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Calibration of a low-accuracy magnetic linear encoder

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Abstract
Linear encoders are an essential part of many metrology applications, coming in various length, accuracy classes and resolutions. Completely different measuring technologies can be used, such as optical or magnetic scanning, with optical read-heads reaching the highest accuracy levels at the highest cost per unit length and high demands for shielding from contamination. Magnetic encoders are typically lower accuracy systems, on the order of several tens of µm/m. One fundamental obstacle to reaching higher accuracy seems to be the random nature of scale errors, which makes typical calibration at just several lengths impossible. The topic of this research was to establish whether this error is truly random, and if not to determine its repeatability, by measuring the scale error for every encoder count over its entire length. A magnetic encoder with nominal accuracy of ± 40 µm/m was chosen for this experiment, having a nominal resolution of 0.244 µm and total length of 1.5 m. The encoder was calibrated with a laser interferometer, first over the entire active length, and then by using a custom drive system to calibrate the encoder at every count over a shorter span. This procedure provides some insight into the stability of the linear encoder, and can potentially lead to much better accuracy after calibration. The entire measurement procedure and obtained results are presented and discussed.

Keywords: length metrology, linear encoder, accuracy

1. Introduction

Linear magneto-resistive encoders (ME) are used in various automation applications where required accuracy is relatively low, such as general machine tools, packaging, conveyers, etc. [1]. The advantages they offer over other linear encoder designs such as optical are high speed, low cost, and resistance to contamination [2],[3]. However, they are not typically used in high-accuracy applications such as dimensional metrology because it is assumed that ferromagnetic linescales exhibit large random errors, again when compared to other encoder designs. Typicall accuracy reported by manufacturers range from 30 µm/m to 50 µm/m.

2. Experimental setup

A commercially available ME read head (RLS LA11) was used with s compatible ferromagnetic scale (RLS AS10) which was 1500 mm long. The read head was rigidly attached to a linear stage with recirculating ball bearings (Figure 1, 1), which also housed a retroreflector for the laser interferometer (LI) system (Renishaw ML10). LI (Figure 1, 3) was bolted to an optical table, together with beam steering optics and the ME scale. Temperature correction was applied using three calibrated PT100 sensors (Figure 1, 2), placed near the position of the ME scale. Custom software was developed to synchronously acquire ME readings, LI measurements, temperature data, as well as to control the motion of the linear stage. A high-precision NEMA 14HM35-0404 stepper motor (Figure 1, 4) was used to move the linear stage using a 6 mm GT2 drive. To to further enhance positioning resolution stepper motor driver TMC2209 v3.1 was used and configured for 64 microstepping. Minimum incremental motion equal to 1 µm was achieved with

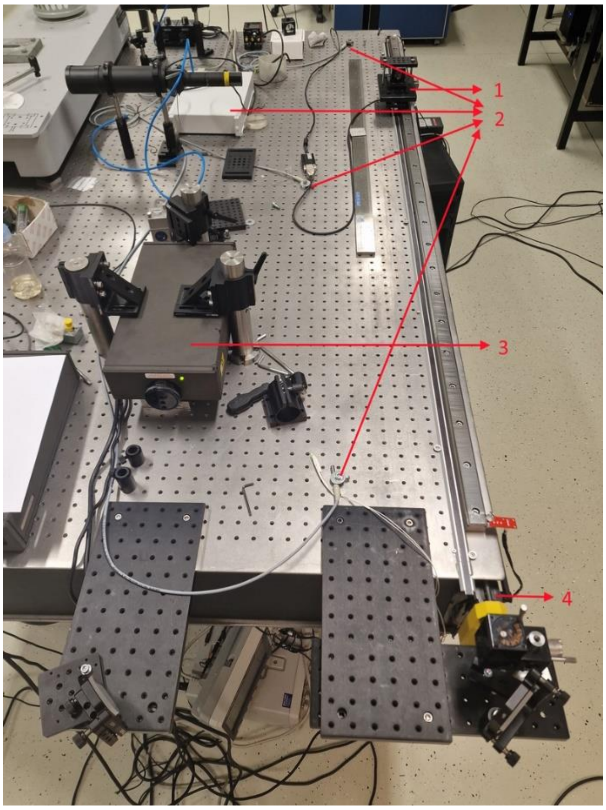

Figure 1. Experimental setup.

this setup, with speed of approx. 1 µm/s. While minimum step size is too large when compared to ME resolution of 0.244 µm, the speed is low enough so that each ME count can be reliably acquired by the laser interferometer.

3. Results

Initial verification of specified accuracy was carried out by five repeated measurements over the entire length of the ME scale (1500 mm) with step size of 5000 encoder counts (~ 1.22 mm), as shown in Figure 2. The deviation conforms to the specified accuracy interval of ± 40 µm/m. There is no significant linear trend in the results, indicating that temperature correction is properly applied, and the deviation itself appears to be systematic.

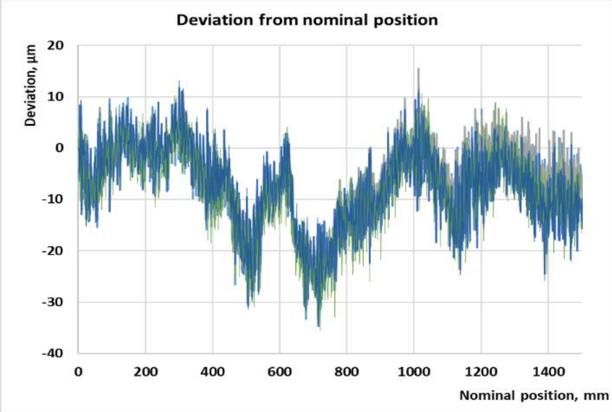

Figure 2. Deviations from nominal values for five repeated measurements.

When average deviations are calculated for each measured position and applied to correct the original data, results shown in Figure 3 are obtained. After correction of this systematic error, all deviations are contained in within a 10 µm interval, which represents an improvement of almost a full order of magnitude. Estimated standard deviation was also calculated, as shown in Figure 4, and doesn't exceed 5 µm. It also exhibits a periodic change, with most of the values much lower than 5 µm.

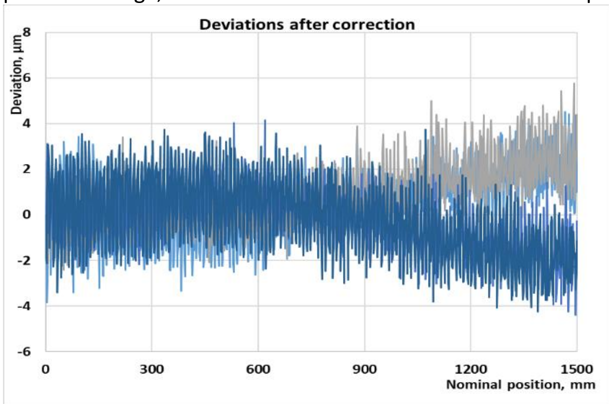

Figure 3. Deviations from nominal values for five repeated measurements, after correction.

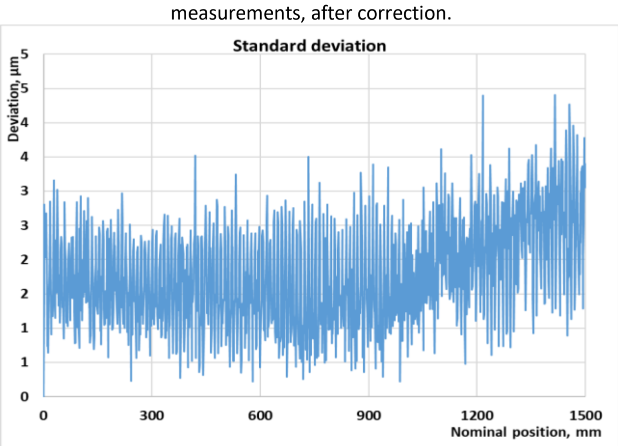

Figure 4. Standard deviation of the measurement results.

In order to further evaluate this behaviour, deviations of every count of the ME over the length of 3500 counts (~ 0.85 mm) was measured, with ten repetitions. When standard deviation of these results is observed (Figure 5), a periodic increase of standard deviation is cleary visible having approximately 0.1 mm interval, with larger peaks occurring with 0.2 mm interval.

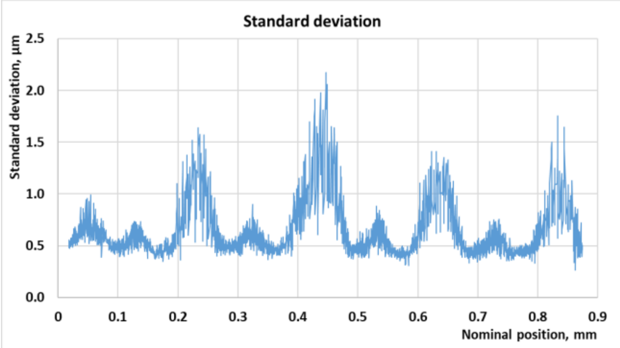

Figure 5. Deviations from nominal values for five repeated measurements.

These results indicate that a full characterization of an ME scale error can be used to significantly improve the accuracy of what is otherwise a relatively low-accuracy linear encoder. Standard deviation of most counts is at 500 nm level, with a periodic increase to up to 2.2 µm. The periodic nature of change in standard deviation that was determined could be explained by a periodic change in offset between the ME scale and readhead, some periodic variability in the manufacturing process of the scale itself, or residual errors in the readhead interpolation electronics. The first option is least likely, as the flatness tolerance of the optical table and straightness tolerance of the linear stage are both < 50 µm, which is well within the specified tolerance for rideheigth given by the manufacturer (500 µm).

3. Conclusion

A full characterisation of a magneto-resistive linear encoder was presented, along with the experimental setup used to perform the calibration. Results show that, after applying the temperature correction, a large improvement in accuracy can be achieved: from ± 40 µm/m to better than ± 5 µm/m. Further investigation revealed a periodic variability in the standard deviation of measured results, which ranged from 0.5 µm to 2.2 µm over 3500 consecutive counts. This effect points to a potential route for even better calibration results if nominal values are selected based on the value of standard deviation, which should be investigated in future research.

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