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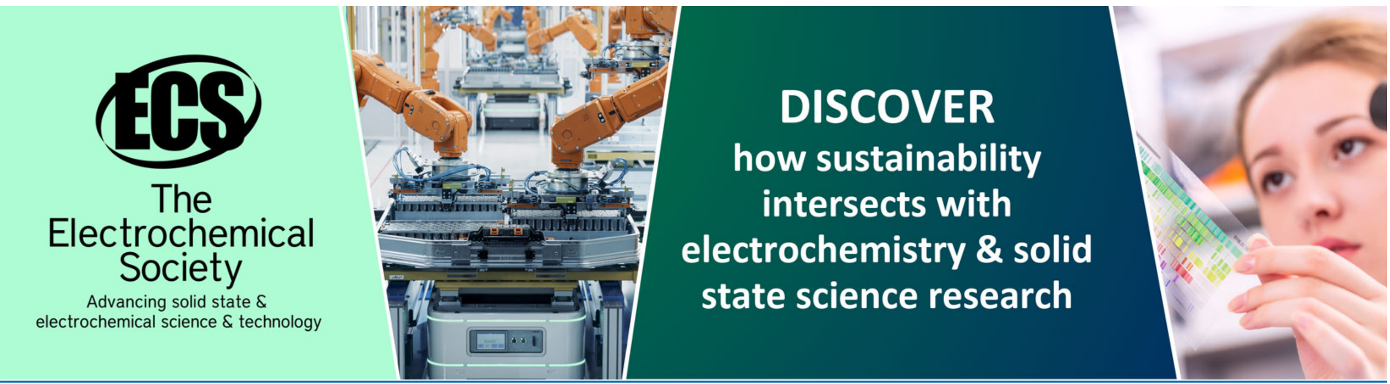

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A Faraday effect magnetic stripe scanner

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1 Abstract

We report on the realization of a Faraday magnetometer to characterize the magnetization of a magnetic foil during its production process at full speed of 3 m/s. The system is designed towards attaining a spatial resolution both in feeding direction and transverse to it of approximately 60 μm and is able to acquire in excess of 60.000 scan lines per second obtained from a line-scan camera with 128 pixels. We further report on the resolution of this system regarding the magnitude of the magnetization of the stripe and contrast this to the attainable noise figure determined by the optical properties of the used crystal, the illumination system and the camera.

2 Introduction

The technical implementation of a magnetic-field camera which is based on the Faraday–effect and which is capable of acquiring field images at a sustained line-frame rate beyond 50 k lines/s at a spatial resolution of 128 pixels across an 8 mm wide swath is causing quite some engineering problems that are discussed in some detail in this contribution.

The Faraday-effect within a magneto–optically active material is rotating the plane of linearly polarized light dependent on the line-integral of the magnetic field strength projected along the propagation path of the light and scaled by a material dependent constant (the Verdet–constant) [1]. A typical highly sensitve materials in that respect is TGG (terbium gallium garnet, exhibiting a Verdet-constant $V \approx 140$ rad/Tm). We used a rare–earth substituted bismuth-iron garnet crystal of the company matesy® that exhibits a very high Verdet–constant of $V_m = 2.5 \times 10^6$ rad/Tm, is, according to the company, grown to about 5 μm thickness on a glass substrate using liquid-phase epitaxy, is protected by a thin layer of chemically deposited diamond (CVD-diamond), and can be used for up to 2 kA/m fields, thereby yielding a maximum rotation of $\pm 6°$. The stand–off distance, the minimum distance, between the magneto–optically active crystal and the magnetized specimen for geometrical reasons is given to be 5 μm. This distance between the magnet and the camera is to be considered when a calibrated measurement is sought after.

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Figure 1 (a) shows the principle optical setup. It consists of a high-power LED (Osram LRW5SN) providing a luminous flux of 192 lm @ $I_{LED} = 1.0$ A, centered around the peak emission wavelength of 625 nm, collimated by a condensor (Kowa LM12 JC f/1.4), and linearly polarized by an absorptive foil-polarizer, to illuminate evenly a 10 mm diameter spot at the Faraday crystal. The observation path includes an analyzer, an objective lens (Kowa LM75 JC f/2.8) set to an optical magnification of unity, and a highly sensitive (output voltage 80 V/lx s) line-scan camera (Hamamatsu S11106-10, consisting of 128 $63.5 \times 63.5\ \mu\text{m}^2$ pixels). The necessary signal processing is performed within a Raspberry Pi 3B and the processed data is streamed to a mass storage device (Samsung T3 500 GB solid state disk).

The system is designed to image the magnetization in the quality control of magnetic stripes as typically seen in the production of e. g. credit cards at full production speed (feed rate of the foil 3 m/s), and is capable of a guaranteed scan rate of 63.5 k scans/s sustained over several km lengths of the foil in a roll-to-roll production process. One has to note that the possible exposure time, limited by the demanded scan-rate and the camera read-out time is less than 15 μs.

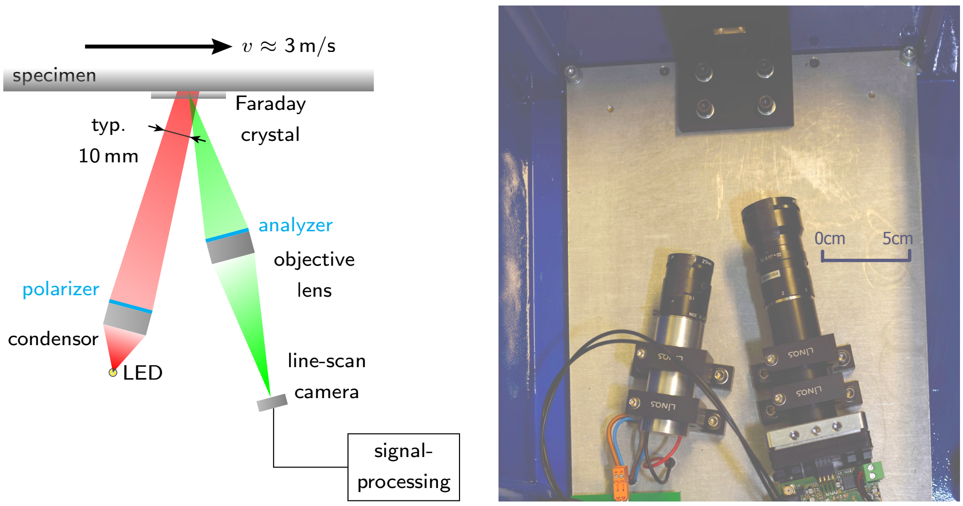

Fig. 1. Schematic of the optical set–up of a Faraday–system (left) and photo of the realized system (right). The size of the system's base plate is 180 mm × 210 mm.

It is required to both analyze the geometry for physical correctness (the spacing of the magnetic pattern) and the thickness of the magnetic ink used to

3 Measurement results

In order to be able to correctly interprete the magnetic imaging system a static calibration was performed. The results of which are detailed in a parallel contrubution [2]. Here we report on the fully operative high-speed scanning system and its limitations caused by camera read-out noise, slightly fluctuating LED illumination and, possibly, fluctuations caused by the dynamic behaviour of the magnatic foil being moved by the magnetic imaging system and experiencing some aerodynamic flutter. Figure 2 shows a zoomed-in view of a full-speed scan

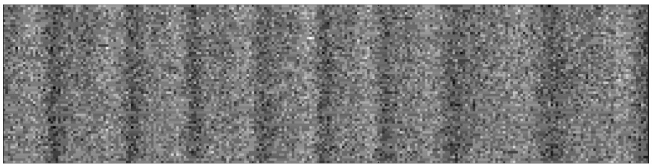

Fig. 2. Recorded pattern (feed direction from left to right) at a scan-rate of approximately 64 k scans per second without magnetic excitation, thus showing the noise limit and some periodic pattern presumably caused by the non-ideal stability of the light source (the LED and its driving circuit). The imaged area represents 16.5×8.1 mm^2.

of a non-magnetized section (the center part) of the magnetic pattern depicted in Fig. 4. It can be observed that some periodic pattern is recorded superposed by some random noise component. We interpret the periodic signal component to be partly due to aerodynamic flutter of the speeding tape and/or the slight residual fluctuations of the light source's drive current being supplied by a switching-regulator power supply. One has to note that in absolute terms these variations

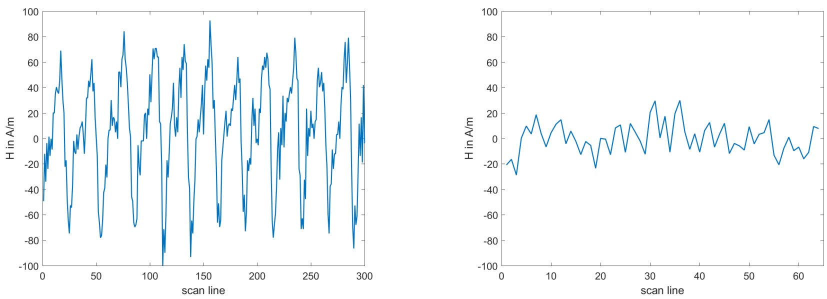

Fig. 3. Interference and noise: periodic variation of the LED drive current causes intererence with a standard deviation of ≈ 41.8 A/m (left) and thermal and read-out noise of the camera alone (standard deviation of ≈ 12.31 A/m) (right).

are only minute but giving the fact that the polarization rotation of the Faraday effect is limited to $\pm 6°$ the magnetic modulation of the camera exposure is small, too, so the influence on the mapped field strength is still significant. Figure 3 (left) shows in terms of magnetic field strength an average over all 128 recorded pixels ploted along the scan index. A maximum deviation of $\approx \pm 100$ A/m is seen yielding an uncertainty due to that component of 41.8 A/m (1 σ). On the right hand side of Fig. 3 an averaging and statistical analysis perpendicular to the feed-direction is displayed, yielding $\approx \pm 20$ A/m uncertainty. The standard deviation in this case is determined to be $\sigma = 12.3$ A/m.

Figure 4 shows a magnetization image of a 50.8×8.1 mm^2 segment recorded during the manufacturing process at the full production speed of 3 m/s of a magnetic foil. Different test patterns can easily be discerned (centered around lines 100 and 600) with a non-magnetic section in between. The magnitude of the pattern was determined to be fully saturated (± 2 kA/m) with alternating north and south poles on the left hand side and yielding a north up magnetization of 1977 A/m equivalent to magnetic flux density of $B = 2.49$ mT.

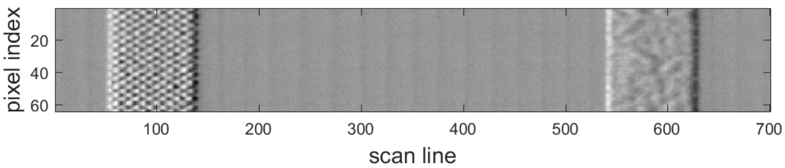

Fig. 4. Pattern of magnetization on a magnetic stripe recorded at a scan-rate of approximately 64 k scans per second for a foil speed of 3 m/s. The true size recorded per pixel is 63.5.5 μm^2, thus the imaged area represents 50.8×8.1 mm^2.

4 Discussion

The major problems in designing the Faraday magnetometer turned out to be finding a sufficiently sensitive camera with a large dynamic range that is able to cope with the less than 15 μs exposure time which resulted in choosing rather large pixel sizes thereby setting a useful limit to the spatial resolution. Since the Faraday rotation is rather small only a minute variation in reflected intensity is caused by magnetic fields thus a very stable illumination source is necessary. The crystal itself is exhibiting magnetic domain wall movements limiting the spatial resolution of images magnetic fields. The attained resolution of less than 50 A/m (1 σ) turned out be be sufficient to yield significant images of foil magnetization.

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