

Energy-Efficient Magnets for PSI Large Research Facilities

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1) Introduction

Recent geopolitical events and the growing impact of climate change have highlighted the urgent need to implement eco-responsible energy policies, particularly in centers utilizing large research instruments and particle accelerators. The Paul Scherrer Institute, with its five major research facilities, has been committed to this path for some time, especially during the planned upgrades of its machines in the near future. These include the upgrade of the Swiss light source SLS2.0 (scheduled for commissioning in 2025) and the construction of two new beamlines connected to the high-energy proton cyclotron (HIPA) to capture a significantly increased number of muons by two orders of magnitude (High Intensity Muon Beam-HIMB, scheduled for commissioning in 2027-2028). This presentation aims to provide an overview of the program by the PSI magnet section to develop efficient permanent and superconducting magnets in terms of energy consumption for both SLS2.0 and HIMB. The focus will be on the various aspects on the use of superconducting magnets, including the effects of radiation on superconductors and the reduction of CO₂ emissions.

2) The Permanent magnets for the SLS2.0 Upgrade

PSI's commitment to energy efficiency was demonstrated in the SLS2.0 upgrade, where replacing one third of electromagnets with permanent ones (373) reduced magnet power consumption by 60% and contributing to a total reduction of 30 % of the total energy consumption.

3) Superconducting Solenoids for the HIMB muon beam lines Energy

The two future beam lines MuH2 and MuH3 of the HIMB project will significantly raise power consumption, from 120 kW to over 600 kW, mainly due to the power demands of resistive large aperture magnets. PSI magnet section in collaboration with the University of Malta is investigating the use of low-power superconducting solenoids as replacements for conventional magnets. Superconducting magnets offer a significant advantage by reducing resistive losses and requiring less cooling, presenting a promising solution to decrease power consumption and CO₂ emissions. This study focuses on replacing a part of the 13 high-power resistive solenoids with superconducting Nb-Ti solenoids. The nine resistive solenoids in the MuH2 beamline currently consume 16.9 kW, while the four in MuH3 consume 14.3 kW. In contrast, a superconducting solenoid requires only 4.6 kW, primarily for cryogenic cooling. Annually, each superconducting solenoid consumes 18.4 MWh, compared to 67.6 MWh for resistive solenoids. Over 15 years, this transition would save approximately 63 tons of CO₂ emissions. Although superconducting solenoids have a higher initial cost, the long-term energy savings make them a cost-effective solution, with the break-even point occurring after 15 years. During this period, the total energy cost reduction using one superconducting solenoid instead of a resistive one is estimated at 160 kEuros. These savings underscore the financial viability of superconducting technology for PSI's long-term operations.

Preliminary life cycle analyses indicate that each Nb-Ti superconducting coil also reduces CO₂ emissions by an estimated 8.5 tons during the production phase, further emphasizing their potential as a more sustainable alternative to resistive magnets.

4) Future Directions for Energy Efficient magnets at PSI

Looking ahead, PSI aims to expand the use of superconducting and permanent magnets across its facilities. In particular, future upgrades to the HIPA complex may incorporate high-temperature superconductors (HTS) like YBCO, which offer significant advantages in reducing cooling costs. HTS technology, capable of operating at temperatures above 20 K, provides even greater energy efficiency, especially in radiation-heavy environments such as the HIMB beamline.

PSI also plans to undertake comprehensive life cycle assessments to evaluate the environmental impact of its magnet systems, from material extraction through to end-of-life disposal. By analyzing the entire lifecycle of these systems, PSI seeks to identify additional opportunities to reduce the carbon footprint of its research infrastructure and ensure more sustainable operations moving forward.

5) Conclusions

Future energy-saving efforts on magnets at PSI will likely involve the adoption of HTS technology, further reducing the energy demands of cryogenic systems. These advancements align with PSI's broader commitment to developing cutting-edge, energy-efficient, and environmentally sustainable technologies for large-scale research facilities.