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High-precision Hall Sensor Array Magnetic Field Measurement System

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Abstract. A Hall sensor array magnetic field measurement system consists of 16 HHP-MU [1] Hall sensors powered by a Keithley 6220 precision current source, which has been built and deployed at SSRF [2]. The voltages of the 16 sensors are sampled by 4 NI PCI-4462 and further converted to the magnetic field strength. The sensors mounted on a high-precision three-dimensional translating stage are used to scan the surface of a magnet block with the step-length of 1 mm. The surface field distributions of the magnet blocks within an in-vacuum undulator are obtainable using this system. Based on the data measured, the magnet blocks are sorted and installed on the undulator girders. The magnetic measurement results of this undulator indicate that this sorting strategy works well.

INTRODUCTION

The SXFEL free-electron laser currently under construction is designed to construct two undulator lines, of which the user facility undulator line will be constructed by adopting the planner undulator with the segment length of 3 m and the period length of 23.5 mm [3,4,5,6,7]. The SBP beamline will be driven by the in-vacuum undulator with period length of 16 mm. Based on the experience of developing IVUs at SSRF, the first prototype of IVU16 is adopted with hybrid structure, using permanent magnets made of Sm2Co17 and poles made of vanadium permendur. The length of the undulator is 4 m with 243 full periods operating at a very small magnetic gap of 4 mm. The effective peak field can reach 1.05 T. In total about 1000 magnets are required. All of the blocks have to be satisfy the following technical specification. The distribution of magnetization should be less than ±1%, the maximum deviation angle should be less than ±1 degree, and the magnetic fields divergence measured at symmetric positions relative to the north and south pole faces of the magnet should be in the range of ± 2.5 % with an average close to zero. Besides, the measurement location is to be centered on the pole face, 5 mm in height above the surface.

Many sorting methods were suggested that order and arrange magnets using the principal component of the magnetic moment *M*. All three components *Mx*, *My* and *Mz*, are obtained by Helmholtz coil measurement. However, the magnet material may be inhomogeneous. The sorting methods based on three moments of the magnet block above cannot accurately characterize the magnetic field properties. We propose a novel system of the hall sensor array magnetic field measurement to collect the magnetic field data on the north and south pole faces of the magnet. In this paper we will describe this measurement system completely.

ARRAY OF HIGH-LINEARITY HALL EFFECT PROBES HMA16-MU

The HMA16-MU is a non-standard custom-designed Hall array, assembled of 16 customized Hall Effect sensors based on AREPOC s.r.o. company HHP-MU chip. The distances pitch between individual active areas is 2.6 mm with nominal tolerance ±0.1 mm. The total distance between the centers of the first and the last active areas is 39 mm. Sensors are arranged in a single line array and fixed to a fiberglass (G10) supporting plate from the left (sensor no. 1) to the right side (sensor no. 16). Outer dimensions of the assembly are labelled in figure 1 (a).

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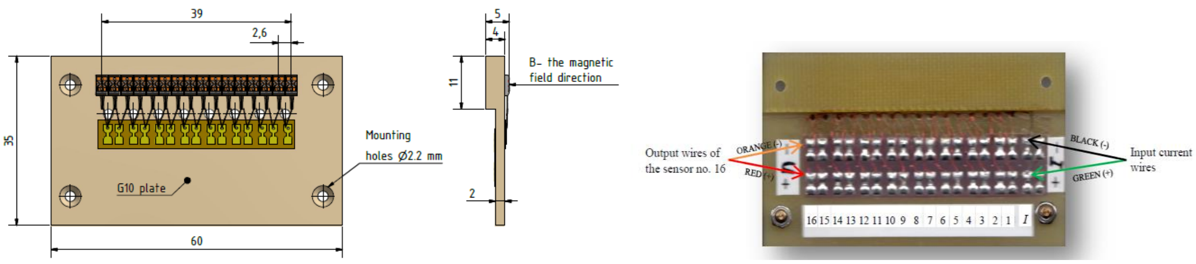


(a) (b)

FIGURE 1. (a) Outer dimensions of the HMA16-MU Hall array assembly (b) Rear side of the Hall array and configuration of soldering terminals

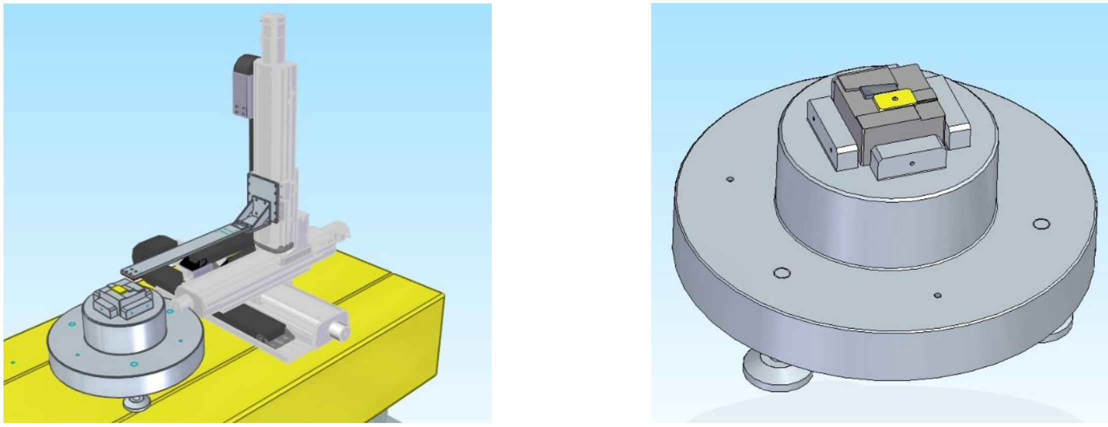
Inputs of all 16 Hall sensors are connected in series to allow common input current feeding from a single current source. Serial interconnections between green/black input wires are made on small soldering terminals on the front side of the G10 plate (directly below the sensors array). The first (green) and the last (black) input wires are guided through small holes to the rear side of the holder and soldered to terminals on the right side. Output wires (red/orange) of individual sensors are guided through small holes to the rear side of the G10 plate and soldered to the two-rows terminals. Figure 1 (b) shows the rear side of the G10 plate and configuration of soldering terminals. Table 1 shows the basic parameters of the HMA16-MU Hall array.

TABLE 1. Table with basic parameters of the HMA16-MU Hall array

Parameter	Unit	297K
Nominal Control Current, I_n	mA	10
Maximum Control Current	mA	12
Input Resistance at B=0T	Ω	457
Linearity Error at 0.1 T	%	< 0.1
Change of Sensitivity Due to Reversing of the Magnetic Field	%	< 0.5
Active Area Dimension of Sensors	µm	100 x 100

MECHANICAL SYSTEM

The mechanical structure of the system is mainly composed of marble base, linear motion platform, Hall probe mounting plate and magnetic block installation adjustment platform, as shown in Figure 2 (a)(b). The magnet needed to be tested is fixed on the marble table with fine-tuning positions through the plastic wedge blocks. The marble table is placed on the marble base. A three-dimensional motion platform is installed on the marble base, and the Hall probe array plate is installed at one end of the connecting plate, and the other end of the connecting plate is fixed on a three-dimensional translating stage. When screening a batch of magnets, we adjust the position relation between the magnet fixed platform and the Hall probe at first. Thus, the relative position of the magnet and the Hall probe will not be changed in the process of replacing the magnets. The coordinate axes *X*, *Y* and *Z* are established from ultra-high precision stages. Each of the linear stages has 400 mm route. The position feedback on all axes is derived from Renishaw Tonic linear encoders with ± 0.1 um accuracy. Precision ball screws are used on all axes along with crossed roller guide rails. The measurements of the magnetic field profile along the bench are executed on the fly with the typical measurement speed of 25 mm/s. The maximum movement speed can by up to 100 mm/s. The position controlled triggering is provided by the electronics of the linear encoder. An autonomous motion control unit allows for the simultaneous control of three axes. It allows a fast probe positioning with the highest accuracy and repeatability.

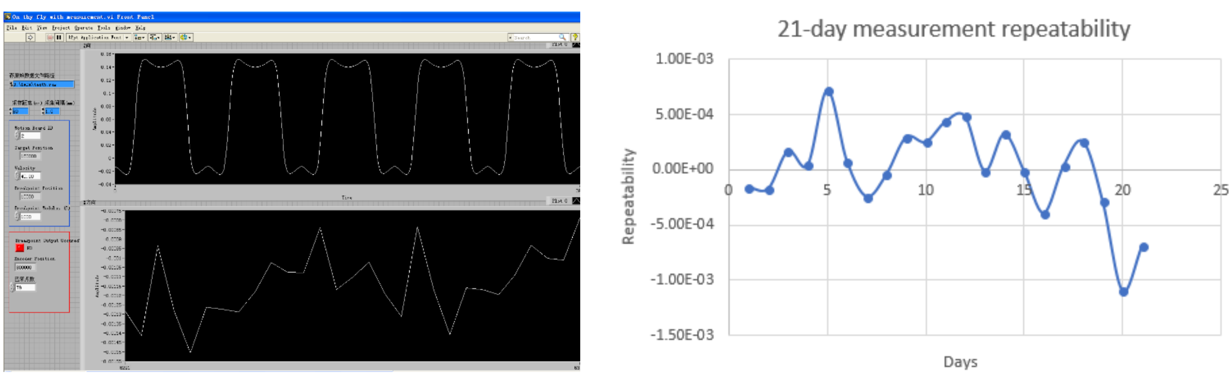


(a) (b)

FIGURE 2. (a) Mechanical structure of the magnetic camera. (b) Partial enlarged drawing.

DATA ACQUISITION SYSTEM

The HMA16-MU outputs 16 analog signals, and these signals are transferred directly into the 4 NI PCI-4462 high-precision data acquisition cards. The analog input channels of NI 4462 devices have 24-bit resolution ADCs which are simultaneously sampled at software-programmable rates for standard audio applications. The analog inputs offer programmable AC/DC coupling, and a programmable gain amplifier stage on the inputs gives gain selection from -20 to +30 dB in 10 dB steps. The card combined with the LabVIEW software is ideally suited for high-resolution magnetic field measurements. Figure 3 (a) shows the magnetic camera measurement panel.



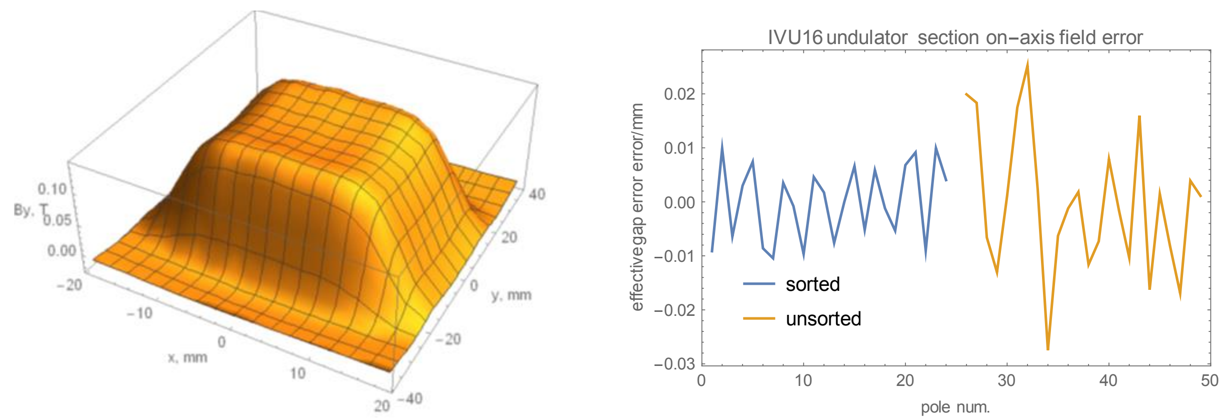
(a) (b)

FIGURE 3. (a) The magnetic camera measurement panel. (b) 21-day measurement repeatability.

When measuring the magnetized block, we scan a plane from above one surface of the magnetized block with a step size of 1 mm. Then flip 180 degrees and measure the reverse side of this magnetized block. We measured 1,200 magnetized blocks in 21 days, one of which was measured daily, and Figure 3 (b) shows the center of the magnetized block for 21 days of measurement repeatability.

MAGNET BLOCKS MEASUREMENTS RESULT

In April of this year, the surface field strength of first batch 60 blocks was obtained using this system, one of which is shown in Figure 4 (a). With a currently developed software based on the least-square fitting method, the magnetization errors inside each block were further determined. The impacts on the on-axis field error of these errors within each block were predicted by RADIA calculation when it is installed together with iron poles on girders. Therefore, these blocks were sorted based on the predictions and finally installed on a 25-period undulator section. For comparison, an identical section is also constructed with the only difference that the block is not sorted. From Figure 4 (b) it is obvious that the pole-to-pole variance of our sorted case is smaller than the unsorted one, which demonstrates the effectiveness of our method.



(a) (b)

FIGURE 4. (a)Surface field strength distribution of a magnet block. (b) Sorted and unsorted field variation in units of effective gap error.

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