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Secondary Parameters of technologically relevant materials and their relation to quantitative MOIF measurements

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1. Secondary parameters of magnetic encoders

1.1 General information

The secondary parameters of magnetic encoders as defined in this document, are taken from the DIN SPEC 91411 draft document on “Requirements for the technical representation of magnetic measurement scales in design drawings”, from September 2021. This documents describes an approach to determine the secondary parameters of real scales using qMOIF combined with mathematical analysis tools.

1.2 Relevant qMOIF KCCs

All secondary parameters of magnetic encoders are derived from the quantitative magnetic stray field distribution of the magnetic $B_z^{s,qMOIF}$, which is the 2D flux density distribution in a plane at the surface of the scale over the area covered by the qMOIF measurement. With typical imaging areas of several square centimeters, $B_z^{s,qMOIF}$ typically will cover the complete orthogonal magnetic pole extension (perpendicular to the direction of motion of the write head but may only cover a subset of the poles in the direction of the motion of the write head. The flux density at any other distances d in a plane parallel to the sample surface, $B_z^{d,qMOIF}$, can either be measured directly by qMOIF by using spacers to adjust the distances or by mathematical operations from $B_z^{s,qMOIF}$.

1.3 Secondary parameters of magnetic scales

<u>Magnetic poles and periods</u>

Magnetic poles are defined by the effective magnetic charge density of the scale M_z^{eff}. M_z^{eff} is the unique 2D magnetic charge density distribution at the scale surface that would generate the same field distribution as the 3D magnetization distribution of the magnetic scale. The effective magnetic charge density of the scale is equivalent to half the perpendicular magnetic stray field component at the surface of the scale as measured with MOIF, i.e. the pole parameters can be derived from $B_z^{s,qMOIF}$.

1.3.1 pole pattern

The pole pattern is directly given by $0.5\ B_z^{s,qMOIF}$

1.3.2 magnetic pole number

The magnetic pole number is given by the by the number of primarily upward and downward magnetized areas according to $B_z^{s,qMOIF}$.

1.3.3 magnetic period

The magnetic period is extracted from $B_z^{s,qMOIF}$ by appropriate mathematical operations, like spectral analysis, autocorrelation or fitting of pole functions combined with statistical methods.

1.3.4 magnetic pole width, magnetic trace width

The pole width is determined from the effective surface magnetic charge density M_z^{eff} and thus from $B_z^{s,qMOIF}$. However, the pole magnetization typically decays gradually with the perpendicular distance and depends on the parallel position on the pole. Also, the pole width may vary from pole to pole. Therefore, indicating a pole width requires (i) a cut off criterion for the flux density to determine the edge of a pole, (i) a mathematical algorithm to determine a pole width from the pole edge positions varying over the length of an individual pole, and (iii) a mathematical algorithm to determine a characteristic pole width from a set of pole widths varying over the trace.

1.3.5 magnetic pole length

The magnetic pole length can be determined from M_z^{eff} and thus $B_z^{s,qMOIF}$. It requires the definition of the pole edge in parallel direction. Typically, the pole edge is defined by the zero crossing of M_z^{eff}. However, the measured $B_z^{s,qMOIF}$ has a finite noise level and the M_z^{eff} distribution in parallel direction is not smooth and steady, thus an appropriate interpolation technique needs to be applied to define the position of the zero-crossing. Additionally, the position of the zero-crossing may vary over the pole width. Therefore, mathematical algorithm must be defined, to define the net zero-crossing form the distribution of zero-crossings. This can be an average over a well-defined range of the pole width.

1.3.6 magnetic pole length deviation

The magnetic pole length deviation is the deviation of the pole length of a pole at a certain position from the nominal pole width. The nominal pole width is a predefined ideal pole width.

1.3.7 pole location

the pole location is the position of the first zero-crossing of M_z^{eff} for a certain pole. As for the pole length, the width dependence of the zero-crossing needs to be taken into account. Therefore, a mathematical algorithm must be defined, to define the net zero-crossing form the distribution of zero-crossings. This can be an average over a well-defined range of the pole width.

1.3.8 pole location deviation

The magnetic pole length deviation is the deviation of the pole location of a pole at a certain position from the nominal pole location. The nominal pole location is a predefined ideal pole location

Magnetic flux density

1.3.9 flux density

The 2D flux density distribution at the surface is directly given by $B_z^{s,qMOIF}$. The flux density at any other distance d from the surface of the scale, $B_z^{d,qMOIF}$, can either be measured directly by qMOIF by using spacers to adjust the distances or by mathematical operations from $B_z^{s,qMOIF}$.

1.3.10 flux density deviation, parallel

The parallel flux density deviation can be calculated as the difference between the measured flux density distributionB_z^{qMOIF} at a given distance d and the nominal flux density distribution along any given line at a certain width in parallel direction. The nominal flux density distribution is a predefined ideal or target flux density distribution.

1.3.11 flux density deviation, orthogonal

The orthogonal flux density deviation can be calculated as the difference between the measured flux density distribution B_z^{qMOIF} at a given distance d and the nominal flux density distribution at distance d along any given line at a certain length in perpendicular direction.

2. Example measurements

qMOIF is an imaging technique that can be used in different analysis geometries, In particular, it can be used for a one-shot characterisation of magnetic scales over areas of several square centimetres with the capability to detect fields from the millitesla (mT) to the tesla (T) range with µm spatial resolution. Fig. 1 shows images of a magnetic scale (Sensitec) taken with Matesy cmos-magview system. The scale exhibits a varying pole width, the left image is measured with a pixel resolution of 25 µm x 25 µm and the right image shows a zoomed in area measured with a higher pixel resolution (4.5 µm x 4.5 µm).

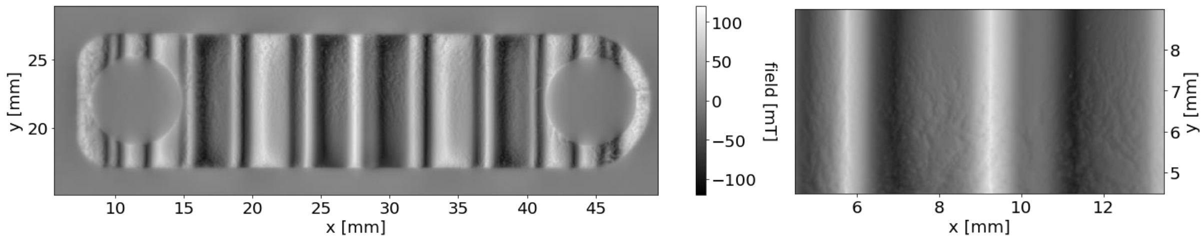

Figure. 1. spatially resolved flux density distribution $B_z^{s,qMOIF}$ measured by qMOIF (Matesy cmos magview) at the surface (distance 3 µm) of a magnetic scale with varying pole width.

Recording the images above takes a few seconds. The images directly reveal the pole geometries. The right image shows the impact of the surface roughness (granularity) on the local flux density distribution. These data cannot be extracted by using the sensor of the sensing circuit due to its limited (lateral) resolution.

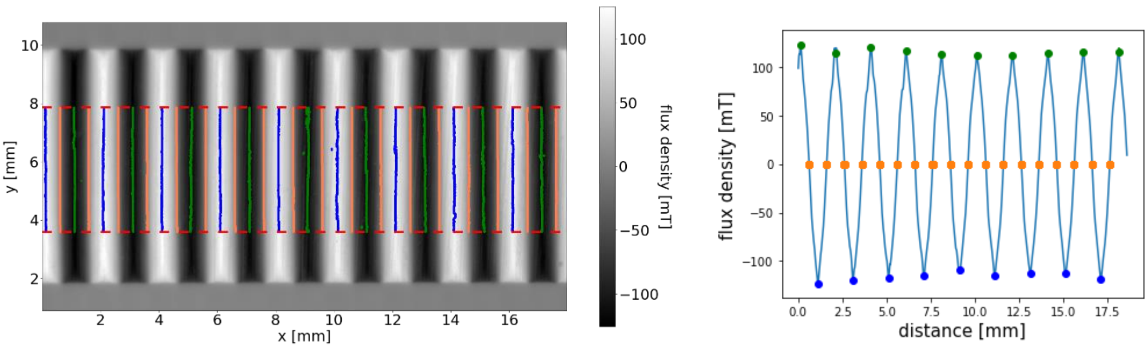

Figure. 2: left Spatially resolved quantitative flux density distribution of a magnetic scale. An Area of Interest is selected (dotted red liens) and the data are analysed with respect to the positions of the minima (green), maxima (blue) and zero-crossings (orange) of the flux density along horizontal cross-sections (left image). The mean positions and flux density values of the minima, maxima and zero-crossings are plotted together with the averaged flux density in the right image.

Fig. 2 shows an qMOIF image of an incremental magnetic scale with a nominal pole width of 1mm (Sensitec). An area of interest (AoI, red dashed) is selected, representing, e.g. the perpendicular dimensions of the sensor used in the sensing circuit. From this image for each horizontal line, the position of the maxima (blue), minima (green) and zero crossings (orange) can be found, as shown in the left image of Fig. 3. To this end, the data of each horizontal cross section are smoothened using a Savitzky-Golay filter. To determine the positions of the zero-crossings, sign changes in the datapoints of the horizontal cross-section data are identified. Alternately, the data might be fitted by an appropriate fit function. The right image of fig 3 shows the averaged positions of the cross-sections, minima and maxima. The average is taken over the pole width within the AoI.

The data can be further analyzed as shown in Fig. 3. The left image in Figure 3 shows the averaged position of the zero-crossings along the scale axis as a function of their consecutive number (index). To analyse pole widths, the difference of consecutive zero crossing positions was calculated, and the result is shown in right image with the error bars. Here, poles with negative field tend to be slightly wider than poles with the opposite magnetization orientation.

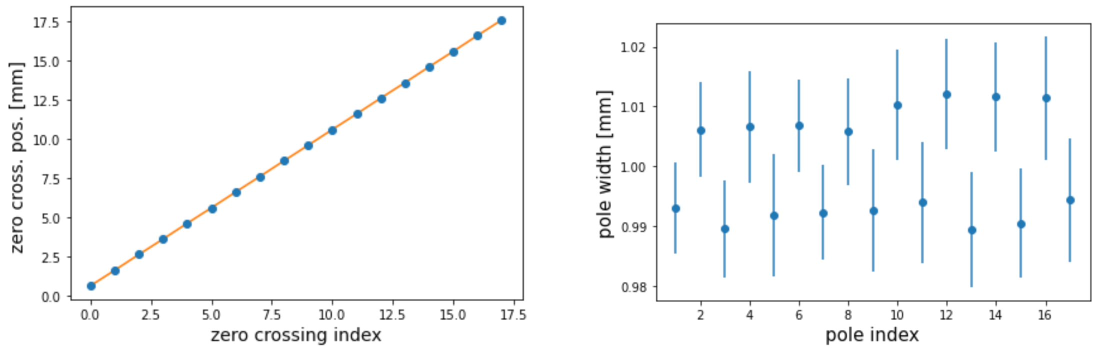

Figure. 3. Averaged position of the zero crossings of the flux density distribution in the AoI of the magnetic scale (left) and thereof derived pole width as a function of pole index (right) calculated from the qMOIF measured flux density distribution.

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