STATUS OF MAGNETIC MEASUREMENT BENCHES FOR INSERTION DEVICE CHARACTERIZATION AT MAX IV LABORATORY

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Abstract

Insertion Devices (IDs) are the sole source of radiation used in all beamlines in MAX IV Laboratory with 14 IDs in operation of which 6 were built in-house. This paper shows the current capabilities and performance of the of the ID magnetic measurement systems, and the ongoing development work.

INTRODUCTION

MAX IV Laboratory is a unique synchrotron radiation facility which was the first to implement a diffraction limited storage ring design and relies solely on Insertion Device (ID) radiation. The technological needs led to the creation of a dedicated ID laboratory [1].

There are currently 14 active beamlines and 2 under construction. Six of the active beamlines are powered by APPLE-II Elliptically Polarizing Undulators (EPUs) which were designed, built, tuned and commissioned in-house at the ID Laboratory.

The tuning process involves local and integral magnetic measurements of IDs. Local measurements are taken using the Hall-Probe mapper (HP) and Pulsed Wire (PW) systems, while the Flip Coil (FC) and Stretched Wire (SW) systems are used for integral measurements. These measurement systems were also developed and commissioned in-house and this paper presents their capabilities and performance.

THE HALL-PROBE MAPPER

The Hall-Probe mapper (HP) sits at the heart of the ID laboratory as the well-established method for characterizing and tuning of IDs. Incorporating 3D low noise Hall sensor attached to an accurate 3D positioning system, it performs “on-the-fly” measurements at a scanning speed of 150 mm/s. HIPPIE is a 4 m long APPLE-II EPU with a period length of 53 mm that was measured by the HP system at MAX IV. Figures 1 and 2 show the resulting magnetic field and phase error.

The measurements precision of the HP mapper was examined for the major undulator parameters. Repeating the measurements obtains the standard deviation (STD), which is summarised in Table 1.

For determining the accuracy of a measurement system, an external reference is required, a beam-based measurement was carried out by comparing the measured radiation spectrum from the HIPPIE ID in the 3 GeV ring at MAX IV Laboratory with the calculated spectrum based on the magnetic measurements, which showed excellent agreement [2].

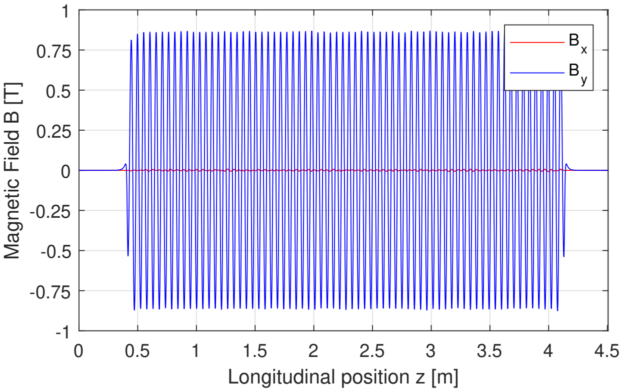

Figure 1: HP Measured Magnetic Field.

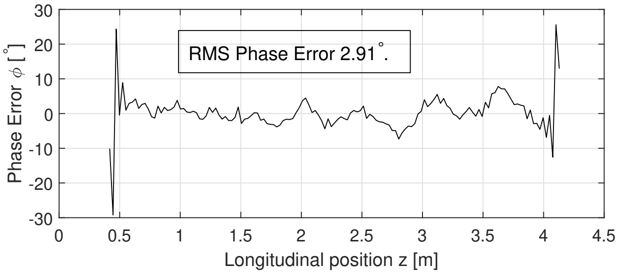

Figure 2: HP Measured ID Phase Error.

Table 1: HP System Precision Analysis

Parameter	Value	STD	STD/Value
Peak Field	0.772 T	16.1 µT	20.9 ppm
Effective Field	0.781 T	12.7 µT	16.3 ppm
Effective K	3.863	68.8 ppm	16.3 ppm
RMS Phase Error	2.682°	0.009 1°	0.34 %

THE FLIP COIL SYSTEM

The Flip Coil system (FC) utilises a long coil of multiple turns stretched along the length of an ID and can measure the magnetic field integral by integrating the induced potential across the coil as it moves. Therefore, can operate in two ways, the rotate mode and the translate mode.

The rotate mode rotates the coil along its axis, this results in an absolute magnetic field integral reading. Meanwhile the translate mode keeps the wire flat (horizontally or vertically) and moves it across the horizontal axis of the ID and results in the relative change of the magnetic field integral from the starting point and therefore needs to be corrected by obtaining at least a single rotation measurement to correct this offset.

The two modes of measurements were tested on the 3m long SPECIES EPU with a period length of 61 mm, which

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is equipped with a special L-shaped magnetic shims that create a vertical field gradient to correct for dynamic multipoles. The coil was 5 m long and 5 mm wide, consisting of 20 turns. The results of this precision comparison as well as the standard deviation of the measurements are shown Fig. 3. Where we can see the precision of the FC system falls well under 1.5 G cm and the two measurement modes are yielding consistent results.

The accuracy of the FC system was again compared using beam-based measurements at the 3 GeV ring by compensating the ID's effect on the e-beam orbit using a feed-forward correction scheme measured in the ring, then calculating the magnetic field applied by the correctors and comparing against the FC measurements. This comparison is shown in Fig. 4 for the 4 m long SoftiMAX EPU with a period length of 48 mm and an excellent agreement between the FC and the e-beam measurements can be observed.

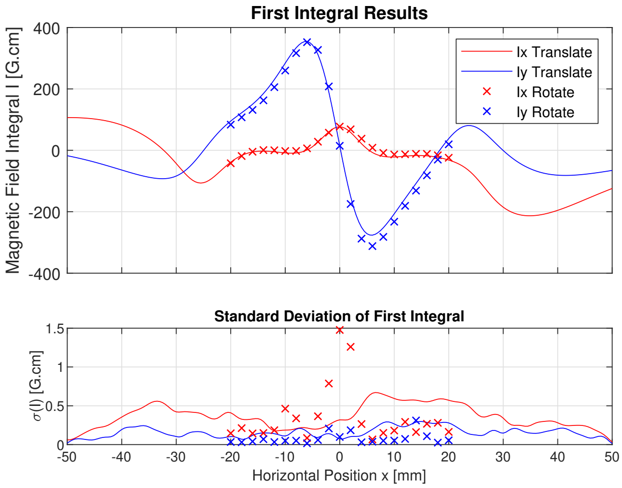

Figure 3: FC measurement results using two modes.

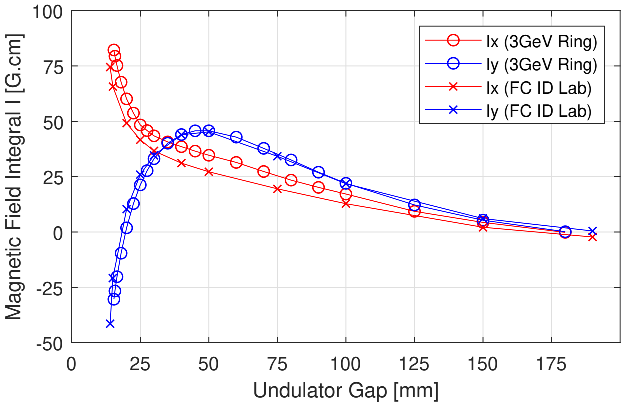

Figure 4: FC results compared against e-beam in the ring.

The FC system is also capable of obtaining the 2nd magnetic field integral by twisting one end of the coil by 180° relative to the other.

THE STRETCHED WIRE SYSTEM

Similar to the FC, the Stretched Wire (SW) is also an induction-based method for obtaining magnetic field integrals, utilising a single wire instead of a coil. This makes it ideal for smaller gap IDs such as In-Vacuum Undulators (IVUs).

The SW system can operate in two modes: translate and rotate. The translate mode moves the wire horizontally and vertically while performing the potential integration, and is used in obtaining the first or second field integrals. The rotate mode moves the single wire on a circular path of arbitrary radius forming a virtual rotating coil that can measure the field multipole components within it, this is used on machine magnets to obtain field centre location, gradient and higher order content.

The translate mode was used for measuring a 3 m long 16 mm period length DanMAX IVU, and was later compared against e-based measurements in the 3 GeV ring. The result of this comparison is shown in Fig. 5. Where we can observe very good agreement between the two independent measurements.

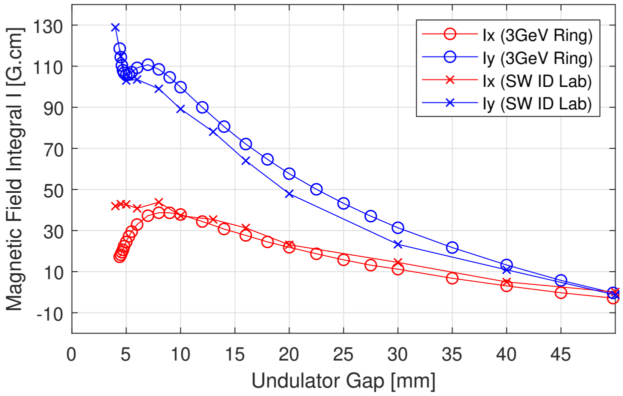

Figure 5: SW results compared against e-beam in the ring.

The rotate mode of the SW system was tested on an unknown short iron-yoke skew quadrupole magnet, the measurement radius used was 30 mm, and the field multipoles were calculated at a reference radius of 22.5 mm. The resulting integrated field contents, centre location and their standard deviations (STD) are shown in Table 2. Where higher order multipoles are represented by "units" of 10^{-4} relative to the main components.

We can again see that the SW can achieve excellent precision in detecting the higher order multipole content of a quadrupole. However, an external measurement of the same magnet would be needed to judge on the accuracy this measurement and determine systematic error effects.

THE PULSED WIRE SYSTEM

The Pulsed Wire (PW) measurement technique is an interesting method for obtaining local magnetic field information using a thin stretched wire, it operates by sending

Table 2: SW Measurements of a Quadrupole Magnet

Component	**Value**	**STD**
Normal Dipole	−0.61 G cm	0.28 G cm
Skew Dipole	−5.19 G cm	0.31 G cm
Normal Quadrupole	1.66 mT m/m	10.8 µT m/m
Skew Quadrupole	125.7 mT m/m	14.2 µT m/m
Normal Sextupole	15.5 unit	0.24 unit
Skew Sextupole	−3.54 unit	1.26 unit
Normal Octupole	1.92 unit	0.44 unit
Skew Octupole	−2.65 unit	0.50 unit
Normal Decapole	109.4 unit	0.18 unit
Skew Decapole	−11.7 unit	0.49 unit
Normal Duodecupole	20.91 unit	0.23 unit
Skew Duodecupole	500.0 unit	0.31 unit
Hor. Magnetic Center	41.4 µm	2.2 µm
Ver. Magnetic Center	−4.3 µm	2.0 µm

a short pulse of current through the wire which exerts a force through the interaction with the magnetic field and excites a travelling wave propagating in both directions. An optical sensor is placed outside of the undulator detects the travelling wave as it passes through it. The magnetic field profile along the wire is then calculated by analysing the wire oscillations.

The PW method is therefore ideal in closed structure IDs and small gaps, as opposed to full lateral access required by the Hall-probe mapper. Which is why a PW system is currently under commissioning at MAX IV.

Ongoing tests are performed on a 2 m long 69.1 mm period length test ID that has been pre-characterized using the HP and acts as reference measurements during the PW system commissioning. Preliminary results of the magnetic field and phase error measurement comparisons are shown in Figs. 6 and 7 respectively.

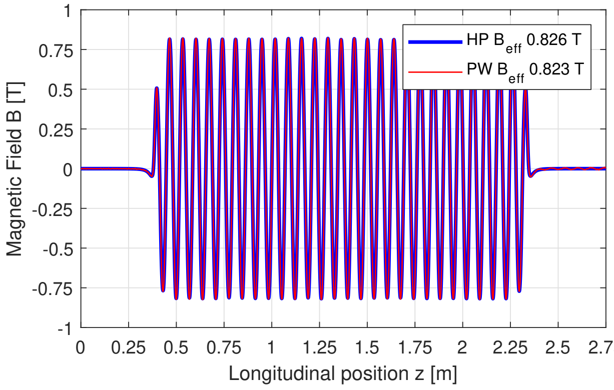

Figure 6: PW vs HP measured magnetic field.

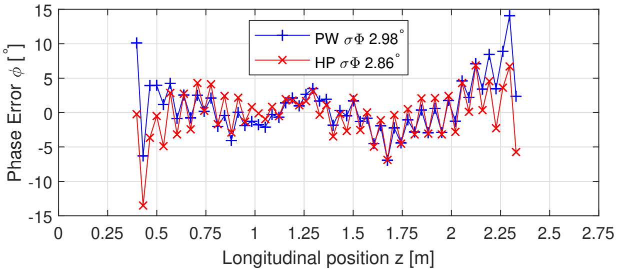

Figure 7: PW vs HP measured ID phase error.

We can see an excellent agreement between the HP and PW measurements under these conditions. The reported phase error difference $\sqrt{\sigma^2_{\phi,PW} - \sigma^2_{\phi,HP}}$ is under 0.84° RMS, while the difference in the effective magnetic field was under 0.4%.

Development work is still ongoing to enhance the robustness of PW method under various wire materials and small period length IDs.

CONCLUSION

The ID laboratory at MAX IV has been equipped with in-house built magnetic measurement systems that are capable of characterising existing and upcoming devices, these systems has been used and tested during the construction of many in-house build IDs which are now in operation. Beam-based measurements on these devices show excellent agreement with lab ones, this gives confidence in the delivery of high-quality insertion devices to our beamlines.

ACKNOWLEDGEMENTS

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REFERENCES

[1] M. Ebbeni, H. Tarawneh, and A. Thiel, “Status of Insertion Device Measurement Systems at MAX IV Laboratory”, in *Proc. 7th Int. Particle Accelerator Conf. (IPAC’16)*, Busan, Korea, May 2016, pp. 4047–4049. doi:10.18429/JACoW-IPAC2016-THPOW046

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