Reducing spindle speed jitter through encoder alignment

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**Abstract**

Low jitter applications often use air bearing spindles due to the fact that they have lower torque ripple than ball bearing spindles. In this work, an air bearing spindle is controlled via a frequency-locked speed control using a linear amplifier. The spindle encoder signal is frequency-locked to an internal or external reference signal for speed control. At speeds within the controller’s response bandwidth to once-per-revolution signals, encoder centering error results in unacceptable spindle speed variation, or jitter. A direct centering technique is described that uses the output from two readheads located 180° from each other as feedback during the centering process. It is demonstrated that improvements in encoder centering result in reduced speed variation error.

1 **Background**

Aligning the encoder grating to axis of rotation is the primary source of controllable error with regard to encoder installation [1]. Several approaches to encoder centering exist including using mechanical, optical, and electrical methods. The mechanical method requires the use of a datum surface on the encoder substrate. A sensor is used to center the encoder substrate before the grating is applied. Ideally, the encoder is installed so that the datum alignment exactly matches the condition of alignment during manufacture. Geometric form errors of the substrate and mounting distortions can make this impossible. This indirect method is the simplest but results in the highest uncertainty of encoder alignment.

Optically centering the grating pattern offers a direct measure of the grating eccentricity. Optically centering the grating relies on the fact that the outer edge of the grating pattern is round. This method requires the use of a camera or other optical sensor to minimize the deviation of the outer edge of the grating during alignment.
The third, and most accurate method, is a functional method which uses the electrical signals from two readheads to minimize centering error. The encoder is centered when the phase between the output signals is constant. This method is the most accurate because it eliminates indirect datums and it mimics the installed condition. Using two readheads diametrically opposed, removes the effects of encoder eccentricity and odd harmonics of the synchronous errors [2]. This is not a novel solution to the eccentricity problem. Mechanical surveying instruments such as the Wild optical reading theodolite were designed so that to the circle graduation was read from opposite sides simultaneously in the same viewing area, thereby eliminating centering errors [3].

Figure 1. Wild optical theodolites going back to the 1920s used the diametrically opposed readings to eliminate centering errors. The instrument used a clever optical arrangement to enable the surveyor to read both sides of the circle in a single window. Photo credit: Mohave Instrument Co.

2 Approach

In order to demonstrate the benefits of accurate encoder centering, speed variation was measured before and after electrical centering. Low jitter applications often use air bearing spindles due to the fact that they have lower torque ripple than ball bearing spindles. A 4096 line count microE encoder is mounted to a Professional
Instruments Company ISO 3R air bearing spindle. The spindle is motorized with an MCS brushless DC motor linear amplifier with frequency lock control. A microE solid state frequency divider is used to reduce the line count to 512. The continuous time intervals between the 512 encoder counts are recorded with an HP 5371A Time and Frequency Analyzer. The test setup is shown in Figure 2.

![Measurement setup with the air bearing spindle used for jitter testing.](image)

Figure 2. Measurement setup with the air bearing spindle used for jitter testing. The continuous time intervals of the encoder data channel output are recorded by the HP 5371A Time and Frequency Analyzer.

## Results

Results illustrating the improvement in spindle speed jitter with improved encoder centering are shown in Figures 3 and 4. Before centering, the phase variation between the two readhead signals was 205º. After centering the encoder, the phase variation was reduced to 11º. This centering improvement resulted in improvements in the total speed variation and jitter. The fft of the time interval in Figure 4 shows the reduction in first harmonic speed jitter by an order of magnitude.
The mean is 244 μs (480 RPM with 512 lines per rev). The jitter range dropped from 850 ns to 625 ns. The standard deviation dropped from 80 ns to 66 ns.

Figure 4. Frequency analysis of the time interval data. The reduction in the first harmonic error is evident—dropping from 105 ns peak-to-peak to 11 ns peak-to-peak.

Conclusion

In this work, an air bearing spindle is controlled via a frequency-locked speed control using a linear amplifier. Encoder centering error results in unacceptable spindle speed variation, or jitter. A centering technique is described that uses the output from two readheads located 180°. It is demonstrated that improvements in encoder centering result in reduced speed variation error.

References: