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MAGNETIC MEASUREMENTS OF THE ALS-U MAGNETS

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Abstract

The Advanced Light Source (ALS) at the Lawrence Berkeley National Laboratory (LBL) is going through an upgrade (ALS-U) where the ALS triple-bend achromat will be replaced by a nine-bend achromat storage ring (SR) with an on-axis injection using beam swapping from a triple-bend achromat accumulator ring (AR). About 700 magnets will be used for the ALS-U accelerator systems. The paper gives an overview of the stretched wire and rotating coil systems used for the magnetic measurements of the ALS-U magnets. We are also describing the fiducialization process, i.e. the mechanical and magnetic alignment of the magnets.

INTRODUCTION

The ALS-U accelerator systems consists of approximately 700 electromagnets. Figure 1 shows and overview of the ALS-U accelerator system. The existing LINAC and booster system that feeds today's ALS electron storage will be used for injecting into the new accumulator ring (AR), which has a triple bend achromat lattice similar to the ALS lattice but is using magnet with smaller aperture than ALS. The ALS-U storage ring (SR) has a nine bend achromat lattice with high gradient multipole magnets, of which a majority have Vanadium Permendur pole tips. At some locations in the SR ring, high field permanent magnet based dipole magnets will be installed to provide hard x-ray dipole radiation in similar way to the superbend magnets in the existing ALS. There is also a set of transport line magnets needed for the transfer of electrons between the AR and SR during the beam swapping. In addition to the 700 electromagnets there are also pulsed kicker and septum magnets. The delivery of the 700 magnets is distributed over time as shown in Figure 2, where the AR magnets are arriving during 2022-2023, while the bulk of SR magnets are arriving later during 2024.

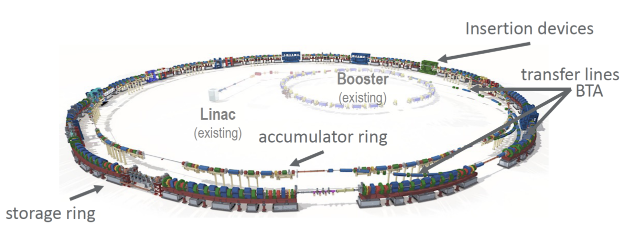

Figure 1: Overview of the ALS-U accelerator system.

In order to verify the higher order multipole contents and fiducialization, the magnets will be magnetically measured. The following sections briefly described the measurement techniques used for the ALS-U. The methods are still evolving and a full error estimation of the methods and statistics

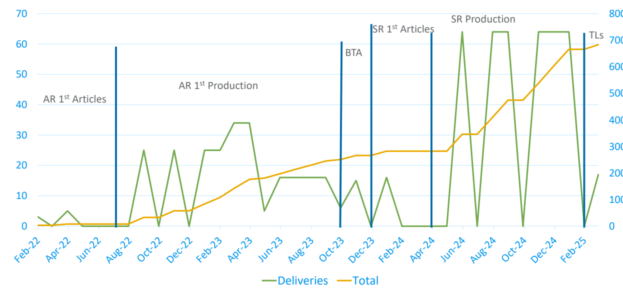

Figure 2: Delivery forecast of the 700 ALS-U magnets.

from measurements series on different magnet types were not at hand at the time of this conference.

MAGNETIC MEASUREMENT TECHNIQUES USED FOR THE ALS-U

The recent accelerator constructions projects at the ESRF in Grenoble and APS at Argonne Laboratory in Chicago have given rise to a development of magnet measurement techniques as described in e.g. [1–4]. For the ALS-U magnetic measurements, the stretched wire technique has been chosen as the main work horse for magnetic measurements due its versatility where it is simple to adapt the stretched wire to different magnet types, its good absolute accuracy for main field components, and its fiducialization capability. Rotating coils [5] are used for high resolution measurements of higher order multipoles, which is needed mainly for the AR magnets. The rotating coil measurements are less time consuming than stretched wire measurements. Hall probe mapping will also be used to measure 3D Hall probe maps of magnets even though the absolute accuracy of Hall probe mapping is determined by the Hall probe calibration. Both Hall probe mapping and Hall probe calibration are slow processes compared to rotating coil and stretched wire measurements.

STRETCHED WIRE

The stretched wire systems are using Newport linear stages to move the wire and Metrolab integrators to record the electric flux during the wire motion. The magnet only needs coarse alignment to the stretched wire setup, which can compensate for magnet roll, yaw, and pitch compared to the coordinate system of the linear stages. Figure 3 shows one of the stretched wire systems. The stretched wire is moved on a circular trajectory and the field components are extracted by a Fourier decompoistion of the measured electric flux.

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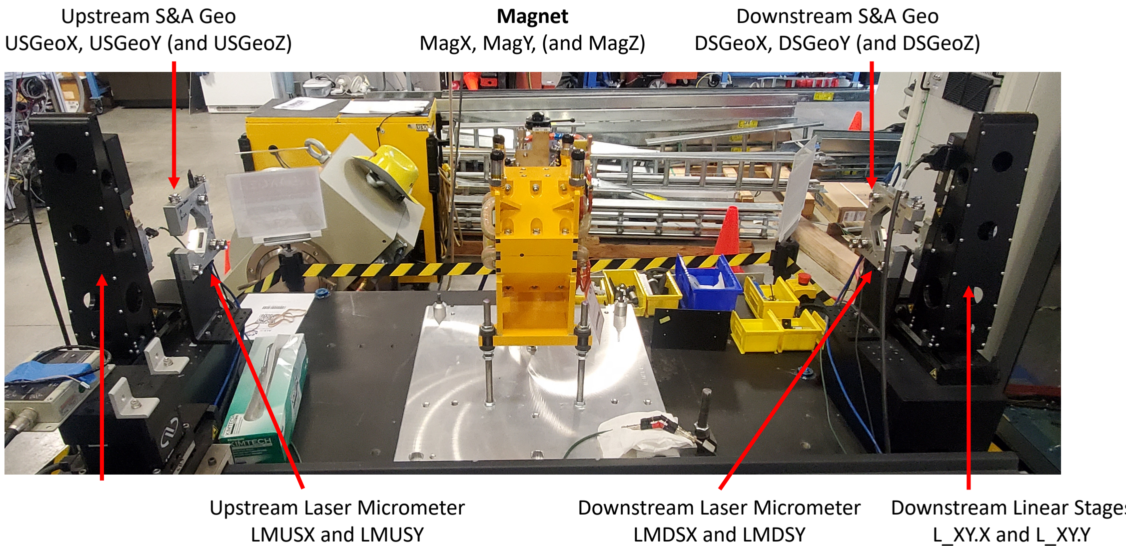

Figure 3: Overview of the stretched wire wire system.

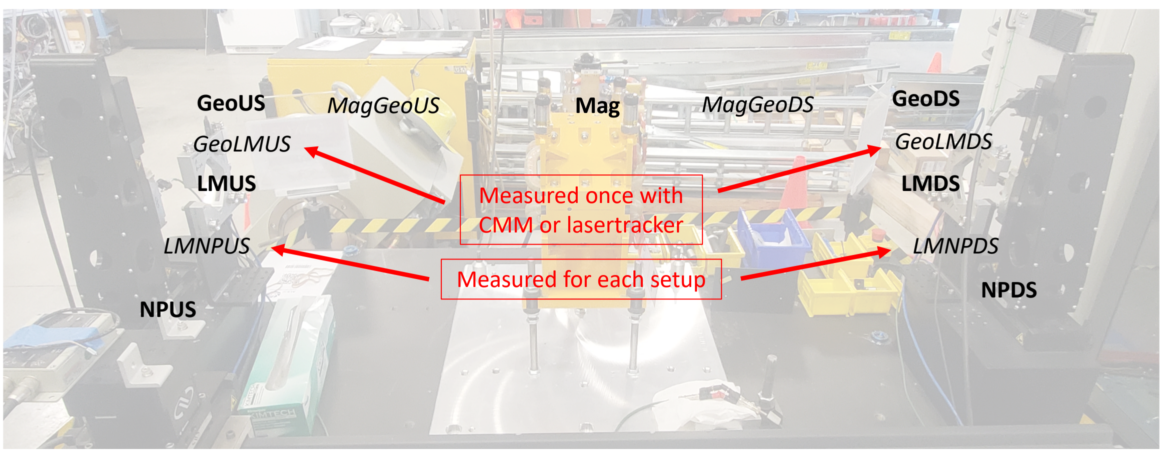

Figure 4: Illustration of coordinate transformations used for fiducialization.

FIDUCIALIZATION PROCESS

The alignment of the ALS-U accelerator system is carried out with laser tracker. Each magnet has lasertracker reflector nests mounted on the magnets. The positions of the lasertracker nests relative to each other and the magnet pole surfaces are measured with a CMM, i.e. they are mechanically fiducialized. The mechanical fiducialization is then compared to the fiducialization found by the stretched wire system. As expected the mechnical and mechanical fiducialization agree well for multipole magnets and the magnetic fiducialization can be used while for gradient dipole magnet the magnetic fiducialization must be used. The key factor for the magnetic fiducialization is to determine the wire position, which is carried out by using Metralight 2D laser micrometers. Figure 4 illustrates the different coordinate systems for the magnet (Mag) and the upstream (NPUS) and downstream (NPUS) linear stages. The coordinate transformations are all linear transformations. The relation between the 2D laser micrometers reading and the fiducial reflector nests mounted on the 2D laser micromters is measured once with lasertracker or CMM, while the relation between the wire position given by the linear stages and the the 2D laser micrometer is measured every time the wire has been mounted.

ROTATING COIL

The rotating coils are designed and used following the principles outlined in [5]. The coils are manufactured by using multiplayer printed circuit boards (PCB) that are mounted in glass fiber rods where there is a groove machined out for the PCBs. The rotation is done with a Newport direct drive rotational stage with high resolution rotational positioning that also give the trigger signals to the Metrolab integrators that are recording the electrical flux during rotation. Figure 5 show an overview of the rotating coil stand. The PCB coils are 55 cm long, while the total length of the rods is 120 cm. The rotating coils have dipole, quadrupole, and sextupole bucking. Two different rod diameters are used

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20 mm and 30 mm and the same type of PCBs are used for both rod diameters. The bucking ratios obtained for the different sets of coils are in the range 230-1000. The rotating coil system has about a factor 10 lower noise floor than the stretched wire for multipole measurements. The rotating coils are calibrated in-situ using well known quadrupole and sextupole magnets.

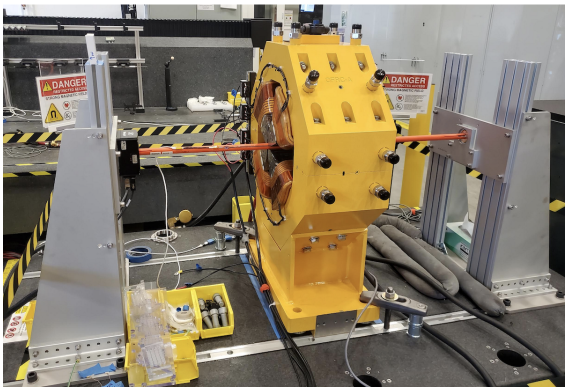

Figure 5: Overview of the rotating coil system.

HALL PROBE MAPPING

In order to make complete 3D Hall probe maps of swept C-shaped gradient dipole magnets a small hall probe bench with 1.2 m travel length along the beam trajectory, 100 mm horizontal travel length, and 35 mm vertical travel length has been constructed. The intention is however to use the stretched wire measurements for the series measurements of the swept gradient dipole magnets since this method is faster and in general has a higher accuracy than Hall probe mapping. In order to increase the absolute precision of the Hall probe measurements a Hall probe calibration magnet and NMR probe have been procured. Hall probes have also been integrated in the Zeiss CMM used for mechanical measurements of the magnets. Figure 6 shows the Hall probe system integrated in the Zeiss CMM. Hall probes are prone to unreliable absolute accuracy due to uncertainties of the Hall probe calibration. I

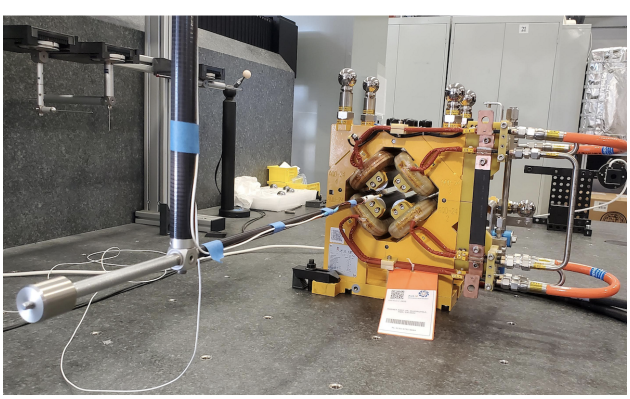

Figure 6: Hall probe system integrated in the Zeiss CMM.

SUMMARY AND OUTLOOK

The main magnetic measurement techniques used for the approximately 700 electromagnets for the ALS-U accelerator systems are the stretched wire technique and rotating coil technique. In addition it is possible to carry out 3D Hall probe mapping of magnets. During 2022 the first article AR magnets have arrived and the magnetic measurements have been carried out. As of 2023, production series AR magnets are also arriving and magnetic measurements are carried out. A magnetic fiducialization process involving lasertracker and 2D laser micrometers has been established. The first article SR magnets are expected to arrive in the second half of 2023.

The magnetic measurement methods are still evolving and a full error estimation of the methods and statistics from measurements series on different magnet types were not at hand at the time of this conference. A more detailed description will be provided in future communications.

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