vertical vibrations of the wheel were measured. The amplitudes in these tests were a little smaller and the frequency a little larger than those in Figs. 51-55.

But these amplitudes were much larger than those where the headstock has a plain bearing. Consequently, the headstock with a ball bearing is more likely to cause vibration of the wheel than the headstock with a plain bearing.

To compare the damping capacity of each main spindle, Figs. 56, 57 show the free vibrations of the wheel of the headstocks with plain bearings and ball bearings, respectively. In the headstock with a ball bearing, the damping capacity of the main spindle is very little when compared with that of a headstock with a plain bearing.

In so far as prevention of wheel vibration is concerned, a plain bearing is superior to a ball bearing.

**Conclusion**

The wheel vibration which frequently occurs in practical grinding process was measured by an optical method, and many types of vibrations were investigated experimentally.

The causes and the characters of these vibrations and some preventative methods were ascertained.

**Discussion**

R. S. Hahn. The novel way in which the author has shed light on grinding-machine vibrations is most illuminating. Vibrations of grinding machines are becoming more important as the demands for high degrees of precision and surface finish increase. The author is certainly to be encouraged to continue his interesting work.

There are several comments the writer would like to make. Under the section entitled Vibration per Revolution of Grinding Wheel, it is not clear why chatter marks occur on the workpiece, Fig. 5, at a spacing corresponding to every revolution of the wheel, unless (a) the wheel was dressed by a diamond at some point other than the point of contact between wheel and work or (b) unless the diamond point was in a state of vibration relative to the workpiece during the dressing process. A wheel mounted on an out-of-round spindle should run perfectly true at the point where it was dressed. The point of dressing also should run true independently of unbalance, unless, of course, the amount of unbalance changes during the dressing process. Perhaps the author can shed some light on the dressing procedure and why the "once per rev" pattern is formed.

Regarding vibration caused by belts, the writer has also run into this source, even with commercially used V-belts.

Another question the writer would like to ask pertains to the vibration-measuring equipment. Was the light-receiving film mounted on the frame of the machine, on the floor adjacent to the machine, or seismically?

The excitation of the mode shown in Fig. 41 by the flapping of the belt provides an interesting illustration of instability caused by variable elasticity. The string with variable tension as described by den Hartog is similar to the flapping belt and leads to Mathieu's equation. One can readily see how unstable regions can occur as the belt tension is gradually increased in the presence of pulleys or sheaves which are vibrating or "running out."

H. C. Weimar. From the author's remarks and the damping curves of plain-bearing versus ball-bearing spindles, Figs. 56 and 57, respectively, one could easily get the impression that antifriction bearings are, in principle, unsuited to grinding spindles.

It is conceded that in case of a spindle design such as shown in Fig. 50, having considerable overhang of the wheel and flexibility between the bearings, the lower damping factor of the ball bearings would be quite serious.

However, if an antifriction-bearing spindle is designed with sufficient rigidity and short overhang of the wheel, so as to assure a high natural frequency, then even a small damping factor keeps the amplitude of vibration well within permissible limits for most grinding conditions.

**Author's Closure**

The author wishes to thank Dr. R. S. Hahn and Mr. H. C. Weimar for their valued comments.

Dr. Hahn asks about the chatter marks per revolution of wheel on the workpiece. When the diamond dressing was not done over a long grinding process, the periphery of wheel gradually wore down to form an eccentric circle. The chatter pattern (Fig. 5) was produced when the wheel having an eccentric of periphery about 0.001 in. was used.

Concerning the belt, even with V-belt, the size may not be uniform. If there is conspicuous irregularity of size in any part of belt, it might cause the same vibration of wheel as if the irregularity were the seam of a flat leather belt. Further, I think that the characteristic of the flapping vibration of belt (Figs. 43, 44) would be the same even with V-belt.

To isolate the vibration-measuring equipment from the seismic machine, the microscope which magnified the disk vibration was fastened to the angle plate which was mounted on the heavy surface plate having four legs. The surface plate was situated on the concrete foundation separated from that of the grinding machine. The light-receiving film was also mounted on another angle plate which was situated on the concrete foundation.

As Dr. Hahn points out, the excitation of the mode shown in Figs. 36-39 by the flapping of belt provides an instability caused by variable elasticity.

Concerning the remarks of Mr. H. C. Weimar, I should say my description may not be suitable if it gives the impression that antifriction-bearing are unsuited to grinding spindle. It is well known that the antifriction-bearing has many excellent properties, especially in the case of high revolution of spindle. The antifriction-bearing, however, has a smaller damping factor than that of plain bearing. Therefore when the antifriction-bearing is designed, a sufficient rigidity of spindle and short overhang of the wheel is preferable.


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