Investigation of Retention Knob Geometry on Machining Dynamics

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Abstract
In this study, impact testing is used to determine the potential effects of retention knob design on tool-holder-spindle-machine assembly dynamics. Three different knob designs are selected and used to clamp a simple geometry artifact in a CAT-40 interface spindle. The mean and standard deviation repeatability limits are compared for frequency response functions measured using the three designs. It is shown that the knob geometry does not exhibit a significant influence on the assembly dynamics.

Keywords: Machine tool, spindle, milling, dynamics

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1 Introduction

One limitation to milling productivity is self-excited vibrations, or chatter. Milling process models, including time- and frequency-domain stability analyses, may be implemented to select operating parameters that avoid chatter at the process planning stage. These models require that the frequency response function (FRF) at the tool point is known (Tlusty, Altintas, Schmitz and Smith). The required tool-holder-spindle-machine FRF can be obtained by impact testing, where an instrumented hammer is used to excite the assembly and a linear transducer (such as an accelerometer) is used to measure the response.

The tool-holder-spindle-machine assembly is composed of two primary connections: 1) the connection between the tool and holder, which includes thermal shrink fits, deformable collets, and other manufacturer-specific systems; and 2) the holder-spindle connection, including HSK, CAT, BT, and others. For CAT and BT holders, the holder taper is ground to match the spindle taper and the holder is drawn into the spindle using a drawbar mechanism that externally grips a retention knob threaded into the narrow end of the tapered holder. Recently, increased attention has been given to retention knobs. It has been suggested that the knob geometry, as well as the torque used to insert it in the tapered holder, affect the final holder shape and, subsequently, the machining process. Variation in tool life based on the amount of radial taper deformation relative to the nominal surface has been reported (Zelenski).

In this study, the effect of retention knob geometry on the tool point FRF was investigated. The goal was to identify the level of FRF sensitivity to various knob geometries in order to determine if this is an important parameter for: 1) traditional impact testing and process modeling (using the stability lobe diagram that separates stable and unstable zones over the selected spindle speed-axial depth of cut domain); and 2) ongoing efforts to predict the tool point FRF (or receptance) using Receptance Coupling Substructure Analysis (RCSA) (Schmitz and Donaldson, Schmitz *et al.* 2001a, Schmitz *et al.* 2001b, Schmitz and Duncan, Kumar and Schmitz).

In the RCSA approach, the tool-holder-spindle-machine assembly is considered as three separate components: the tool, holder, and spindle-machine and the individual FRFs of these components are coupled analytically. The archived measurement of the spindle-machine receptance is coupled to the free-free boundary condition receptances of the tool and the holder derived from Timoshenko beam models (Weaver *et al.*). Because different retention knob geometries may be selected to connect the holder and spindle, it is important to determine the effect this may have on the holder-spindle response.

Figure 1. Photograph of modified boring bar (artifact) mounted in the CAT-40 spindle interface; the retention knob cannot be seen. The accelerometer and hammer are also shown for an *x* direction measurement.

2 Experimental Setup

The measurement setup for a CAT-40 spindle-holder interface (Haas TM-1 CNC machining center) is displayed in Fig. 1. The PCB 086C04 modal hammer was used to excite a modified boring bar (Kennametal CV40BB400600) and the response was measured using a PCB 352A21 accelerometer. This 44 mm diameter, 57 mm long solid cross section artifact was selected because it is used to identify the spindle dynamics in the RCSA approach. After a single measurement at the free end of the artifact clamped in the spindle, the portion of the artifact beyond the taper is removed in simulation to isolate the spindle dynamics (Kumar and Schmitz).

Three retention knob geometries were selected to represent the range of available types; see Fig. 2. The thread length, as well as its position within the holder taper, were different for the three geometries.

- For the left knob in Fig. 2 (design A), the thread length is restricted to 14 mm for the 28 mm extension below the bottom face of the knob flange. The stated intent of the restricted length (Zelenski) is that there are no threads near the holder taper end, where it is most likely to deform in the radial direction.
- The middle knob (design B) has a 15 mm thread length and a shorter extension of 26 mm. The threads begin 14 mm from the flange face for design A and 11 mm for design B.
- For the traditional design C, the extension is 25 mm and the 19 mm long thread begins 6 mm from the flange.

In summary, from left to right in Fig. 2, the threads are extended farther away from the knob flange (that seats against the holder taper) and are, therefore, moved farther from the narrow taper end. The concept is that moving threads away from the narrow end of the taper reduces the radial deformation.

Three tests were performed using each retention knob. The artifact was released from the spindle and replaced in the same orientation between each test. Repeat testing was performed to identify the level of dynamic repeatability from one clamping condition to the next. The knobs were inserted in the CAT-40 taper using a torque of 36.6 N-m (27.0 ft-lb) applied with a torque wrench. For all measurements, the rotational orientation of the spindle/artifact was maintained.

Figure 2. Three retention knobs: (left) restricted thread length design A; (middle) restricted thread length design B; and (right) traditional design C.

3 Results

For each retention knob, the mean and standard deviation of the real and imaginary parts of the FRFs (on a frequency-by-frequency basis) were calculated. The results for design A are plotted in Figs. 3 and 4 for the x and y directions, respectively. The mean is represented by the solid line, while the one standard deviation repeatability limits are identified by the dashed lines. Figures 5 and 6 display the results for all three retention knobs. In these figures, the frequency range is limited to the largest amplitude mode to enable more convenient visual comparison. Additionally, knob design A is identified by the solid lines, design B by the dashed lines, and design C by the dotted lines.

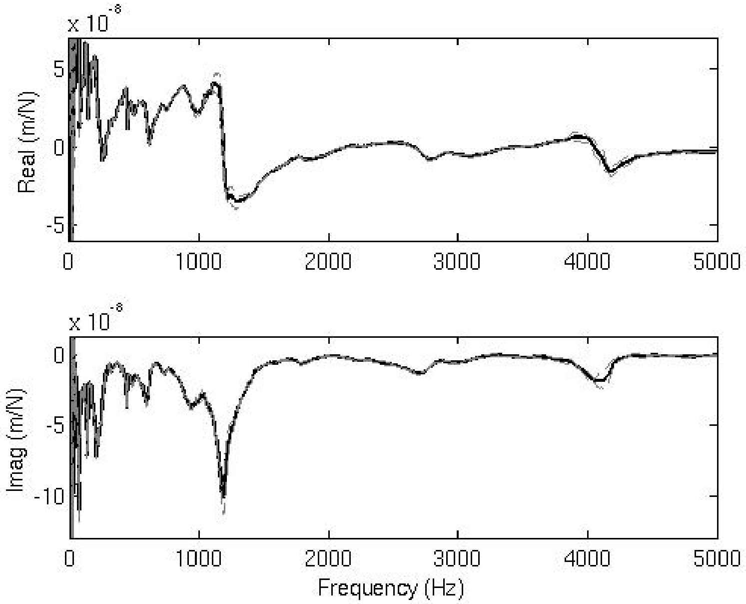

Figure 3. Mean (solid line) and mean +/- one standard deviation (dashed lines) for the *x* direction measurements using design A.

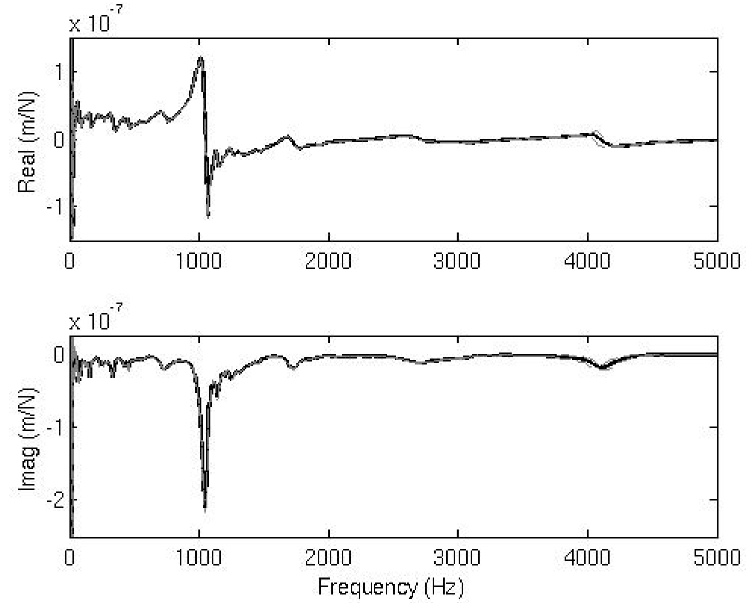

Figure 4. Mean (solid line) and mean +/- one standard deviation (dashed line) for the *y* direction measurements using design A.

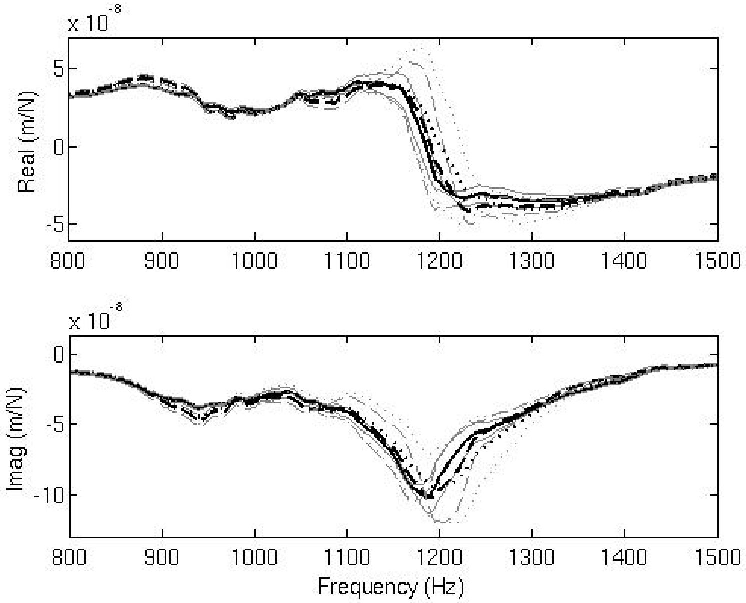

Figure 5. Mean with +/- one standard deviation for the *x* direction measurements using design A (solid), B (dashed), and C (dotted).

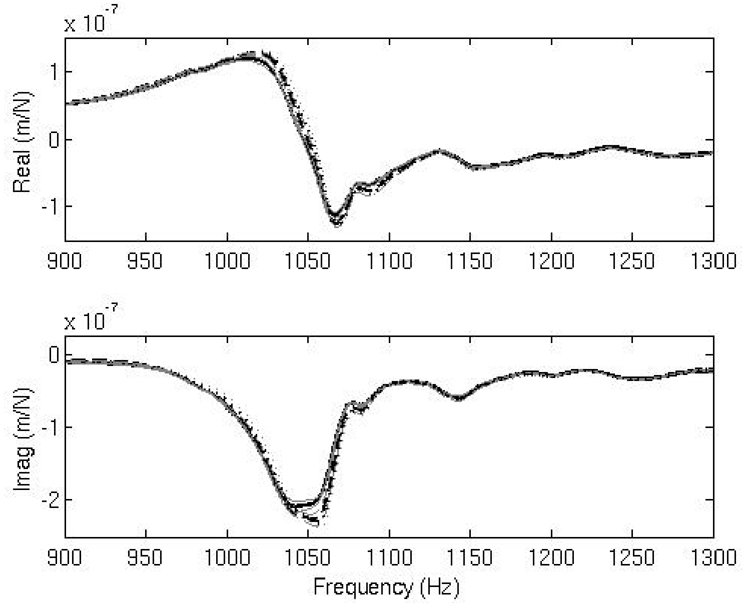

Figure 6. Mean with +/- one standard deviation for the *y* direction measurements using design A (solid), B (dashed), and C (dotted).

Figures 5 and 6 show that the level of disagreement between the three retention knob FRFs is within the repeatability established by removing and replacing a single knob-artifact assembly in the spindle. This suggests that the retention knob design does not play a significant role in the tool point dynamic response. This does not refute or establish the claims that the retention knob design affects tool wear, however. This effect was not evaluated.

4 Conclusions

In this study, the potential effects of retention knob design on the machine-spindle-holder-tool dynamics were evaluated using a simple geometry artifact and impact testing. For the three representative knob designs evaluated, no significant influence on the assembly frequency response was identified.

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