TEST BENCH DESIGN AND FIRST MEASUREMENT RESULTS FOR THE PETRA IV FOFB ACTUATOR CHAIN

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Abstract

A fast orbit feedback system is currently being developed for the upcoming PETRA IV at DESY Hamburg. The performance of the FOFB system depends mainly on the frequency response of the subsystems, i.e. the corrector magnets, power supplies, cables and vacuum chambers. A test bench is being developed for measuring the field quality of FOFB corrector magnets and system identification of all integrated subsystems in the kHz range. The first design of the test bench and the initial idea for the different types of measurement methodologies to find the frequency response and magnetic field of corrector magnets are presented below. The subsystems integration and combined frequency response of the FOFB system will be measured in later stage of the project.

INTRODUCTION

The upcoming PETRA IV (a fourth-generation light source) is being designed at DESY. One of the main contributors to the beam quality in PETRA IV will be the Fast Orbit Feedback (FOFB) system [1]. The main purpose of the system is to stabilize the orbit of the beam by applying fast corrections based on the fast input data stream (130 kHz) of the Beam Position Monitors (BPM). The FOFB mainly includes the fast corrector magnets, power supplies, and digital process unit. The overall performance of the FOFB system depends on the frequency responses of the subsystems, such as the corrector magnets, the cables connecting the power supplies to the magnets, and the power supplies themselves, as well as the vacuum chamber under the fast correctors. The most critical subsystem is the corrector magnet in terms of both frequency response and field quality.

A test bench has been developed for the system identification of FOFB subsystems initially for prototypes and later to characterise the series production of the magnets. The following requirements dictate the design of the test bench:

- The fast corrector magnets must be characterised for the position-dependent field quality (DC) as well as the integrated transfer function (frequency sweep) in all three directions. This requires a movable stage to scan the 3D field strength.
- Beyond field quality, the measurement setup should support an integrated field measurement for the system identification of corrector magnets alone and for adding other subsystems in the loop, i.e., vacuum chamber, power amplifiers, and cables. The parasitic capacitance effect of the cables and its effect on the overall signal transfer to the magnet is important to be measured.
- A high-resolution spatial magnetic Hall probe to measure the position-dependent field as well as a search coil for integrated field measurement.
- The setup must also allow investigation of magnetic hysteresis under varying excitation conditions to capture non-linear effects and behaviours crucial to understanding residual fields.
- Frequency sweeps (position-dependent as well as integrated field) with constant amplitude, both with and without DC offset, are also required to evaluate the operating point dependence of transfer functions.

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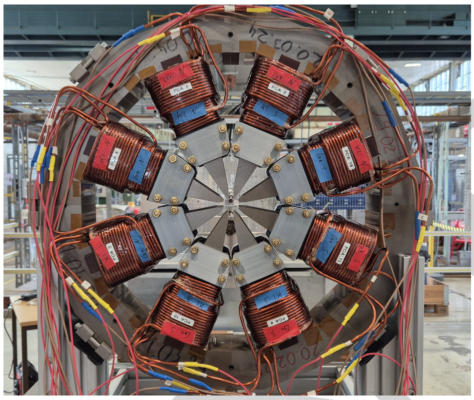

Figure 1: Prototype magnet I.A.

MEASUREMENT SETUP

Prototype Magnet PETRA IV's fast corrector is based on a special 8-pole design for both planes, ensuring better field quality than a dipole geometry per plane, as confirmed by simulations. The first prototype magnet (I.A) is shown in Fig. 1 and differs from the final design in terms of yoke material and lamination thickness; i.e., the yoke (86 mm in length) is made of 1 mm-thick Power-core 1400 AP lamination instead of about 0.3 mm-thick laminations. This first prototype serves as a benchmark for validating the simulations. Coil connections via external bridges allow reconfiguration from dipole to quadrupole mode for magnetic centre measurements. Those external bridges might exhibit greater resistance than direct connections. Lamination misalignments of approximately ±200 μm due to glueing were also observed.

Excitation and Measurement Instrument The Digilent ADP3450 is used as a portable, high-resolution mixed-signal oscilloscope [2]. It combines a signal generator, an oscilloscope, digital inputs and outputs, and other measurement tools in a compact system, making it ideal for testing, analysing and generating signals in electronics. Thanks to its remote access capabilities, it is particularly useful for laboratories and research purposes, as it can capture both analogue and digital signals at high resolution, making measurements more precise and versatile.

SENIS Hall Sensor The SENIS sensor is the three-axis Hall-effect magnetic sensor used for position-resolved measurements. It provides an active sensor volume of 0.15 mm × 0.01 mm × 0.15 mm, a detection bandwidth from DC to 25 kHz, and operates over a full-scale range of ±40 mT with a sensitivity of 250 V/T. Anyhow, we used it only for DC and low-frequency field measurements [3], as the magnet generates a field below the sensor's resolution for small-signal excitation at higher frequencies due to eddy-current effects in the yoke. The differential output is used, effectively extending the measurable range to ±80 mT, for DC case.

Search Coil A rectangular search coil was designed to measure the integrated magnetic field over the full length of the fast corrector magnet, extending ±150 mm around the magnet centre. The measurement of the induced voltage signal at each frequency provides the integrated field strength using Faraday's law of electromagnetic induction, and a transfer function is calculated by normalising with the current in the magnet coil. This setup eliminates the need for a movable stage and enables measuring the transfer function up to high frequency, but it loses position-dependent measurement, so a combination of the two measurement setups helps to fully characterise the system. The housing for the coils has been designed in the CAD software and was 3D printed in-house.

Current Sensor The magnet coil current is measured using an ACS712 current sensor from Allegro Micro-Systems. This Hall-effect-based sensor provides a linear response over a range of ±20 A with a bandwidth from DC to 80 kHz. The sensitivity is 100 mV/A. For the sake of simplicity, we also used the Fluke 325 current clamp for DC bias measurements.

Impedance Analyzer The frequency-dependent resistance and inductance of the magnet provide an alternate way to compute current in the magnet coil by using the measured applied coil voltage, and R&S® HM8118 LCR meter was used for this purpose. To automate the frequency sweep, an appropriate device is being procured.

3D Movable Stage The three-axis movable table provided by the DESY-MEA team is used for position-dependent measurements with the SENIS sensor. The stage is driven by DC motors and provides a positioning resolution of 0.2 mm. With six degrees of freedom, it enables precise placement

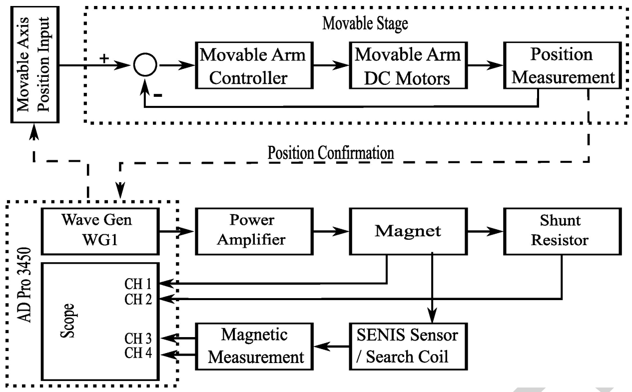

Figure 2: Block diagram of test bench setup.

of the sensor within the magnetic field of the corrector magnet. This allows accurate spatial characterization of the field distribution. The motors are controlled via National Instruments (NI) hardware, and a LabVIEW-based control system and specialised driver modules.

EXAMPLES OF THE MEASUREMENTS

The test bench has been set up, and the prototype magnet has been characterised. Here we outline three example measurements. First, the LR measurement is performed; it is independent of any additional components in the measurement circuit and serves as an initial check of the frequency-dependent characteristic curve. The two additional measurements are performed by the Digilent ADP3450, which applies the input signal to the magnet and records the primary side (coil voltage and current through a precise shunt resistor) and the secondary side (the generated magnetic field). Figure 2 shows the block diagram of the measurement setup.

LR Measurements

Initial magnet characterisation was carried out using an R&S® HM8118 LCR meter, with coils from both magnet planes connected via clamp wires. Series inductance and resistance were recorded at discrete frequency points. This setup required manually entering excitation frequency data at each frequency step, which will be automated with a new measurement device. Figure 3 shows the frequency-dependent LR meter measurements for prototype I.A magnet in the range of 20 Hz to 10 kHz. Both planes show almost identical frequency-dependent resistance and inductance, as expected by design.

Scan Using Movable Stage

The DC and low-frequency (≤5 kHz) analyses were performed using a SENIS sensor mounted on a movable stage. Initially, the transverse centre of the magnet was located, and the sensor, attached to the robotic arm of the movable stage, was aligned using an alignment scope. A longitudinal positional sweep was then carried out with the magnet operating in quadrupole mode to determine its longitudinal magnetic centre. This center was defined as the origin of

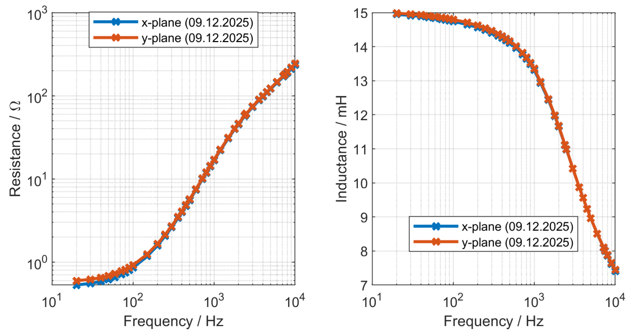

Figure 3: LR meter measurements for prototype I.A.

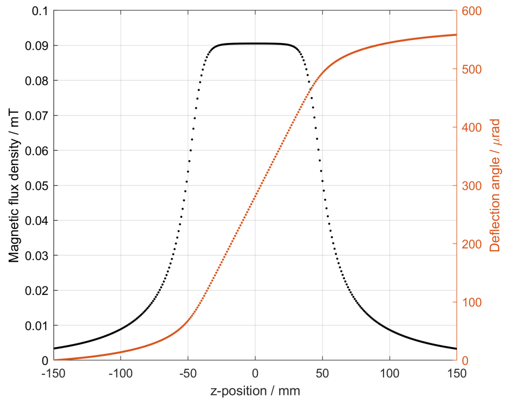

Figure 4: Longitudinal scan of the transverse DC magnetic field and corresponding kick strength for 6 GeV electron beam, using a Senis sensor.

the z-axis. The field was then measured along the longitudinal axis within a range of ±150 mm. Additionally, both the transverse planes, i.e. x and y, have been scanned at the longitudinal centre within a range of ±3 mm to validate the simulation. The DC analysis was conducted by supplying the maximum rated current of 15 A to the magnet, and a measurement of the transverse field along the z-direction and corresponding kick strength for 6 GeV electron beam is shown in Fig. 4.

For the AC measurements, a frequency-sweep excitation signal from the Digilent ADP3450 was applied to a power amplifier (gain 2.4), and its output was used to excite the corrector magnet at each longitudinal position of the sensor. Due to the limited number of input channels (two channels used by the sensor's two differential outputs), frequency-dependent measurements were taken for one plane at a time. The AC scans for one plane are shown in [4].

AC Characterization with Search Coil

High-frequency analysis was conducted using the search coil setup. The wave generator channel of Digilent ADP3450 provided the excitation voltage signal to drive the magnet current without an amplifier in between. The induced voltage across the search coil was simultaneously captured by its oscilloscope channel. Figure 5 shows a measurement of the integrated magnetic field normalised with the coil current and scaled to a quasi-DC value of 0 dB as we are mainly interested in frequency-dependent relative changes.

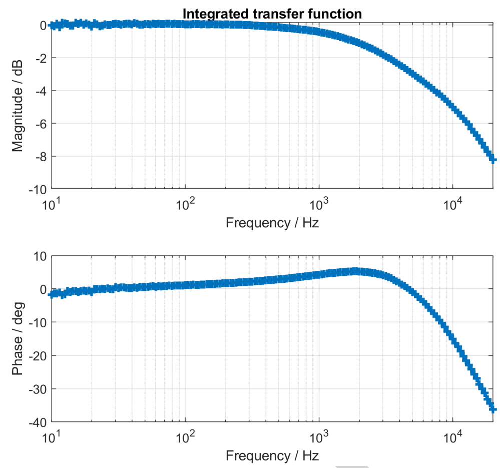

Figure 5: Transfer function for the integrated field of prototype I.A using search coil.

CONCLUSION

A testbench for characterising the actuator chain of the FOFB system for PETRA IV has been developed, initially for the prototype program and also for later use in series production of the magnets. The two-sensor approach has been deployed, i.e. one using a SENIS magnetic Hall probe for detailed position-dependent field quality and transfer function measurements, which are limited to the lower frequency side, and a search coil for integrated field and transfer function measurements that can go to higher frequencies. A movable stage has been used for the positional scans of SENIS sensor. Initial results of the two sensors are presented along with impedance measurements of the magnet.

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