The Role of Natural Frequencies in Grinding Systems Vibration

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Excessive machine tool vibration during a precision grinding operation can result in poor workpiece quality in the form of chatter, rough finishes, burn, etc. One possible reason for excessive vibration is directly associated with the relationship between natural frequencies of a machine tool system and the operating speed of the grinding wheel spindle.

A machine tool system can comprise the entire machine or some sub-component of the machine, such as the grinding spindle, the fixture, workhead, etc. and multiple natural frequencies exist in all structures, including grinding machines. A natural frequency is the rate at which an object vibrates when a shock force excites the system, such as a tuning fork when it is struck. A system's natural frequency can also be excited by vibrational forces such as the centrifugal force generated by a rotating grinding wheel. Vibration severity can increase dramatically if this vibrational force frequency (e.g. wheel rpm) coincides with, or is close to, the natural frequency. This is also known as resonance frequency.

Machine tools are typically, but not always, designed to avoid this situation by keeping the natural frequency away from wheel operating speeds. For this reason natural frequencies are generally not an issue.

However, adding fixtures, grinding quills or grinding wheels can change the systems dynamics and as such either introduce new natural frequencies and/or modify existing natural frequencies.

An example of this type of vibration took place during a grinding test that was evaluating the effect of the wheel speed on a workpiece surface finish. Figure 1 shows the workpiece. During the test it was found that chatter amplitude on the workpiece had unexpectedly increased greatly when the wheel speed was reduced from 7,000 rpm to 6,250 rpm. Figure 2 shows the roundness when the workpiece was ground at 7,000 rpm and Figure 3 when ground at 6,250 rpm. This was inconsistent to what would be expected since reducing the wheels speed should decrease the centrifugal force and reduce vibration. Therefore it was decided to evaluate the vibration levels of the machine

Figure 1 The workpiece.

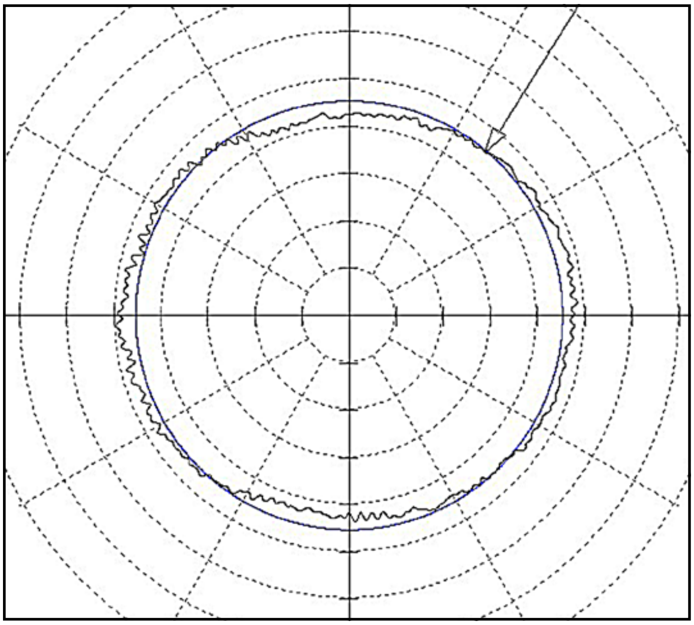

Figure 2 The workpiece with no chatter.

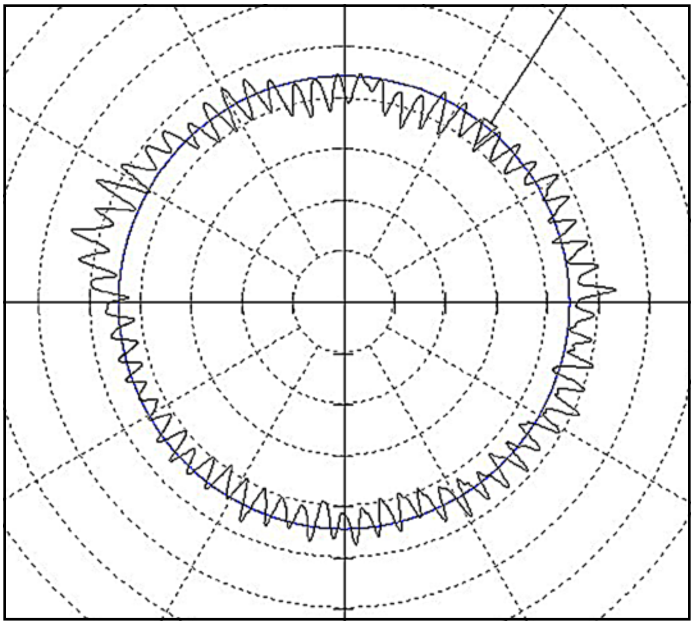

Figure 3 The workpiece with chatter.

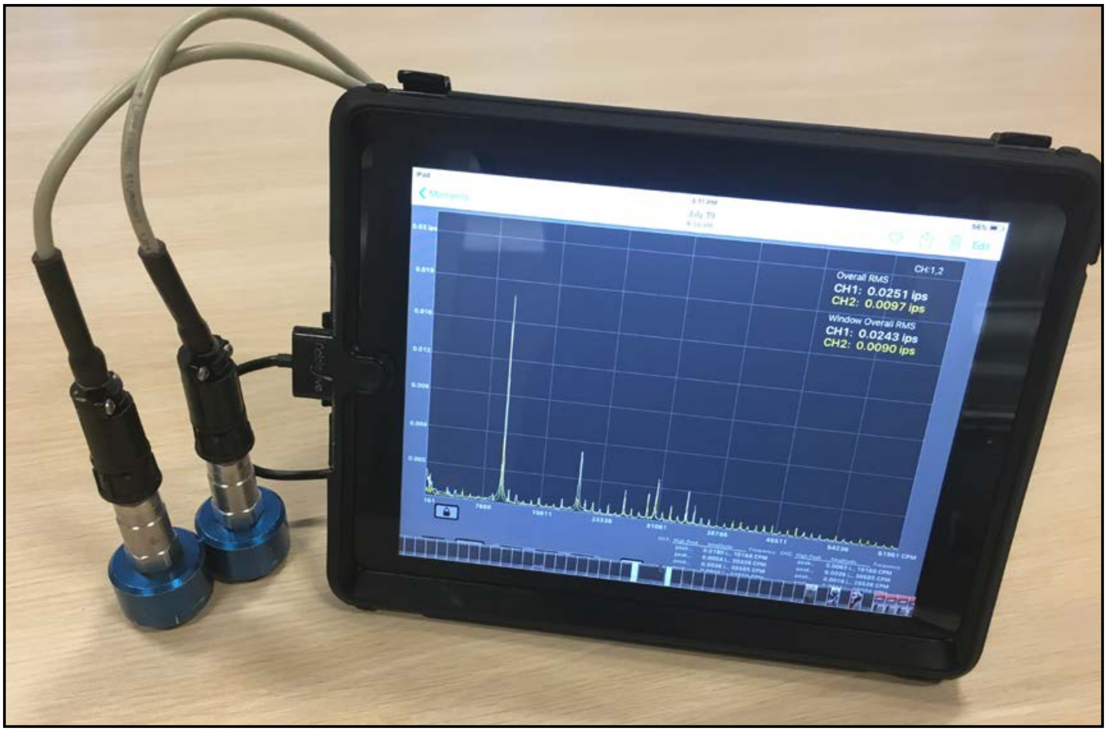

Figure 4 iPad based vibration analysis (VA) equipment.

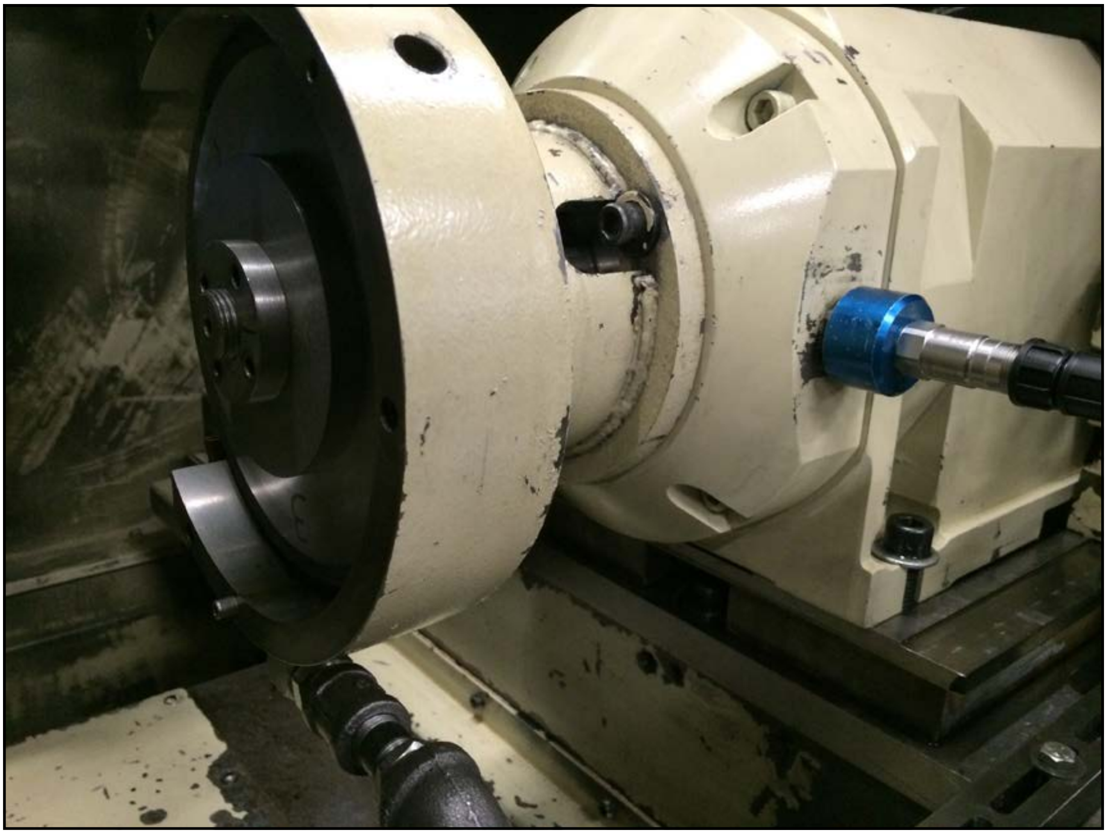

Figure 5 Machine spindle.

at the different operating speeds. The vibration analysis (VA) equipment shown in Figure 4 was used to measure the vibration amplitude at nine different operating speeds between 5,400 rpm and 7,453 rpm. The accelerometer was placed horizontally on the spindle as shown in Figure 5. The results showed that the vibration amplitude (Displacement Mils PK-PK) increased substantially as the speed approached 6,250 rpm and decreased away from this speed, as shown in Figure 7. Based on this data it appeared that there was a natural frequency at approximately 6,250 cpm (104 Hz).

In order to confirm this conclusion, an impact test was performed on the grinding spindle. The impact test was carried out

Figure 6 Chatter on gear tooth.

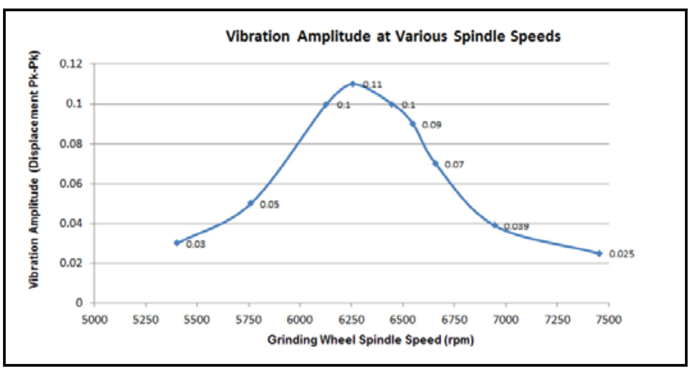

Figure 7 Vibration at different speeds.

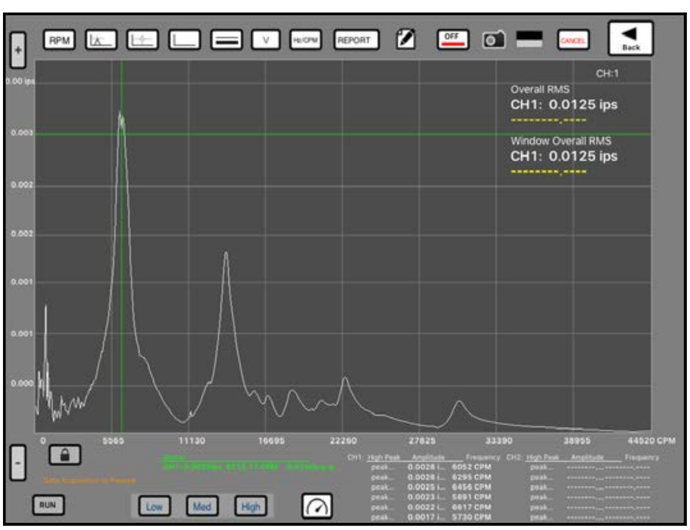

Figure 8 Impact test results.

using the same vibration analysis equipment. The accelerometer was mounted as shown in Figure 5. The spindle was then lightly tapped with a plastic hammer creating the shock force required to excite the natural frequency. The results of this test are shown in Figure 8. The large peak at 6,250 cpm (104 Hz) verifies that there is a natural frequency was causing the chatter issue.

The example in the case study describes the issues encountered when grinding the outside diameter (OD) of a workpiece on a cylindrical grinder. However this type of vibration issue is not unique to any one type of grinding machine or operation. Natural frequencies and the resulting detrimental vibration can be potentially found in many grinding processes, including creepfeed grinding, surface grinding, internal grinding, gear grinding, etc. In a gear manufacturing process, grinding the teeth is typically the final step when the required surface finishes and tooth profile are being generated. It is therefore critical that vibration is kept to a minimum. At this late stage of the process a tooth face with poor surface finish or chatter (Figure 6) could result in rejections, reworks and possibly additional honing time, if there is a subsequent honing operation. Poor quality surface finish can also result in an increase in gear noise and a reduction in gear life for the end users.

Dealing with Natural Frequencies

In the example described above the solution was to run at spindle speeds of 5,500 rpm and 7,300 rpm to avoid the natural frequency. In most cases the best and only solution is to adjust the wheel speed away from the natural frequency by about 15 to 20 percent. There are other available options such as trying to move the natural frequency by changing the system stiffness or mass, but these actions can be complicated and difficult to apply. However, improving the system stiffness by adding support brackets or improving the setup design should be considered if some component of the machine is clearly weak, as in a workpiece fixture or grinding quill. Utilizing a tuned mass damper is another option to consider. A tuned mass damper (TMD) is a device that is tuned closely to the same frequency as the natural frequency. The stiffness and mass of the damper is adjusted to obtain the target frequency. When the machine starts to vibrate the TMD will vibrate out-of-phase at the same frequency with the machine and as a result, reduce the vibration amplitude. Various versions of TMDs are used in many applications to combat natural frequencies, including, buildings, spacecraft, planes, bridges, etc. If considering this approach it would be advisable to consult a company that specializes in this type of device to determine if a TMD a good solution for your application.

Conclusion

A machine tool with a spindle speed range that overlaps a natural frequency can result in high vibration levels, leading to poor part quality and disruptions in production. Recognizing this type of issue can be difficult because in many cases the natural frequencies are not known. The best way to prevent vibration issues is to be proactive in measuring and tracking machine vibration by using vibration analysis equipment like the system shown in Figure 4, or similar types of equipment. This type of equipment can also be used for problem solving techniques like the impact test described above.

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