant frequency. Higher damping ratio moves the stability boundary upward and stability region become wider. From the Figure 5, it understood that the higher damping ratio has a wider stability region.

V. EFFECT OF SPEED ON SYSTEM STABILITY FOR DIFFERENT STIFFNESS

The variation of stability as function of speed for different stiffness of cutting tool is clearly shown in the Figure8. The stability plot is based on the approximated values of mass and damping, the plot shows the effect of the variation of stability with the change in speed by keeping the damping ratio and mass of the system constant with different values of stiffness. When stiffness increases, the natural frequency is also increased. If the natural frequency increases then the boundary curve moves right. Moreover, if it decreases on the contrary then the curve moves left.

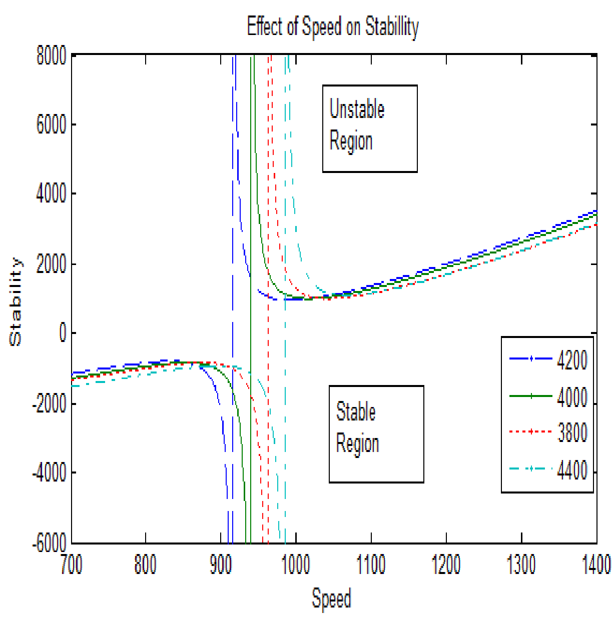

FIG 6: Effect of speed on stability for different stiffness

VI. CHARACTERISTICS OF STABILITY LOBE ACCORDING TO NATURAL FREQUENCY AND DAMPING RATIO

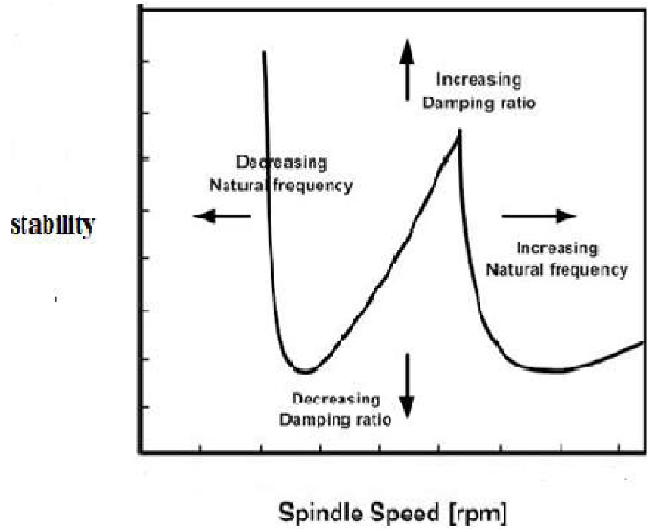

FIG 7: Stability lobe behavior according to natural frequency and damping ratio[11]

The characteristics of the stability curve with respect to the dynamic parameters, damping ratio and stiffness are combined and presented in the Figure 7

From the Figure 9 it is seen that the stability lobe boundary moves upward and the stability region becomes wide when the damping ratio increased. However, the boundary region moves downward for lower damping ratio and the size of stable region becomes smaller and narrower. If the natural frequency increased then the boundary curve moves right. On the contrary, if the natural frequency decreases then, the curve moves left.

VII. STABILITY LOBE FOR CUTTING TOOL SYSTEM

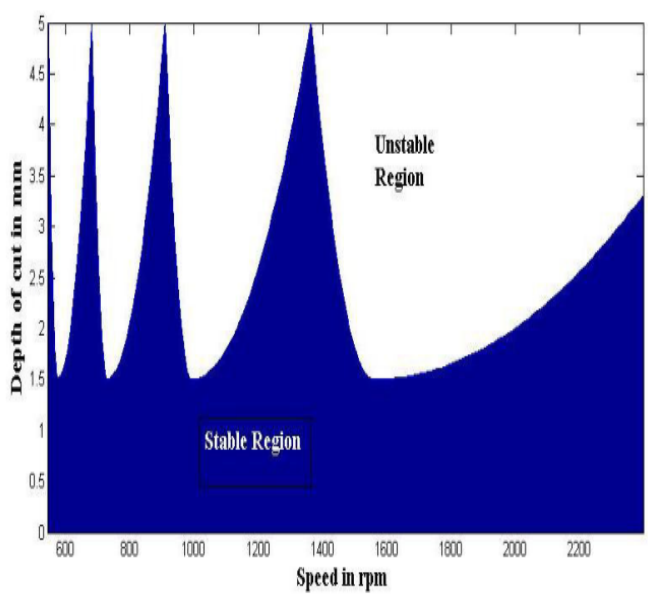

FIG 8 : Stability Lobe Diagram for hard turning

The relationships among the chatter frequency f, and the tooth frequency f_t, and the lobe number n, together with equation , they form the governing relationship between the depth of cut a_p and spindle speed N. Using MATLAB program relationship between depth of cut a_p and spindle speed N are plotted in Figure 8. Since the series of relationships curve in Figure 8 is shaped like lobes, the graph is usually called a stability lobe diagram. A stability lobe diagram shows the relationship between chip width (or depth of cut) and spindle speed, with the lobe number as a parameter. Usually, the variable on its x-axis is represented as spindle speed N, tooth frequency ft, the variable on its y-axis is represented as depth of cut a_p.

There is an optimal depth of cut for every cutting speed, which gives maximum cutting speed boundary value. There is an optimal cutting speed, which gives the best margin of cutting speed.

VIII. RESULTS OF STABILITY ANALYSIS

The above simulation revealed the following

- The stability limit of cutting tool with different dampers can be predicted using MATLAB.
- The permissible stability value r* is minimum at $\alpha = \beta/2 = 30$. And between $60 < \alpha < 180$ the self-excited vibrations due to mode - coupling would not occur.
- Higher damping ratio lifts the stability lobe upward and widens the stability region. However, the boundary region moves downward for lower damping ratio and the size of stable region becomes smaller and narrower.
- By increasing the stiffness of system, the natural frequency is increased and the boundary curve moves right. Similarly, if the stiffness is decreased then the curve moves left.
- This finding confirms that the dynamic stability can be increased without any modification in structure and the weight of the existing machine tool.

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