ESRF

IMMW21

International Magnetic Measurement Workshop

24th – 28th June 2019

ABSTRACTS

Monday 24th – Morning session

Overview of the Magnetic Measurement activities at Sirius

Luana Vilela, James Citadini

Brazilian Synchroton Light National Lab-LNLS

More than 1000 magnets have been installed on the Sirius accelerator and all have been magnetically characterized by rotating coil techniques or hall sensor mappings. The presentation shows the entire infrastructure used for the manufacture and characterization of magnets from the mechanical to the magnetic point of view and presents the details of the magnetic measurement systems and production results of the booster magnets and the storage ring.

Status of magnetic measurements for the Advanced Photon Source Upgrade

Animesh Jain, Charles Doose, Scott Izzo, Mathew Virgo, Robert Soliday

Argonne National Laboratory

The new storage ring for the proposed upgrade of the Advanced Photon Source (APS-U) at Argonne National Laboratory (ANL) will require 1320 new magnets. About 80% of these magnets are already ordered, and production is essentially complete for two of the quadrupole types. A new magnetic measurement laboratory is built to measure field quality and to fiducialize these magnets. Installation of the first rotating coil bench is currently underway and we expect to be well into production measurements by the time of this workshop. Details of the measurement benches that will be installed, data acquisition and analysis methodology to be used, and the status of magnetic measurements will be presented.

Recent activities at NSLS-II Insertion Device Magnetic Measurement Facility

Toshi Tanabe, Todd Corwin, Dean Hidas, Yoshiteru Hidaka, David A. Harder and Marco Musardo

Brookhaven National Laboratory

As of June 2019, 23 insertion devices in 16 straight sections and five three pole wigglers (3PWs) have been installed to operate 23 beamlines at the NSLS-II facility. Since IMMW20, two refurbished insertion devices have been installed in addition to four 3PWs. Example of recent activities are: a major rework of cooling lines for the refurbished IVU18, extensive studies on the effectiveness of active 2nd order compensation for EPUs and a compensation of gap dependent beam coupling due to residual skew quadrupole of one of IVU20s. The repair and retuning of damaged 3m-long IVU20 were the most significant event. During the course of IVU20 repair, we have encountered various issues such as small demagnetization at the beginning of the array, unorthodox gap dependent phase error variation. We use a new shimming technique with NiCu sheet for this device.

For the general measurement capabilities, we have made an effort to improve the repeatability of flip coil measurement system and on-the-fly wire measurement. A pulsed wire measurement system is re-established to allow the measurement of small aperture (5mm diameter) permanent magnet quadrupoles for Ultra-fast Electron Microscope (UEM) project as well as that of 1.2m-long, 70mm-period super conducting wiggler (SCW) with 4.3T peak field to be built for High-energy Engineering X-ray (HEX) beamline.

This paper describes the details of these activities.

High precision magnetic measurements at very high magnetic fields up to 37 T

Kevin PAILLOT, Steffen KRÄMER

CNRS Grenoble

The Laboratoire National des Champs Magnétiques Intenses (LNCMI) is a CNRS large scale facility. It operates very high static magnetic fields up to 37 Tesla (Grenoble site) and pulsed magnetic fields up to 100 Tesla (Toulouse site) and provides worldwide user access. At LNCMI Grenoble the static magnetic fields are produced by water cooled resistive magnets operating up to 66 kA at 24 MW electrical power. Moreover, the experiments often require very low temperatures down to 20 mK. Combining these two extreme conditions is a particular challenge that LNCMI has to deal with.

The LNCMI undertakes considerable efforts to produce, control and measure magnetic fields to a very high precision level of better than 20 ppm. Apart from a precise calibration of the magnetic field value, the spatial field distribution and temporal field variation are of great importance, since they affect the sample and experiment properties and can also interact with the low temperature environment leading to exotic phenomena like levitation induced loss of cooling power at high magnetic fields.

In our contribution we present an overview of the magnetic measurements at LNCMI for field characterization (pick-up, NMR, Hall-effect), selected results, current challenges and future evolution plans.

Magnet section activities at the Paul Scherrer Institute: Horizon 2020 and beyond

S. Sanfilippo

Paul Scherrer Institute

This talk gives an overview of the activities and plans for the design, production and tests of magnets in two main projects at the Paul Scherrer Institute: the upgrade of the Swiss Light Source and the 16T Canted-Cosine Theta dipole R&D program in the framework of CHART (Swiss Accelerator Research and Technology Center). The presentation describes the challenges related to the magnet specifications, the infrastructure and the measurement strategy for project completion within the next five years.

Monday 24th – Afternoon session

High-accuracy Hall-based sensors for high magnetic field applications

Vincent Mosser[1], Rémi Boucher[2], Enrique Minaya[3]

1 ITRON France, Meudon, 2 CAYLAR, Villebon, France, 3 CNRS-IPN Orsay, France

We demonstrate here the capability of GaAs based quantum well Hall sensors (QWHS) for high-accuracy magnetometry at high magnetic field. Such devices, with a Hall sensitivity around 700 Ω/T and an intrinsic thermal drift of the Hall plate around -50 ppm/°C (or -0.005%/°C) in the -100/+200°C temperature range, already demonstrated their attractiveness for high-accuracy measurement at low field.

A microsystem was built, including a mixed-mode analog/digital signal processing based on the spinning current modulation technique (SCMT), for achieving dynamic offset cancelation. The circuit-board discussed in IEEE Trans. Instrum. Meas. 66, 637 (2017) was specially adapted for high-field operation in order to be able to handle the large Hall voltage at several tesla.

We will report on experiments performed in the 7T superconducting magnet of the double Penning trap mass spectrometer MLLTRAP at IPN, as well as in different environments with low magnetic noise (amagnetic chamber, 1T static magnetic circuit). Thanks to SCMT, a system with +/-10T input range is able to discriminate a +/-10 microtesla superimposed square signal. Its residual offset measured in an amagnetic chamber is less than 1 microtesla. We also quantified the noise increase as a function of magnetic field strength. The power dissipation in the Hall plate is below 0.1mW at 7T.

Latest developments at SENIS

Dragana Popovic Renella and Radivoje S. Popovic

SENIS AG

A novel miniaturized Hall-based 3-axis low-noise teslameter developed for SwissFEL will be used for high fidelity characterisation/optimisation of undulators. The teslameter will be placed between the undulator and its outer shell in a very limited space of 150mmx50mmx45mm. Together with the SENIS 3-axis Hall probe the setup will traverse along the undulator length on a specifically designed rig. The new instrument provides a very accurate magnetic field map in the µT range with simultaneous readings from the position encoder at an accuracy of ±3µm. Performance results also include offset fluctuation and drift (0.1Hz – 10Hz) with a standard deviation of 0.78µT and a broadband noise (10Hz – 500Hz) of 2.05µT with an acquisition frequency of 2kHz. The calibration techniques used for the corrective improvements include non-linearity, temperature offset, temperature sensitivity compensation of the Hall probe and electronics temperature compensation. Further planned improvements of the miniaturized 3-axis teslameter could allow the use of a novel Cryogenic 3-axis Hall probe. Last but not least, the long expected unique low-noise 3-axis teslameter with very high resolution 2ppm (1uT), accuracy of 0.005%, selectable sampling rate of 10Samples/sec-15kSamples/sec, high temperature stability: <20ppm/°C, selectable magnetic field ranges (100mT, 500mT, 2T, 20T), is ready and will be briefly refreshed.

Latest developments at Metrolab

J. Tinembart

Metrolab

Since IMMW20, we've been working to extend the range of use of our NMR and Hall probes. During this talk, we will present our latest NMR probes development one addressing small gaps and another one devoted to hall calibration laboratories. We will also share measurements made in cryo-conditions with our MV2 hall chip. Finally, we will also highlight what's cooking in the lab.

Method for high-speed/resolution harmonics measurements with a multi-vertex rotating coil probe array

J. DiMarco

Fermi National Accelerator Laboratory

A multi-vertex arrangement of Printed Circuit Board probes is explored. Using a high-accuracy calibration technique, the localization of probe windings within the multi-vertex array can be accurately determined, which together with some modified analysis techniques enables the possibility of measuring at higher effective rotation rates and compensating for motion errors (and thereby perhaps allowing for higher accuracy/resolution measurements in general).

Optimal positioning of single sensors to measure integrated dipole field

Marco Buzio

CERN

In this talk we discuss the problem of placing optimally a single small sensor, such as a Hall probe, inside a dipole magnet in order to derive the integral. First, we introduce a simplified analytical model showing, under general assumptions, the existence of an optimal point located towards the edge of the poles. Then we compare the model with FE calculations and magnetic measurements. Finally, we give a few suggestions for implementation and outline the planned work on this topic.

Tuesday 25th – Morning session

Magnetic measurement activities at Pohang Accelerator Laboratory

Jang Hui HAN

Pohang Accelerator Laboratory

Abstract: PAL-XFEL and PLS-II are operational at Pohang Accelerator Laboratory. PAL-XFEL has two undulator lines. The hard x-ray lines consists of twenty undulators with 5 m length and 26 mm periods. There are seven undulators with 5 m length and 35 mm periods in the soft x-ray line. PLS-II has eleven planar in-vacuum undulators, three APPLE-II, two wigglers, one out-vacuum undulator and one revolver in-vacuum undulator. For the past few months one additional undulator for the PAL-XFEL hard x-ray line was manufactured and one in-vacuum undulator in the PLS-II ring was re-tuned. The magnetic measurement and tuning of the undulators are reported.

Magnetic measurement activities at CERN

Marco Buzio

CERN

In this talk an overview is given on the status of magnetic measurements activities at CERN, including a description of the ongoing and upcoming accelerator projects, recent organizational and workflow changes, technical advances and ongoing developments.

Overview of Magnetic Field Measurement in NSRRC

C. Y. Kuo, C. K. Yang, J. C. Jan, F. Y. Lin, C. H. Chang, J. C. Huang, T. Y. Chung,C. W. Chen, C. S. Hwang

NSRRC

Several field measurement methods were developed for various lattice magnets, pulse magnets and insertion devices in NSRRC. A measurement system that combine a stretch wire and a Hall probe can be used to separately measure the integral multipole field and the phase error in the cryogenic undulator. Meanwhile, for the accelerator magnets in the diffraction-limited storage ring, the high precision of stretch wire system and 3D compact Hall probe system in a 2-D elliptical (circle) measurement trajectory was developed to measure the integral multipole field components and to map the field profile, respectively. A long loop coil system and search coil can be used for the field measurement of the pulse magnets. In addition, the 3D Hall probe measurement system with various mapping trajectories can measure the different types of magnets. The field measurement concept, analysis algorithm, the field measurement results, and the relative issues are also discussed herein.

Magnetic Measurements for the ALS-U

E. Wallen, C. Wouters, R. Teyber, and L. Fajardo

Lawrence Berkeley National Laboratory

The existing 1.9 GeV ALS storage ring will be upgraded to a 2.0 GeV low emittance lattice, called ALS-U, using a multibend achromat with 9 bending magnets and offset quadrupole magnets used as reversed bend magnets. The new lattice will allow the installation of undulators with a small diameter round vacuum chamber, such as X-type undulators, at the straight sections The talk will cover the development of magnetic measurement systems and methods used for the magnet characterization and fiducialization of the accelerator magnets, which are stretched wire systems, vibrating wire systems, rotating coils, and Hall probe mappers. The talk will also cover the development of a Hall probe system capable of measuring the magnetic fields in the circular vacuum tube of undulators having a round vacuum chamber with down to 6 mm inner diameter. The GaAs based Hall probes are made in-house at LBNL and the readout of the Hall probe signals is made with small footprint ADCs.

Magnets for the up-grade of the Storage ring at PSI

M. Negrazus, S. Sidorov, A. Gabard, G. Montenero, C. Calzolaio, S. Sanfilippo, Ph. Lerch

Paul Scherrer Institute

The upgrade of the Swiss Light Source (SLS2) for 2024-25 foresees the exchange of the existing storage ring by a new one using the same foot print and providing about 40–50 times lower emittance in user operation mode. A science case and a conceptual design for the machine were developed. A detailed technical design study is underway. To achieve the desired emittance reduction, a novel type of lattice is based on compact multifunction magnets, longitudinal-gradient bends (LGBs) and reverse-bending magnets. LGBs with peak field strength of 1.7 T are foreseen using permanent magnet technology in order to save space and operation costs. At a later stage, three PM-LGBs will be removed and replaced by superconducting devices providing a higher peak field value up to 4T. Quadrupoles, sextupoles, and octupoles are planned as electro-magnets. The status of the project is presented from the perspective of the magnet design, manufacturing and measurement.

Measurement and fiducialization of the ESRF-EBS magnets

G. Le Bec, L. Lefebvre, C. Penel, J. Chavanne

ESRF

A new electron storage ring is being installed at the ESRF for increasing the ESRF brilliance by a factor 30. This new storage ring is based on small aperture magnets defining a seven-bend achromat lattice. In the past few years, more than one thousand magnets were procured. Most of them were characterized and fiducialized at the ESRF using stretched wire benches developed in-house.

After a rapid review of the measurement strategy and resources at the ESRF, results will be presented. Statistics on fiducialization accuracy and on magnetic field errors were extracted from the measurement of the magnet series. Detailed measurements of spare magnets are still on-going for finely characterizing field errors due to magnet cycling, cross-talks, thermal effects, etc. These measurements will be presented in the last part of the talk.

Magnetic field measurements of superconducting dipole magnets for the SIS100 Synchrotron

Florian Kaether, Patricia Aguar Bartolome, Giancarlo Golluccio, Jochen Ketter, Pavel Kosek, Febin Kurian, Vasily Marusov, Christian Roux, Kei Sugita, Anna Szwangruber, Alexander Warth, Harald Weiß, Aziz Zaghloul

Gesellschaft fuer Schwerionenforschung - GSI

The SIS100 cyclotron, which is currently under construction as part of the FAIR project at GSI in Darmstadt, requires 108 fast-ramped Nuclotron-type superferric dipole magnets, all of which are currently tested on site. Among several extensive tests, the magnetic field is characterized with a dedicated system of rotating coils, developed and built in collaboration with CERN.

The design of the measurement system posed two main challenges: tracing the curved beam path and operating at cryogenic temperatures. It was realized by several segments which are connected together with special ball bearings and bellows.

The system was commissioned in 2017 and has been used to map about one third of all series dipole magnets. Details on the design, operation and the measurement results will be given.

Tuesday 25th – Afternoon session

Performance assessment of a new on-the-fly Cartesian field mapper for longitudinal gradient magnets

P. La Marca, Ph. Lerch, A. Gabard, M. Tarabini, C. Calzolaio, S. Sanfilippo

Paul Scherrer Institute

A new fast on-the-fly Cartesian field mapper, equipped with a 3D Hall probe, is being developed at Paul Scherrer Institut for the characterization of longitudinal gradient superconducting magnets. The target system accuracy is 0.1% on a magnetic field of up to 6T (with a quasi-hyperbolic field profile along the magnet axis, [1]). The criteria for the robot's mechanical design aim to minimize the uncertainty sources affecting the measurement accuracy. Bounding the systematic mechanical errors allows limiting the uncertainty of the magnetic field measurements to the sensor metrological performances only. The total error budget is estimated trough a thoughtful simulation of the entire system. We anticipate an overall accuracy as low as 5 ppm. In this presentation, Authors review the mechanical design method and shall present the details of the uncertainty analysis, [2]. The performances expressed as position accuracy and magnetic flux density vector are measured and compared to the simulations.

Magnetic measurements systems for the Super-FRS magnets

P. Kosek, G. Golluccio, S. Russenschuck, K. Sugita, G. Deferne, A. J. Windischhofer

Gesellschaft fuer Schwerionenforschung - GSI

The Super-FRS (Superconducting FRagment Separator) is part of the new superconducting accelerator complex (FAIR) [1] under construction at the Helmholtz Center for Heavy Ion Research (GSI) in Darmstadt, Germany. The acceptance tests and magnetic measurements of the superferric multiplets [2], as well as dipole magnets, will be performed at CERN, where a dedicated cryogenic test facility has been constructed [3]. The first of so-called short multiplets, consisting of one quadrupole magnet and one sextupole magnet has been delivered to CERN in February 2019; the extensive magnetic-measurement campaign is scheduled to start in June.

This presentation provides an overview of the magnetic measurement instrumentation that will be used in the series testing of the multiplets. To assess the field quality in terms of multipoles, a large rotating-coil magnetometer (370 mm in diameter) was built [4] with induction coils in printed-circuit board technology. A stretched-wire system, capable of three operation modes - stretched wire, oscillating wire (non-resonant) and vibrating wire (resonant), with a large stroke (400 mm) will be used for the magnetic axis and integral field strength measurements. In this talk the results of commissioning of the systems are presented with focus on mechanical and electromagnetic metrological characterization and comparison of their performance with the well-established systems used at CERN.

Optimization of a Three-Axes Teslameter for the Calibration of the Athos Undulators at PSI

Johann Cassar

University of Malta

In the framework of the SwissFEL project at the Paul Scherrer Institute (PSI), a Hall probe bench is being developed for the high-precision magnetic characterization of the insertion devices for the ATHOS soft X-ray beamline. For this purpose a novel three-axes teslameter has been developed which will be placed between the undulator and its outer shell in a very limited volumetric space of 150 mm x 50 mm x 45 mm. Together with a Hall probe at the center of the cross sectional area of the undulator, the setup will traverse along the undulator length on a specifically designed rig with minimal vibrations. The teslameter incorporates analogue signal conditioning for the 3-axes interface to a Hall probe, a linear absolute encoder interface and a high resolution 24-bit analog-to-digital converter. This contrasts to the old instrumentation setup used which only comprises the analogue circuitry with digitization being done externally to the instrument. The new instrument also provides a very accurate magnetic field map in the µT range with simultaneous readings from the position encoder. Performance results demonstrate an offset fluctuation and drift (0.1 - 10 Hz) with a standard deviation of 0.78 µT and a broadband noise (10 - 500 Hz) of 2.05 µT with an acquisition frequency of 2 kHz.

First results of the MAX IV pulse wire measurement system for ID characterization

P. N'gotta, M. Ebbeni, A. Thiel, H. Tarawneh

Lund University

The Pulse wire measurement system (PWM) is an attractive tool for insertion devices characterization, particularly in the case of undulator with small gap and or with limited transverse access, where the use of the Hall probe is restricted. Furthermore, the PWM is a versatile tool enabling to fully characterize an ID by its ability to measure both the local field and field integrals usually done by a flipping coil and Hall probe systems. However, despite of its implementation simplicity, the PWM suffers of limitations such as the signal distortion and a low signal to noise ratio, which affect the accuracy of the measurements. This presentation report the development of a PWM bench based on a lock in amplifier to recovery the signal with low noise. Signal correction Simulations of a short period undulator model are performed in order to evaluate the efficiency of the dispersion correction algorithm. Finally, measurements results of a 2m, 68mm period length undulator performed by the PWM and the Hall probe are compared, especially for the phase error, a key parameter which relate the undulator radiation performance.

A stretched wire system for the measurement of accelerator multipole magnets

Cheng Ying Kuo, Jyh Chyuan Jan, Fu Yuan Lin, Chin Kang Yang, Ting Yi Chung and Ching Shiang Hwang

NSRRC

A stretched wire system was developed for precise measurement of the integral harmonic components in the accelerator multipole magnets. 1D Linear and 2D circular and elliptical trajectories were executed to scan the magnetic field and associated with the different analysis methods was also discussed. The measurement precision of the system is within 2.0 G cm for the integral field and 0.005% for the harmonic integral field components of accelerator multipole magnets. This system can also be used for analyzing the integral multipole components in the insertion devices. The measurement results were compared to rotating coil system and Hall probe system. The system setup, measurement methods, and analysis concept of the system will be presented herein.

High-Precision Magnetic Field Measurement and Mapping of the LEReC 180˚ Bending Magnet Using Very Low Field NMR Probe (<400 Gauss)

H. Song, D. Bruno, K. Capobianco-Hogan, C. Degen, A. Fedotov, D. M. Gassner, P. Joshi, J. Kewisch, C. Mi, T. Miller, S. Seletskiy, P. Thieberger, J. Tuozzolo, P. Wanderer

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LEReC presently under construction at BNL will be the first bunched electron cooler and will cool colliding beams of heavy ions in RHIC. One of the key components is the 180 degree bend dipole which steers the electron beams from the “Yellow” to the “Blue” RHIC rings. Precise knowledge of the magnetic field is critical and 10-4 accuracy in the integral field is required. The center uniform field is in the range of 180 – 325 Gauss much lower than the traditional NMR range limit of ~400 Gauss. CAYLAR has developed a very low field NMR probe for BNL which is able to measure fields down to 143 Gauss with accuracy of 50 milligauss. Outside of the homogeneous regime, the field measurement was seamlessly continued with a Hall sensor. Moreover we have developed a new approach, i.e. move-wait-measure, turning off the motor current during the ~10 second wait which allows the NMR probe to accurately lock its signal. With a LabVIEW-based precise control of position and DAQ system, a full mapping has been achieved at 5 radii horizontally, 5 heights vertically, and 3 magnetic fields. Detailed analysis has been performed including fixing drop-outs, motion accuracy check, and integral field calculation. (Work supported by Brookhaven Science Associates under DOE contract DE-AC02-98CH10886)

Wednesday 26th – Morning session

A Novel Magnetic Measurement System Being Developed for the Superconducting Undulator Program at the Advanced Photon Source

Matthew Kasa and Yury Ivanyushenkov

Argonne National Laboratory

As the superconducting undulator (SCU) program at the Advanced Photon Source (APS) prepares for the upgrade of the APS, a novel method for performing magnetic measurements of SCUs is being developed. SCUs that were previously constructed at the APS were housed in a 2-m long cryostat and measured using a system and techniques adapted from the Budker Institute of Nuclear Physics. The system allowed SCUs to be characterized in the operational cryostat under normal operating conditions. SCUs for the APS upgrade will be housed in cryostats that are 4.5-m long and the current method of magnetic measurements proves to be difficult to scale. In response to the difficulties, a novel method has been proposed and is currently being developed. Importantly, the ability to characterize the magnet in the operational cryostat is maintained. The system is compact, basically portable, and capable of supporting common measurement techniques such as Hall sensor, rotating or scanning coil, and pulsed wire measurements of SCUs. The mechanics and performance of the system prototype will be described.

In-vacuum cold measurement bench development for the CPMU upgrade programme at Diamond Light Source

Zena Patel

Diamond Light Source

The ID group at Diamond Light Source have developed its first in-vacuum Hall probe measurement system for field mapping as part of the CPMU upgrade programme. The Hall probe bench is complemented by a stretched wire system for measuring field integrals, supplied by Danfysik. The mechanical details including the design, alignment, motion, and repeatability will be discussed, along with the magnetic measurements taken with a CPMU prototype at room temperature and at 80K.

The CPMU prototype was first measured using the main measurement system (Hall probe bench and rotating coil). The measurements from the in-vacuum bench were assessed against the main measurement bench results and were found to be in good agreement when comparing the peak field and electron trajectories. A large difference in electron trajectories, phase error, etc. was found between the room temperature and cold measurements of the cold bench, partly related to mechanical issues. Currently, a new measurement bench is under design review to overcome these issues, and to measure the first in-house built CPMU due for installation.

General status of ID magnetic measurements laboratory at ALBA

Jordi Marcos, Valentí Massana, Josep Campmany

ALBA-CELLS

In this talk we will present the last measurements we did as well as the improvements we have made in order to measure and characterize closed structures, small gap multipolar magnets, and Hall probe accurate characterization.

The main development regarding the magnetic measurements Hall probe bench build to measure closed structures is that, once the concept has been proved by a prototype, we will modify it in order to characterize the new in-vacuum undulator that is being build for XAIRA beamline, measuring it with the vacuum chamber installed.

Besides, we will present our new shaft with a diameter of 10 mm for rotating coil, designed to characterize small-gap multipolar magnets. We will summarize the challenges faced as well as the solutions adopted.

Finally, we will describe a new 3D Helmholtz coil setup that is being manufactured in order to fully characterize the angular misaligments in 3D Hall probes.

A Hall probe calibration system for the accurate magnetic field measurement

Ou Xianjin, Feng Wentian, Jin Xiaofeng

Institute of Modern Physics

A Hall probe calibration system for the accurate magnetic field measurement is developed at the IMP. The system can calibrate four Hall probes at the same time with the contents of residual voltage, temperature coefficient, and magnetic fields coefficient. The absolute calibration of the probes is performed against a nuclear magnetic resonance teslameter (NMR). To get more data, the system is operated in a warm bore which the magnetic field profile is 7 T and provided by a superconducting magnet system, the field homogeneity is better than 0.5ppm in the uniform magnetic field region.

The research of weak magnetic field measurement

Jianxin Zhou

Institute of High Energy Physics

Circular Electron Positron Collider (CEPC) is a next-generation collider proposed by IHEP. The layout of CEPC includes the Linac, the transfer lines, the Booster and Collider. The circumference of the Booster is 100km. There are 15360 dipole magnets with length of 4.7m, and the alternating low field excitation scheme is adopted. The minimum field of the dipole magnet is only 29Gs whereas the max. field is 492 Gs. The repetitive frequency is 0.1 Hz, the field error within GFR will be less than 1E-3. When the magnet reaches to its minimum field, the field reproducibility will be less than 5E-4(0.015Gs). This is a high challenge for the design, processing and measurement of magnets. In order to verify the feasibility of the scheme, two prototypes of magnets have been developed and the magnetic field quality has been tested. The information of the magnet, measurement system and measurement results will be introduced in the report.

A novel method for the field integral measurements with a stretched wire

J. Chavanne, C. Penel, G. Le Bec, L. Lefebvre

ESRF

An alternative to the usual harmonic analysis of the straight field integral has been developed at the ESRF. The method is based on a direct use of the Cauchy integral formula and analytical formulations. It allows an accurate description of the field integral in a Region Of Interest (ROI) which does not necessarily need to be circular but can be of any shape. It is therefore well adapted to magnets with a non circular aperture or good field regions defined with large transverse aspect ratios. Moreover, the formulation allows a direct determination of the mutlipole content in the ROI.

This method can be used advantageously in magnetic measurements performed with a moving stretched wire. Examples of such measurements done on different types of magnets built for the ESRF EBS will be presented.

SW impedance and SW tomography: R&D topics at the ESRF

G Le Bec, M Neufselle, C. Penel, J. Chavanne

ESRF

This poster will present two stretched-wire measurement R&D topics being investigated at the ESRF.

If a stretched wire vibrates in a magnetic field, its impedance is affected. It can be shown that the wire impedance spectrum contains peaks which are driven by the longitudinal modes of the magnetic field. It is expected that measuring the impedance of the magnet would give information on the longitudinal distribution of the field. This measurement method was tested with a demonstrator. A $Z \propto B^2$ dependence of the impedance was observed, as expected from a theoretical model.

The measurement of a field integral along a stretched wire is analog to an X-ray absorption measurement, which is sensitive to the integral of the density of a material. In the latter case, it is common to combine measurements acquired at different angles to reconstruct an image of an object: this is the basis of the CT tomography. The same principle can be applied to stretched wire measurements. An image of a magnetic field can be obtained from integral measurements at different angles. This may be applied to the measurement of permanent magnet blocks. A demonstrator was built at the ESRF and tested on undulator magnets.

Wednesday 26th – Afternoon session

Measurement report on the prototype ZEPTO dipole magnet for CLIC

A. R. Bainbridge, J. A. Clarke, N. Collomb, B. J. A. Shepherd

STFC Daresbury Laboratory

The proposed CLIC accelerator at CERN features an innovative layout involving multiple beamlines, including transfer of energy from a dedicated high current drive beam into the primary collision beam. This design requires a large number of magnets, which represent a significant power draw and heat output. STFC and CERN have examined the feasibility of tuneable Permanent Magnet (PM) systems in place of electromagnets to negate the high energy and infrastructure requirements. This is known as the ZEPTO (Zero-Power Tuneable optics) project.

This collaboration, originally to develop two tuneable PM Quadrupole systems, has now resulted in the design, construction and measurement of a prototype tuneable PM dipole. This prototype has a peak field of 1.1T and a tuning range of over 50%, whilst drawing no power during normal operation and only a small amount whilst adjusting the field strength.

We present a report on the measurement results of the prototype ZEPTO dipole with comparison to simulations. We discuss the unique aspects of the magnet relating to field homogeneity the tuning range and the additional challenges of identifying and measuring the effects of mechanical alignment and movement due to high magnetic forces in the system.

PAL-XFEL hard X-ray planar undulator off-axis field measurements

Sojeong Lee and Jang-hui Han

Pohang Accelerator Laboratory

For the large bandwidth XFEL operation, originally proposed by SwissFEL, a transverse gradient undulator (TGU) is a crucial component. Using APPLE-X type or planar undulators as TGU was suggested to generate either soft or hard X-ray. A planar undulator can provide transverse gradient by using an off-center of the undulator. The operation of a planar undulator as TGU can be applied to an existing usual planar undulator beamline without any modification of undulator. The large bandwidth XFEL is based on Self Amplified Spontaneous Emission (SASE). For a soft X-ray SASE process, the required RMS phase error level is about 5 deg. Usually, the pole tuning process is done to meet the requirements of the RMS phase error at a certain gap along the on-axis line. To review this possibility, the several off-axis field measurements were done with two types of PAL planar undulators. In this poster, the field measurement results and off-axis phase error of normal planar undulators will be presented.

Magnetic measurement of ESS quadrupole and corrector electro-magnets at Elettra

D. Caiazza, D. Castronovo, A. Gubertini, G. Loda, R. Sauro, D. Vivoda

Elettra Sincrotrone Trieste S.C.p.A

Elettra Sincrotrone Trieste (Elettra) is one of the Institutions committed to the realization of the Italian in-kind contribution for the European Spallation Source (ESS), under construction in Lund (Sweden). The European Spallation Source is a pan-European project with 13 European nations as member to build the most powerful spallation neutron source in the world. One major Elettra contribution is the design, prototyping and testing of about 200 magnets, among quadrupoles and correctors, for the Linac Warm Unit, mostly installed between the cryomodules in the superconducting part of the linac. To this aim, we built a new measurement laboratory for multipole magnet characterization and alignment.

The laboratory was first equipped with a rotating-coil magnetometer, realized on *printed circuit board* and using motorized stages and a coordinate measuring arm for fiducialization. The rotating shaft was realized mostly by in-house made components, using the sensing board as integrating part of the sustaining structure. Coil calibration was performed in collaboration with CERN, by combining the calibration in a reference dipole and an in-situ calibration in the measurand quadrupoles. The measurement system was validated against CERN systems, such that series measurements could be launched. Further developments foresee the realization of a hall-probe mapper and stretched-wire systems.

This contribution will give an overview of the system and report about the measurement and calibration techniques employed and the results obtained so far.

Status of magnetic field measurement of MCBRD for the HL-LHC upgrade at the IMP

Yang Wenjie, Ni Dongsheng, Zhao Bo

IMP

The Large Hadron Collider (LHC) upgrade, called High Luminosity LHC (HL-LHC) is planned for the next decade. A set of twin aperture beam orbit correctors positioned on the approaches to the ATLAS & CMS experiments will be development. The orbit corrector MCBRD based on Canted Cosine Theta (CCT) design to achieve 5 Tm field integral and multipoles lower than 10 units in the twin aperture. Tow institutes (IHEP, IMP) and one company (WST) in China will work on the magnet R&D and series production. IMP in charge of the performance test at 4.2 K including field strength and field quality. This talk presents the status of the magnetic field measurements of the first series magnet by a rotating coil probe.

Magnetic Characterization of 1.5 m Long Superconducting Undulator Coils with 20 mm Period Length

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At the Institute of Beam Physics and Technology (IBPT) of the Karlsruhe Institute of Technology (KIT) there is an ongoing R&D program to develop superconducting insertion devices (IDs) together with our industrial partner Bilfinger Noell GmbH. Superconducting IDs can reach, for a given gap and period length, a higher field strength than permanent magnet IDs. As for all IDs it is of fundamental importance to characterize their magnetic properties accurately before installation in synchrotron light sources.

Within the collaboration, the development of a full-scale superconducting undulator with 20 mm period length (SCU 20) has been completed. The conduction cooled 1.5 m long coils were characterized and intensively tested in the horizontal test facility CASPER II before being assembled in the final cryostat.

In this contribution we report on the results of the magnetic field characterization of the 1.5 m SCU20 main coils performed in CASPER II.

Vertical Magnetic Field Measurements of Full-Length Prototype MQXFAP Quadrupoles at Cryogenic Temperatures for Hi-Lumi LHC

H. Song, G. Ambrosio, K. Amm, M. Anerella, D. W. Cheng, G. Chlachidze, J. DiMarco, S. Feher, P. Ferracin, S. Izquierdo Bermudez, A. Jain, P. Joshi, J. Muratore, H. Pan, G. Sabbi, J. Schmalzle, E. Todesco, P. Wanderer, X. Wang, M. Yu

AUP collaboration

The U.S. HL LHC Accelerator Upgrade Project (AUP) (previously LARP) collaboration and CERN have joined efforts to develop high field quadrupoles for the Hi-Lumi LHC upgrade at CERN. The US national laboratories in the AUP program will deliver 10 cryostatted magnets and each cryostat has two 4.2 m long Nb_3Sn quadrupole**s** with 150 mm aperture. The vertical magnet testing facility of the Superconducting Magnet Division (SMD) at Brookhaven National Laboratory (BNL) has been significantly upgraded to perform testing in superfluid He at 1.9 K. Magnetic measurement is an essential step in the AUP magnet to monitor production process and to ensure that the magnetic fields meet the functional requirements and acceptance criteria. We have successfully performed magnetic measurements on the MQXFAP2 magnet in 2018 and the measured field data has provided information on the mechanical assembly and integration. The MQXFAP1b magnet is a magnet reassembled from three coils used in MQXFAP1 and one new coil and it will be tested at BNL beginning in April 2019. This paper will report further magnetic field analysis on the MQXFAP2 and recent measurement activities on MQXFAP1b. The paper will include warm measurement at room temperature, comparison between BNL and Lawrence Berkeley National Laboratory (LBNL) warm measurements, cold measurements at 1.9 K, detailed field analysis and the relationship between the field harmonics and the geometric asymmetries along the axial direction. In addition, recent developments of the magnetic field measurement systems at SMD/BNL will be reported.

Thursday 27th – Morning session

Magnetometry for Gravitational Measurements of Antihydrogen with ALPHA-g

Nathan Evetts, on behalf of the ALPHA Collaboration

The Einstein equivalence principle (EEP) has never been directly examined with an antimatter test body. To address this, the ALPHA Collaboration is constructing a new apparatus (ALPHA-g) which can test the EEP using magnetically trapped antihydrogen atoms. I will discuss motivations for these experiments, as well as the methods we intend to employ. In particular, magnetic field characterization will be an essential component of the experimental methodology. The antiatom gravitational energy difference between the top and bottom of our trap is about a factor of 10_4 smaller than the magnetic confinement energies involved. This necessitates the use of precision magnetometers that will allow us to distinguish between the effects of magnetic and gravitational fields on antihydrogen trajectories. We will accomplish the required magnetometry using techniques drawn from the fields of nuclear magnetic resonance and non-neutral plasmas. I will overview these in the context of the greater experiment.

Overview of Magnetic Measurements of Insertion Devices at DESY

P.Vagin, A.Schöps, M.Tischer

DESY

Friday 28th – Morning session

Magnetic Alignment of Magnets for Cornell Electron Storage Ring Upgrade

Alexander Temnykh

Cornell

Recently we have completed CHESS-U upgrade of Cornell Electron Storage Ring. The upgrade included replacing of 74 m of magnetic structure used in the past for electron-positron beams collision by a new structure optimized for production of synchrotron radiation. The new structure is composed of double bend achromatic (DBA) cells and Cornell Compact Undulators (CCUs) built by KYMA. DBA cells consisted of combined dipole-quadrupole (DQ) magnets and quadrupoles. Prior installation in storage rings, we assembled all magnets on girders and, using combination of vibrating wire magnetic field measurement techniques and field mapping with Hall Probe aligned these magnets in respect to each other and girder fiducials.

In this talk, after a brief description of CHESS-U upgrade and its status, I will present in details the procedure and techniques we used for precise positioning of *magnetic axis* of quadrupoles in respect to girder fiducials and for the alignment of *magnetic axis* of DQ magnets with *magnetic axis* of quadrupoles. In this project we used "vibrating wire" and field mapping with Hall probe. The following beam commission validated this approach.

Performance Study of Vibrating-Wire Magnet Alignment Technique

K. Fukami, N. Azumi, S. Inoue, T. Kai, H. Kimura, J. Kiuchi, S. Matsui, S. Takano, T. Watanabe, and C. Zhang

Spring-8

High accuracy alignment of magnets is one of key issues for next-generation light sources. For the SPring-8 major upgrade, SPring-8-II, multipole magnets need to be aligned within 25 micrometers on a straight section between bending magnets. To align the magnets, we are planning to introduce a vibrating-wire alignment technique for SPring-8-II and a newly designed light source ring in north-east Japan. The technique can directly align magnetic centers on a straight section with enough resolution without any fiducialization, but the imperfection of wire linearity, including a wire sag and local kinks, may significantly deteriorates the accuracy of the alignment. We measured the sag profile of actual wires using a special test bench. We report the measured deviations of the sag from the ideal catenary curve as well as the effects of local kinks. In the presentation, we summarize the whole alignment procedure and discuss error factors such as displacements of magnets after the precise alignment in the transportation, and the change in the magnetic center in case of the magnet reassembly.

The Magnetic Measurement System Based on Coordinate Measuring Machine

Fusan CHEN, Mei YANG, Ran LIANG, Shuai LI, Baogui YIN, Lingling GONG

Institute of High Energy Physics

A magnetic measurement system based on coordinate measuring machine (CMM) is developed for High Energy Photon Source Test Facility (HEPS-TF). This system consists of a CMM, a set of rotating coil system and a stretched wire system. By measuring the positions of the rotating coil or stretched wire related to the magnet, and moving the rotating coil or the stretched wire with two sets of two dimensional motorized linear stage, the alignment efficiency and accuracy are highly improved.

Vibrating Wire Method And Related Positioning Study For TPS

T.C. Tseng, H.S. Wang, W.Y. Lai, S.Y. Perng, C.J. Lin, H.C. Ho, K.H. Hsu, D.G. Huang, C.K. Kuan

NSRRC

The vibration wire method for magnets centering alignment is restudied at NSRRC. It is prepared for the replacement of magnets on a girder at TPS in case of malfunction. In this study, both quadrupole and sextupole magnets were tested. Moreover, due to the quick decay of the laser PSD system between straight section girders, the wire method to replace the laser PSD system is also studied simultaneously. This paper presents the study results.