Celera MOTION
A Novanta Company

Accuracy, Resolution and Repeatability

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INTRODUCTION

There are several key terms that are critical to specifying the optimal position sensor for a given application. This application note defines these key terms and how they relate to the sensor's role in the overall system performance. It is important to consider that precision is very much a system issue and can be dominated by mechanical errors such as eccentricity, straightness and flatness. This paper discusses the most significant mechanical error for rotary applications (eccentricity) and presents an eccentricity tolerant position sensor solution.

RESOLUTION

Resolution defines the smallest position increment that can be moved or measured and is typically expressed in "counts". High resolution is required for high performance servo systems. A positioning system "dithers" between two counts so the higher the resolution the smaller the dither. Resolution also has a significant impact on velocity ripple at low speed. Since velocity is derived from position feedback, if the resolution is low there may be insufficient data in a sample to accurately derive velocity. At high speeds, high resolution devices can generate data rates beyond the tracking capability of the controller or servo drive.

ACCURACY

Accuracy defines how close each measured position is to the actual physical position. Sensor errors include non-accumulating random variations in scale pitch (linearity), accumulating pitch errors (slope) and variations in fidelity of internal sin/cos signals. Precision machine builders typically calibrate out errors via a lookup table of offsets.

REPEATABILITY

Repeatability defines the range of measured positions when the system is returned to the same physical position multiple times. Repeatability can be more important than absolute accuracy. For system inaccuracies to be effectively calibrated it is important for each position reading to be consistent. Sensor hysteresis (different readings depending on direction of approach to measure position) is an important factor in repeatability.

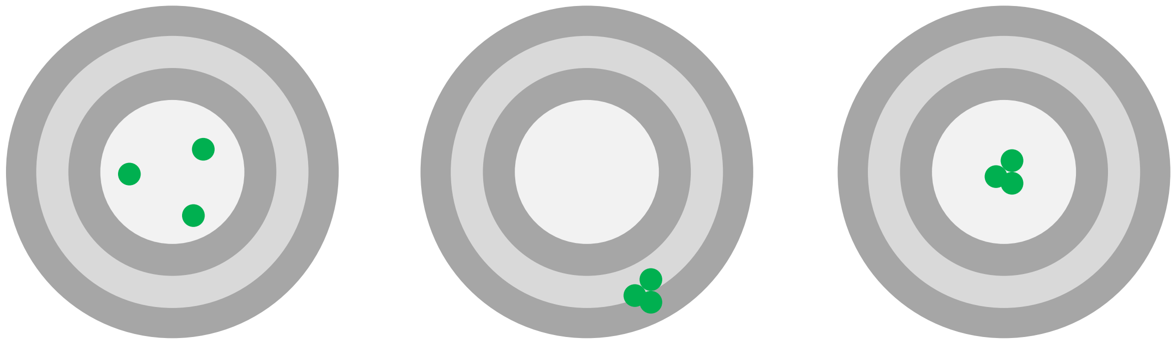

Figure 1 – more accurate shots (left), high repeatability shots (middle), calibrated (right)

Figure 1 provides some insight on the importance of repeatability. Although the left target has more accurate shots, after calibration the higher repeatability shots yield greater precision.

CALIBRATION

As discussed, variations in scale pitch (linearity) can be calibrated out. If the variation in linearity is monotonic or slowly varying, the non-linearity can be easily calibrated using a few reference points. In the example shown below, a fairly non-linear transducer is calibrated in to a highly linear device with a relatively low number of reference points.

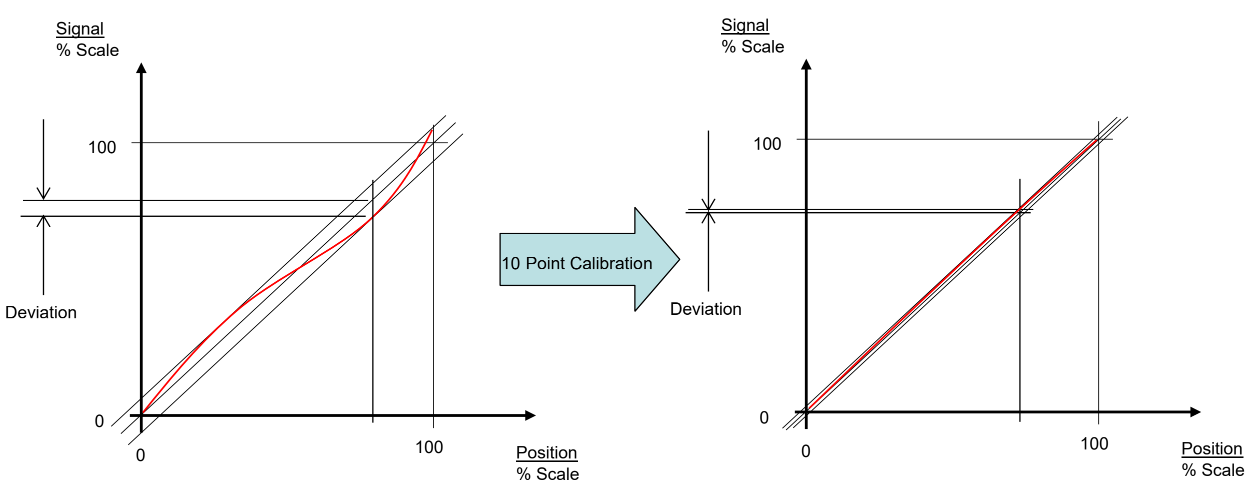

Figure 2 –calibration of a non-linear sensor with slowly varying errors

In this second example, however, a device with a rapidly varying error is calibrated with 10 points and its linearity hardly changes. It may take >1000 points for such a rapidly varying measurement characteristic to be linearized.

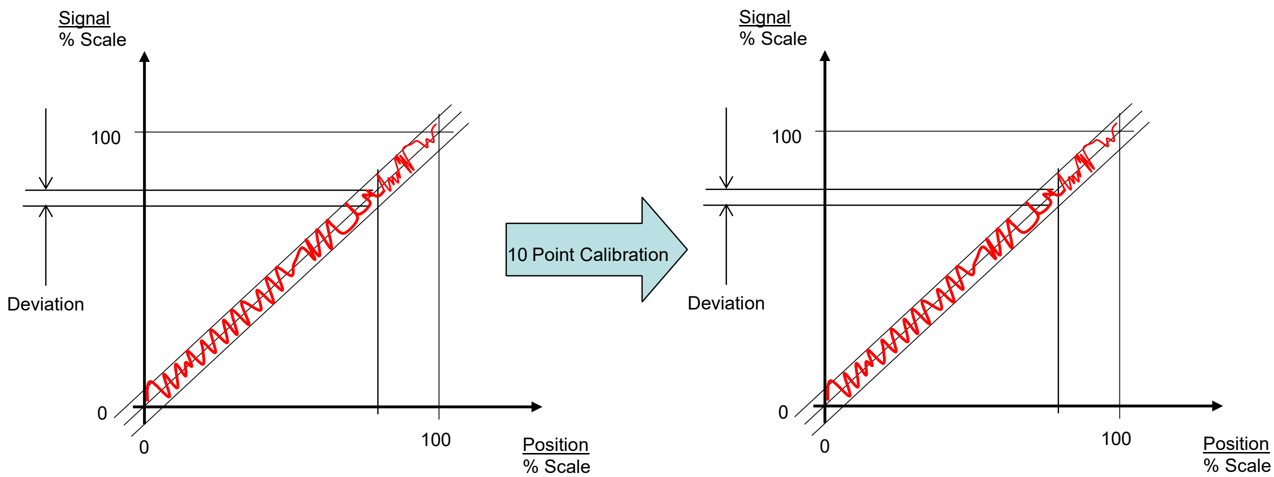

Figure 3 – calibration of a non-linear sensor with rapidly varying errors

ECCENTRICITY

Optical and magnetic encoders typically employ a readhead on the circumference of a scale. This approach can be sensitive to eccentricity error – the offset between the axis of rotation of the scale and the physical center of the scale (see Fig. 4). The offset can be caused by several factors including scale mounting concentricity, rotating shaft concentricity and bearing alignment. The problem with the offset is that the scale moves eliptically relative to the readhead. The readhead sees a longer or shorter arc depending on its position on the circumference.

Encoder manufacturers have a high degree of proficiency on mounting scales with minimal eccentricity. For the highest levels of performance, however, eccentricity error can be effectively eliminated by mounting a second readhead opposite the original readhead. As one readhead sees a longer arc the opposite readhead sees a shorter arc. The two readings can be combined for an average reading effectively free of eccentricity error. This does of course increase system cost but is frequently used when the highest levels of precision are required.

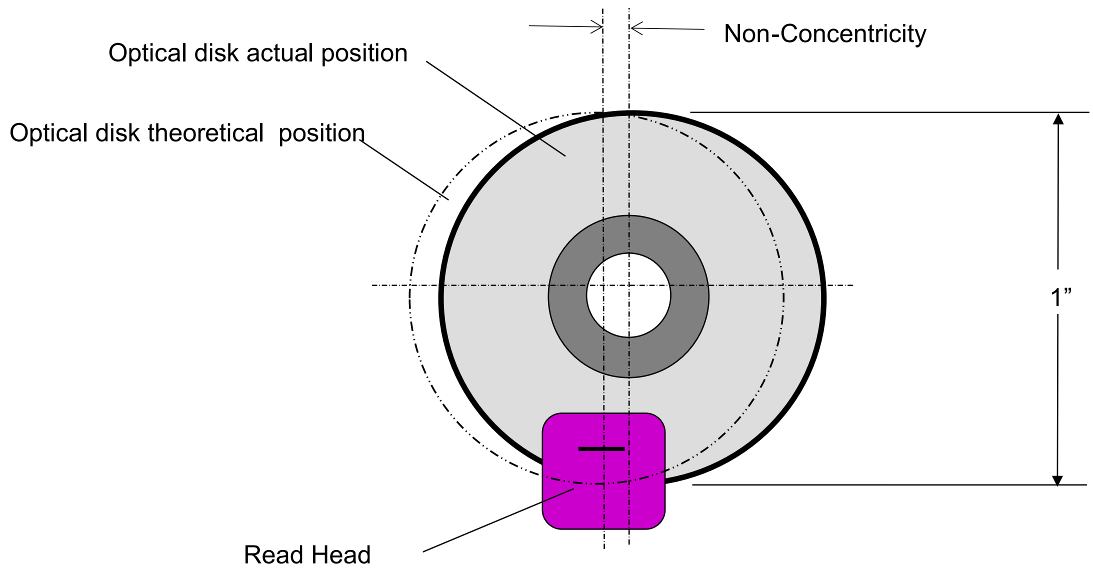

Figure 4 – non-concentric optical disk and read head

ECCENTRICITY TOLERANT SENSORS

The measurement principle of a resolver or inductive encoder is comparatively tolerant to eccentricity. Measurement is based on the mutual inductance between the rotor (the disk) and the stator (reader). Rather than calculating position from readings taken at a point on the scale circumference, measurements are generated over the full face of both the stator and rotor. Consequently, discrepancies caused by non-concentricity in one part of the device are negated by opposing effects at the opposite part of the device.

Figure 5 – eccentricity tolerant inductive encoder