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MODERNIZING OF MAGNET POWER SUPPLIES AT KARA AND A TRANSITION TO EPICS-BASED CONTROL SYSTEM

H. Hoteit, E. Blomley, M. Brosi, A. Mochihashi, A.-S. Müller, J. L. Steinmann, M. Schuh,
Karlsruhe Institute of Technology, Karlsruhe, Germany
S. Marsching, aquenos GmbH, Baden-Baden, Germany
F. Burini, M. Farioli, M. Pretelli, OCEM Power Electronics, Bologna, Italy
D. Molaro, M. Gustin, CAENels Trieste, Italy

Abstract

This paper presents a study on the upgrade and modernization of the magnet power supplies of the KARA (Karlsruhe Research Accelerator) storage ring. The existing power supplies, which have been in operation for more than two decades, were facing obsolescence and operational limitations. To ensure the continued availability and reliability of the facility for the next decade and beyond, a comprehensive refurbishment was required.

The project involved the replacement and upgrade of the power supplies for the dipole and sextupole magnets at KARA, as well as for the dipole and quadrupole magnets in the booster. A key aspect of this modernization effort beside an improvement in efficiency and stability is the migration from a custom control system to EPICS running embedded on the power supplies.

This paper provides an in-depth analysis of the motivations, goals, and technical aspects of the power supply modernization project as well as first measurements with the new power supplies and the project status.

INTRODUCTION

The storage ring KARA in KIT [1] serves as both an accelerator test facility and a synchrotron radiation source, operating within an energy spectrum ranging from 0.5 to 2.5 GeV. The storage ring magnet system [2] consist of 16 dipole magnets, all powered by a single power supply. Additionally, there are 40 quadrupole magnets, each connected to one of five power supplies. Each family of 8 magnets is linked in series to a single power supply. Furthermore, 24 sextupole magnets were distributed between two power supplies: The power supply for the vertical focussing sextupole magnets was connected to 16 magnets, while the power supply for the horizontal focussing sextupoles was connected to the remaining 8 magnets.

As for the booster, 8 dipole magnets are connected to one power supply as well as 8 quadrupole magnets with one family configuration are connected to another power supply.

The commissioning process [3] for the storage ring started in December 1999, and since then, the power supplies have been in continuous operation. However they faced obsolescence issues and operational limitations, while their efficiency was good, their stability left room for improvement especially for the test facility operation with new demands.

In line with its commitment to innovation and continuous improvement, KIT has prioritized the modernization of its power supply infrastructure to ensure optimal performance and reliability for its storage ring facility.

In addition, these power supplies were the last to operate on the ACS control system [4]. To make both software and hardware components more efficient, effective and to ensure standardization, a decision was made few years ago to replace the aging ACS system with an EPICS based system [5].

In order to achieve better low alpha conditions and more flexible accelerator operation modes, the decision was taken to separate the vertical sextupole magnets into two families of 8 magnets each connected to a single power supply.

This upgrade is expected to enhance the overall performance, reliability, and compatibility of the storage ring.

POWER SUPPLY DEVELOPMENT AND UPGRADE STRATEGY:

Three distinct power supply architectures are employed for the bending dipole magnets in KARA, the booster dipole magnets, and the booster quadrupole magnets. Each architecture begins with a 400 V 3-phase input, with subsequent conversion to a DC bus using transformers, diode rectifier bridges, and filter components tailored to the energy ratings of the magnets.

While the sextupole magnet power supplies are made from standard off-the-shelf high performances, high efficiency, and high stability NGPS power supply series [6, 7]. The specified efficiencies of the power supplies when ordered is more than 85%.

In order to assess the choice of various parameters and to evaluate if expected results occur, two types of analysis were done:

Steady State Analysis: The analysis in steady state involves setting constant current reference values for each power supply, with subsequent evaluation of parameters and validation through detailed PLECS simulations. The focus is on achieving expected results while considering

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the unique characteristics of each magnet and power supply system.

Dynamic Behavior Analysis: The dynamic behavior is evaluated through a series of subsequent current cycles, following specifications to confirm the sizing with "fast" ramps. The control system parameters enable precise tracking of reference current peaks. Validation of power electronics components is conducted through simulations, ensuring suitability for both steady state and dynamic operation.

Minimizing Shut Down:

To minimize disruption to KARA operations and ensure a brief shutdown while replacing the old power supplies, all necessary infrastructure components such as power cables, signal cables, and water cooling pipes were prepared in advance of the power supply deliveries. As the power supplies arrived at different times, a scheduled short shutdown was executed after each delivery to remove the old power supply and install the new one. The sextupole PS was the initial unit installed, followed by the dipole PS, and later the booster dipole and quadrupole power supplies were installed simultaneously.

Factory Acceptance Test (FAT):

Before the power supplies were delivered several Factory Acceptance Tests (FATs) were conducted, some of them remotely to shorten the installation schedule, using a dummy load designed to mimic the magnets to which the power supplies would be connected. This ensured the functionality of the power supplies. The tests included:

Visual inspection, verification of main distribution, pressure test of the water distribution plant, dielectric tests, functional test (local control check, remote control check and interface tests, checking of protections, voltage and current accuracy long term stability test, short term stability test and reproducibility, output current ripple test, efficiency, noise level, test of the control system interface and ramp functionality).

Most of these tests were repeated during the site acceptance test (SAT).

Site Acceptance Test (SAT) and Validation:

The SAT for the power supplies was conducted with great care and thorough testing procedures. Below are some results of the performed tests:

Long Term Stability Test: A full current test was performed for more than 8 hours with a constant reference at the maximum operative current. The output current of the P.S. is measured using a digital current measuring system CAEN CT-BOX [8] installed in the power supply. The ambient temperature is also monitored to check any possible correlation and thermal coefficient (see Fig. 1). For the storage ring dipole power supply the total variation of the current is 7 mA, corresponding to 9 ppm peak to peak.

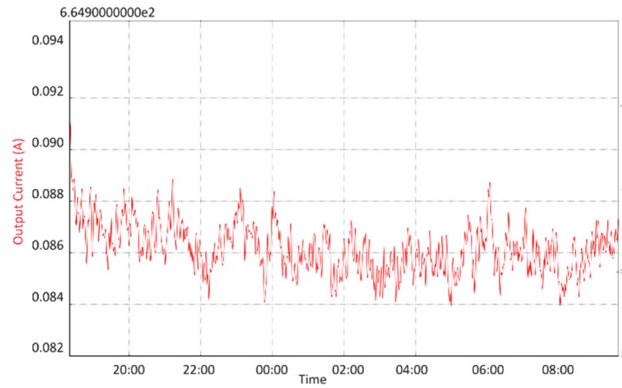

Figure 1: KARA dipole PS stability test.

Short Term Stability and Reproducibility Test: A test is performed for 30 minutes with constant reference. Also, the current reproducibility is checked. After the 30 minutes test, the power supply is switched off for 30 minutes, then it is switched on and set to the same set point and the current value is compared with the previous one. For the booster dipole power supply, the peak to peak variation during the 30 min test is 3mA and the difference between the second current level and the first one is 2 mA which is less than 20 mA (20 mA corresponds to 20 ppm) (see Fig. 2).

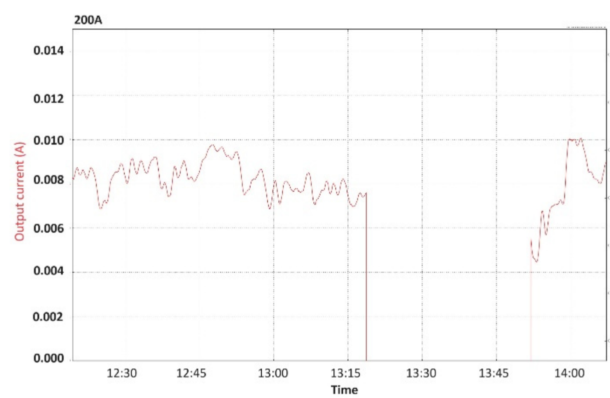

Figure 2: Reproducibility test.

Output Current Ripple Test: the output current ripple is measured with the CT-BOX and elaborated with a Python script that calculates the RMS noise + ripple in the bandwidth from 0.01 Hz to 1 kHz

The current ripple at 150A is 1mA which is less than 3 mA (3 mA corresponds to 10 ppm F S) (see Fig. 3).

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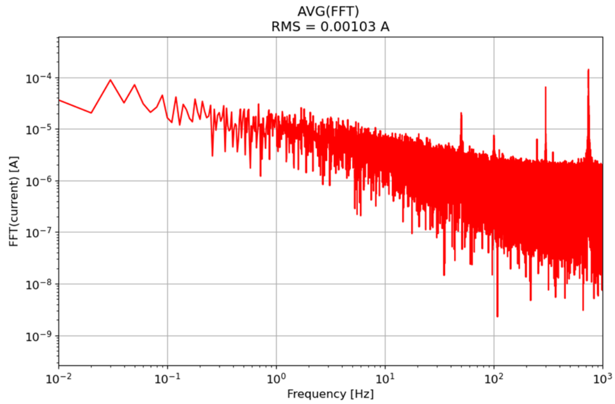

Figure 3: H.sextupole PS current ripple.

Test of the control system interface and ramp functionality: The control system interface was tested both using the web interface and connecting the remote control interface, using EPICS drivers. The PS was controlled remotely and performed a ramp test successfully (see Fig. 4).

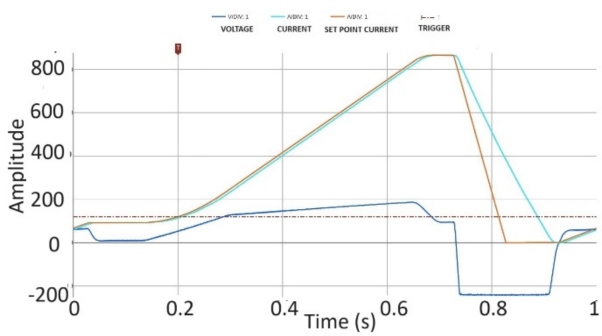

Figure 4: Booster dipole PS ramp.

Control System Integration

With the replacement of the main power supplies the last step of the transition from ACS to EPICS [9] is done. The EPICS IOC is running directly on the power supply control unit and has all required features like custom ramping waveforms and monitoring the power supply internal states.

Due to the EPICS IOC directly running on the control electronics of the power supplies, the control and monitoring of the power-supplies is both very efficient and very reliable. In particular, the loading of large waveforms (up to 500,000 points) can be performed in a very short amount of time (less than 3 seconds).

EXPECTED IMPACT AND FUTURE PROSPECTS:

The implementation of the new power supplies at KARA introduced many improvements, promising not only better efficiency, stability, and performance but also some additional features to meet evolving experimental demands. The efficiency of the dipole magnet power supply has been measured at over 95%, while exceeding 85% for the sextupole magnet power supplies. Furthermore, the long-term stability registers less than 10 ppm full scale for the newly installed power supplies.

One significant improvement involves splitting the vertical sextupole magnets into two independent families, facilitating more precise vertical chromaticity correction and contributing to improved low alpha conditions. Additionally, the introduction of the new dipole power supply enables a controlled decrease in energy from 2.5 GeV. This controlled ramp-down offers several advantages. Firstly, it enhances safety by enabling the dumping of the beam at lower energy levels, resulting in reduced radiation. Secondly, it opens up the option to recycle the beam by ramping down to as low as 500 MeV, allowing for the injection of any lost beam during continuous 24-hour operations. The development for such beam-recycling operations is ongoing, aiming to realize them after the renewal of the quadrupole magnet power supplies for the KARA storage ring

A significant difference from the limitations of the old booster power supplies is the capability of the new ones to operate within varying current ranges. This flexibility gives us the possibility for using the booster as a storage ring at energies of up to 500 MeV.

The next step will be the replacement of quadrupole magnet power supplies, accompanied by explorations into the feasibility of individual powering for these magnets.

These upcoming efforts highlight KARA's commitment to constantly improving and innovating.

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