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Pole positioning for precise magnetic measurement systems

Sebastian Rivera[1], Dr. Rolf Slatter[2]

[1,2] *1st ITK Dr. Kassen GmbH, Beim Eberacker 3, 36533 Lahnau- Germany, s.rivera@itknet.de*

***Abstract* – Modern drive systems rely in terms of accuracy and robustness on the quality of the used position sensors. For high accuracy applications optical position sensors are dominating the market with a trend towards more magnetic systems as their robustness in the field is superior compared to the optical counterparts. While the sensor itself has a great impact on system accuracy, the used scale or pole wheel is of similar importance when evaluating system architectures. ITK presents in this paper a machine setup for high accuracy, single pole writing machines either for linear or rotary magnetic scales. Baseline for the software architecture is the newly released DIN SPEC 91411 which unifies the nomenclature for magnetic measurement system. In addition the paper focus on a systematic approach to also measure the magnetic accuracy. Furthermore, new developments in write head design are presented as new hard magnetic coatings require higher fields for magnetization.**

I. INTRODUCTION

In recent years the development of improved magnetoresistive [1] and hall-effect based sensors as well as new techniques for manufacturing improved magnetic scales has led to an increased usage of magnetic angle- and length measurement systems [2]. Such systems typically comprise a linear or rotational magnetic scale in combination with a sensor head incorporating one or more magnetic sensors (Fig. 1). The magnetic scale can feature different patterns of north and south poles to provide incremental or absolute measurement possibilities.

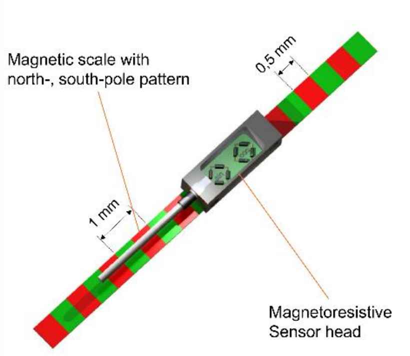

Fig. 1: Typical magnetic length measurement system

A first challenge in the sometimes complex supply chain for magnetic scales is given in the non-unified nomenclature and definitions on how to define drawings and measure the quality of the product. Magnetic scales differ to optical ones in one important aspect, the amplitude of the written pole is not a constant, binary code. For optical scales quality measurements are comparable to any mechanical part which is more complex for the magnetic solutions where amplitude and position depend on the type of measurement sensor and experimental setup.

The quality of the magnetic code depends on a high number of different aspects. Many of the parameters are material or process related, however the definition of who measures in what distance with what sensor is often the main point of discussion between two partners in the supply chain. Just the runout difference of 2 test setups (e.g. outgoing inspection at supplier vs. incoming inspection at customer) with identical reference sensors might have a big impact in comparing measurement results.

In a first step the nomenclature was unified for the supply chain within the recently published DIN SPEC 91411 [3]. In addition to this ITK is again part of the consortium for the second and next DIN SPEC 91479 – characterization of magnetic measurements scales and pole wheels.

Both DIN SPECs form the baseline for machine concepts at ITK and thus provide a guided approach for customers to produce scales and pole wheels (Fig. 2).

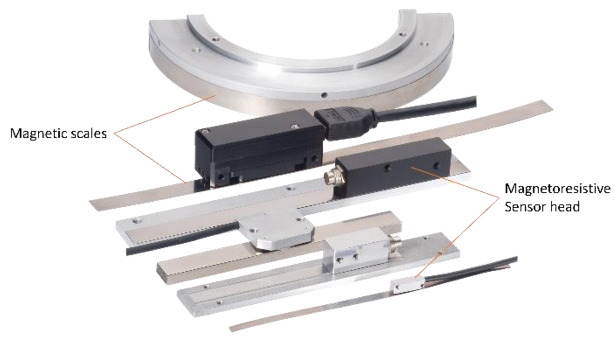

Fig. 2: Typical magnetic scales

The paper provides an overview on how the DIN SPEC is transferred into the latest standard of magnetization machines and in addition insights for the development of new write heads are provided.

Baseline motivation for ITK in this business sector is derived from a lot of empirical know-how in producing and using magnetic scales. Combined with state-funded projects ITK has used empirical data to feed analytical approaches to understand the different parameters that influence the end result of the scale or pole wheel.

II. MAGNETIZATION MACHINES

ITK offers two fundamental concepts for high precision magnetization machines.
3 provide the DIN SPEC 91411 overview for nomenclature for which ITK's magnetization machines are primarily designed.

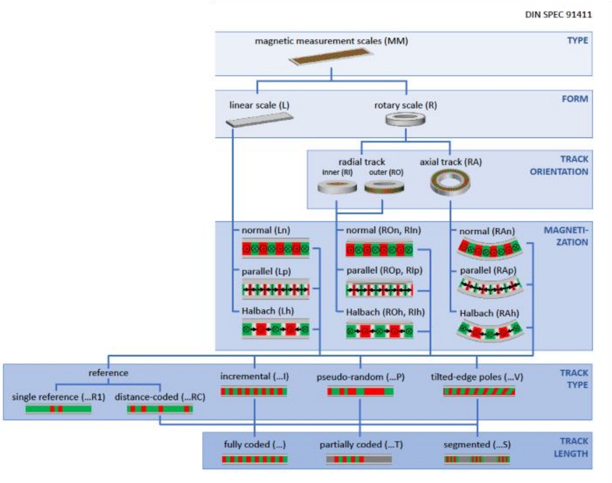

Fig. 3: Extract from DIN 91411[1]

A. RMP – the rotary solution

Apart from the requirement to reflect the nomenclature of DIN SPEC 91411 there is also a requirement for higher accuracy combined with higher flexibility to deal with different pole patterns and different scale geometries. Common features of the new magnetization machine generation are direct drives for the moving axes, high resolution reference measurement systems and powerful graphic interfaces for machine control. 4 provides an overview of the baseline concept and design of ITK's magnetization machines for pole wheels.

Fig. 4: RMP machine

The machine setup is flexibly designed for up to 5 stations with positioning axes in x- and z-directions. All axes are in-house developed and produced. Individualization starts at this point, where customers have differing requirements to the end product. The main design idea is a setup with 3 axes equipped to fulfill the basic functions:

- Runout measurement
- Magnetization
- Magnetic measurement by calibrated Hall sensors

Furthermore, the machine supports on request identification of workpieces (e.g. DMC code) or printing of serial numbers.

Designed as a standalone production machine a communication with the machine can also be realized via OPC UA protocol.

B. LMP – the linear solution

Based on the same principles also magnetic linear scales are highly dependent of the quality of the linear coding. The LMP machines offer a semi-customized solution for each application, assuring coding length as required.

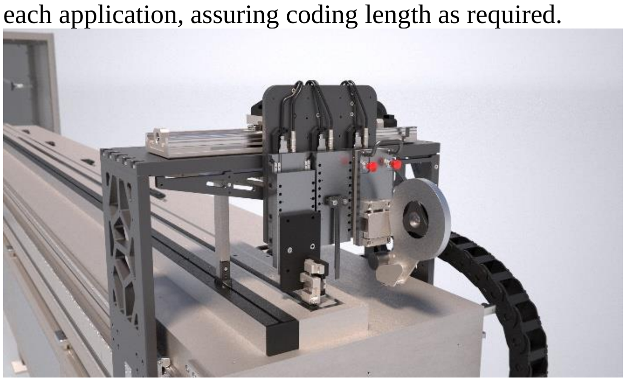

Fig. 51: LMP design

5 shows the basic setup that is a gantry bridge equipped with several functional z-axes for the individual customer needs. The magnetic coding is triggered by a high precision laser interferometer. The drive technology used is the patented ITK linear motors that are not only maintenance free, but also provide a direct driven solution without mechanical backlash.

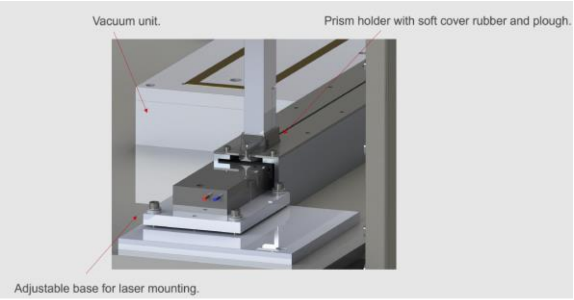

Fig. 6: Details of LMP design

Fig. 6 depicts the design details for the laser interferometer and a metal bar which reflects the beam that moves along with the gantry bridge. The vacuum unit in the background assures flat positioning of the magnetic scale while being processed.

III. WRITE HEAD DESIGN

Magnetization heads or better named write heads are available for either in-plane (ip) or out-of-plane (oop) writing [4]. On the market available solutions were developed years or even decades ago [5] and hardly cope for new requirements that hard magnetic coatings require nowadays.

Within the BMBF-funded KMU Innovativ Project ELM2 the fundamentals and technical limits of currently used inductive write heads for ip writing are analyzed in detail. The development target for a new inductive write head as needed for e.g. pseudo-random code writing process was set to hard magnetic coatings. As such coatings are extremely thin, the common knowledge on magnetism as available for bulk magnets might not be fully applied anymore. Target parameters to meet with the write head were therefore experimentally set combined with a literature analysis on the topic[6]. A simulation based on a carefully selected number of parameters was done iteratively in order to optimize the new write head design.

Variation of core size, core ratio, air gap, etc. lead to an optimized design, the iteration process can be seen in Fig. 7. The ideal design provides a very sharp peak, exceeding the set design targets of 1000kA/m. Within this approach the focus was set on the write head to be able to provide sufficient magnet field for various materials, however it is well known that the interaction between write head and selected material needs to be considered and simulated as well.

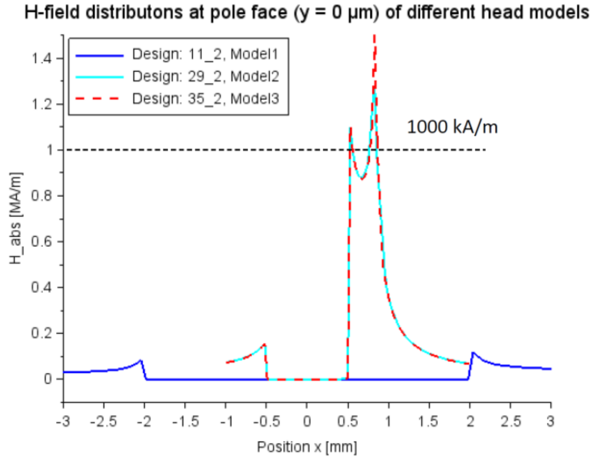

Fig. 7: Iteration of write head designs[4]

The new write head design is currently in final design stage and will be available with first results just before the conference. Results will be presented in the presentation.

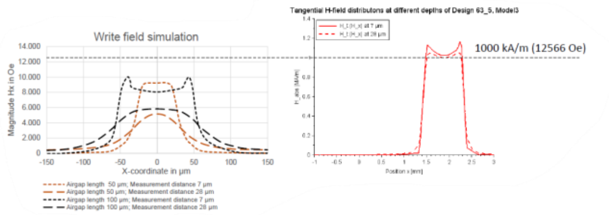

Fig. 8: Comparison of existing vs. new write head[4]

Fig. 8 compares the currently in use write head with the new design by simulation.

The higher magnetic fields are the result of bigger sized write heads. While the overall dimensions were kept, only the width of the write head was significantly changed.

The different write head dimensions are given in Fig.9

and Fig. 10.

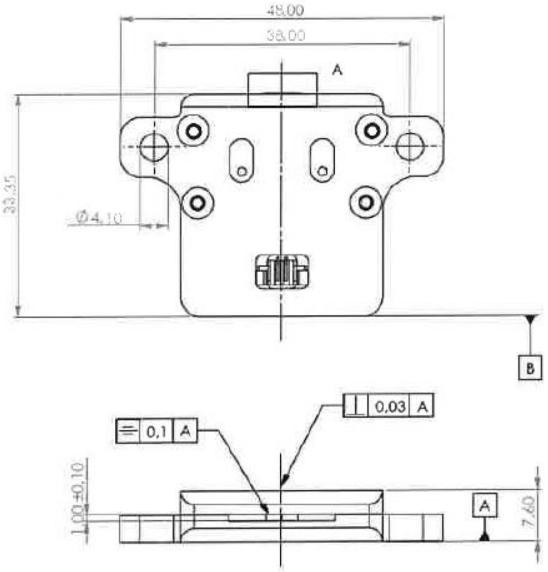

Fig. 9: Outline drawing of former write head

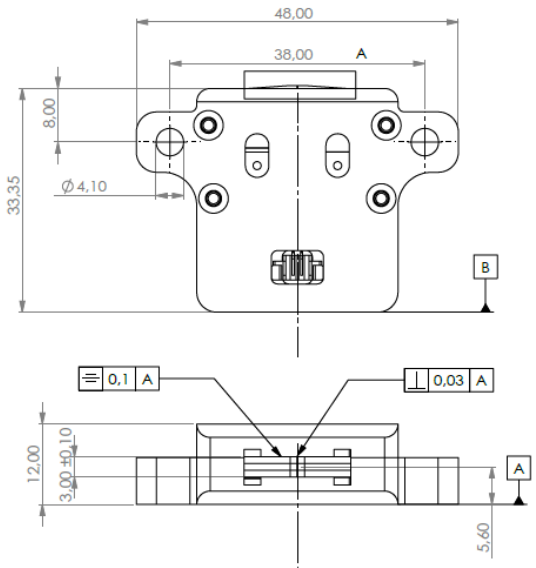

Fig. 10: Dimensions new write head

Simulation results are summarized in Table 1 with the main differentiation results being the higher writing depth and a factor 3 higher writing fields.

Table 1: Old vs. new write head

Parameters	Write field @ Write Depth [kA/m]	Write Depth (nominal) [µm]	Track Width [mm]
MIP in-plane head (for ITK, 3-mm Head)	≥ 477	20	3
MIP out-of-plane head (for ITK, Design 73_2, Model 3)	≥ 1700	110	5

IV. OUTLOOK

The latest generation of magnetization machines are now ready for market entry and will further develop by individual customer needs. First test results with the newly designed write head will be available and presented at the conference.

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REFERENCES

[1] Paul, J., "True power on magnetic position sensor system with submicron accuracy", Proc. of 15th MR-Symposium, Wetzlar, 2019

[2] R. Slatter, „High resolution miniaturized magnetic linear measurement systems for small- and micro-actuators", 12th International Conference for small- and micro-sized actuators", Würzburg, 2019

[3] DIN SPEC 91411 "Requirements for the technical representation of magnetic measurement scales in design drawings", Beuth Verlag, July 2023

[4] M.Rechel, P. Taptimthong, "Meilensteintreffen ELM 2, ITK internal document"

[5] C. Möller, U. Loreit, F. Dettmann, „Neues Verfahren zum berührungslosen Magnetisieren von Maßstäben und Polrädern für die MR-Sensorik, Proc. of 5th MR Symposium, Wetzlar, 2001

T. Schrefl, M.E. Schabes, D. Suess, and M. Stehno, „Dynamic Micromagnetic Write Head Fields During Magnetic Recording in Granular Media, IEEE TRANSACTIONS ON MAGNETICS, VOL. 40, NO. 4, JULY 2004