WHY THE HARMONIZER™ TECHNIQUE WORKS TO AVOID CHATTER!

The following information explains the general spindle speed selection technique for avoiding chatter that is the basis of the HARMONIZER™ package.

Fundamental Concepts: Several fundamental concepts exist in combatting chatter using spindle speed selection.

- Axial and radial depth-of-cut have a direct and proportional affect on the stability of machining.
- Spindle speed has a large deterministic affect on stability.
- Chatter frequency is related to the dominant natrual frequency and spindle speed.
- Chip loads above a small minimal level do not strongly affect stability, only tool displacement.

Stability Plots: The top plot of Figure 1 displays a stability plot (hatch area indicates chatter) for a 2-tooth cutter in terms of axial depth-of-cut as a function spindle speed. The bottom plot displays (**bold non-linear lines)** chatter frequency (Hz) as a function of spindle speed. Also on this plot are lines of tooth frequency (Hz) multiples (straight lines marked $2f_t$, $3f_t$, …) as a function of spindle speed.

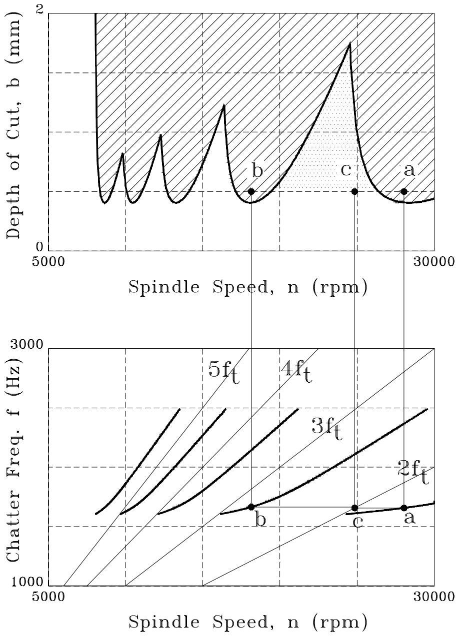

Figure 1.

These two plots completely describe the spindle speed-chatter frequency relationship typical for most tools. The location and height of the curves may change depending on the tooling used but the form and shape of the curves remains very similar. The indisputable concept is that

"spindle speed and chatter frequency are related"

From this relationship, as shown in **Figure 1**, a convergent technique can be applied to find the best spindle speed with minimal effort.

Speed Selection Technique: The basic technique is:

"select spindle speed so that tooth frequency or some multiple of tooth frequency is equal to chatter frequency"

Referring to **Figure 1**, assume that a cut is made at point ***"a"*** at a 0.5-mm depth. The upper stability plot indicates that this cut is chattering. The chatter frequency can be determined in the lower plot by finding the frequency for the same spindle speed point on the lowest chatter curve (**bold non-linear line**). It is about 1,650 Hz. Graphically the technique directs the spindle speed change to the spindle speed curve for the two times multiple of tooth frequency (marked $2f_t$) which corresponds to a spindle speed of just under 25,000 rpm (1650 Hz*60 cpm/Hz÷2 teeth cpm/rpm÷2nd multiple). Returning to the upper plot indicates that the new speed is in a chatter free area at point ***"c"***. Starting at another spindle speed, point ***"b"***, results in a similar outcome demonstrating the convergence of the technique.

Figure 2 more clearly demonstrates the convergence of the method and the benefit in being able to optimize a cutter's performance. A cut is attempted at the maximum speed of the spindle, in this case 30,000 rpm denoted as ***"a"***. The technique selects a spindle speed at ***"b"*** which is stable. The depth-of-cut is then increased to 1.0-mm, point ***"c"***, which chatters. The technique is then applied again and a new spindle speed at point ***"d"***, further into the stable zone, is selected. Depth-of-cut is again increased to point ***"e"***, and this time it remains stable. A further increase results in a chattering cut at point ***"f"*** but since the depth-of-cut is above any stable pockets no new spindle speeds, points ***"g"*** and ***"h"***, can be selected that are stable.

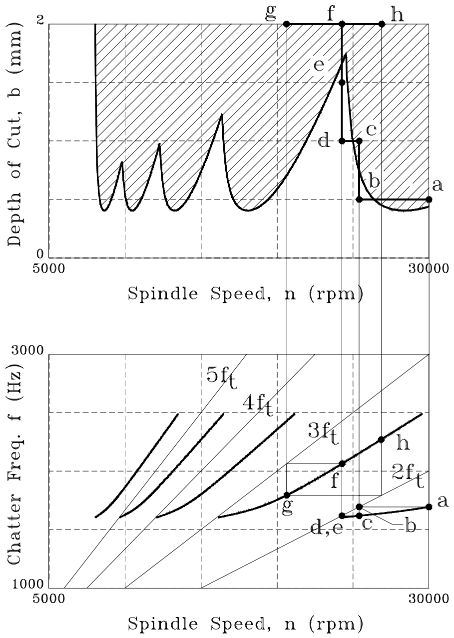

Figure 2.

This example clearly demonstrates that the technique converges to the optimal spindle speed where the highest depth-of-cut can be achieved. Obviously it has good application in testing tooling on a test block as seen in **Figure 3** where the optimal depth of cut can be quickly determined with a simple cutting test.

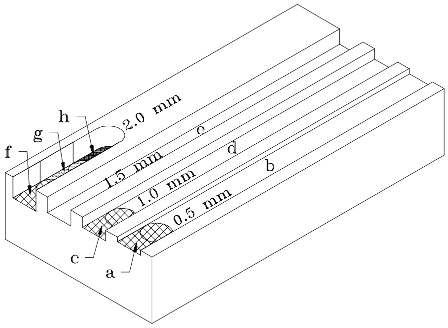

Figure 3.

No Resonant Vibration: The most common misconception is that this technique drives the system into resonance. This is not the case because machining is not a "classic" forced vibration problem where the periodic force is applied regardless of system displacement. The cutting force being applied to the tool is a function of chip-thickness which is dependent on cutter displacement which is dependent on cutting force. Therefore this is very similar to a feedback-type system in which stability dictates not resonant vibration.

Figure 4 illustrates the effect of the force. By synchronizing the phase of the tool vibration so that it coincides with a tooth frequency (or multiple), chip thickness, which is proportional to cutting force, is made constant and therefore force variation is minimized. The spindle speed, as long as it is in phase, only affects the number of vibration cycles between tooth passes.

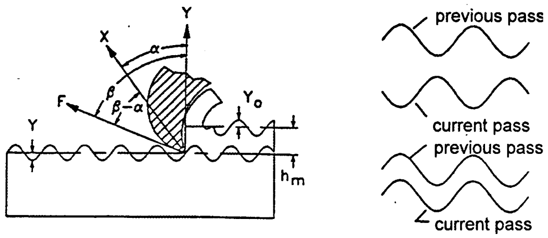

Figure 4

Resonant vibration is not a factor because the force is not independent of the process and therefore is not magnified in the "classical-resonant" sense when operating near a natural frequency. This is well-documented in literature and references can be supplied on request.