Workshop on Special Compact and Low Consumption Magnet Design

Wednesday, 26 November 2014 - Friday, 28 November 2014

CERN

Book of Abstracts

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Corresponding Author: maurizio.vretenar@cern.ch

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Introduction to ”EnEfficient’ Work Package of EuCard2

Corresponding Author: mike.seidel@cern.ch

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The outlook for electricity in Western Europe

Corresponding Author: matthew.wittenstein@iea.org

1st Session / **4**

Why are particle accelerators so inefficient?

Corresponding Author: philippe.lebrun@cern.ch

High-energy accelerators/colliders have developed into large machines consuming high electrical power up to the 100 MW range, thus making the energy bill a major component of their operating costs and eventually of their acceptability by society. With several new projects under study beyond the Large Hadron Collider (LHC), and projections of rising electricity prices by energy agencies, this trend is expected to grow into a critical issue for future machines. While a minimum power duty can be estimated from the beam parameters of both circular and linear accelerators/colliders, they all share low grid-to-beam efficiency entailing much higher power requirements from the electrical networks. We analyse the sources of energy dissipation, from the closest to the farthest from the beams, and discuss the power efficiency of some existing machines and future projects. This methodology also enables to identify possible paths for improvement.

2nd Session: Opportunities of Energy Saving in Accelerators - Part 1 / **5**

CERN plans towards energy efficiency

Corresponding Author: serge.claudet@cern.ch

High energy accelerators are usually great energy consumers and could not escape from being concerned by energy efficiency aspects. After recalling the context, major actions towards energy efficiency will be presented, with plans for the future.

2nd Session: Opportunities of Energy Saving in Accelerators - Part 1 / 6

Magnet Energy Recovery: a way towards more compact and efficient systems

Corresponding Author: k.papastergiou@cern.ch

Magnet energy recovery on a cycle-by-cycle basis shows potential for great energy savings and improvement of the grid power quality. Reducing the magnet duty cycle allows more compact mechanical layout and greater efficiency. To achieve such a benefit a system integration study is essential before starting the parallel development of magnets and power conversion/energy recovery systems.

2nd Session: Opportunities of Energy Saving in Accelerators - Part 1 / 7

Saving opportunities in accelerator magnets

Corresponding Author: davide.tommasini@cern.ch

An accelerator magnet is usually excited either by water cooled copper coils powered with an effective current density in the range of 3-6 A/mm2 or by using superconducting coils, depending on the required field amplitude. Exceptions are often due to technical reasons (special constraints, easier construction, more reliability). Up to now, only in rare cases (in particular in experimental magnets) the energy consumption is an important design factor. The situation is however rapidly evolving and many research institutes are either revising the existing installations or planning the new ones with special attention towards energy consumption. This talk will review several “saving opportunities”presently considered in this domain.

2nd Session: Opportunities of Energy Saving in accelerators - Part 2 / 8

Power Converters design optimization: need for an integrated approach with the magnet design

Corresponding Author: davide.aguglia@cern.ch

This talk presents the basics of the design of a power converter for DC and pulsed magnet. Particularly the impact of the magnet design (inductance, voltage and current adaptation given by the number of turns, etc.) on the converter design is illustrated. Compromises between efficiency, cost and technologies are presented. Finally, the need and benefits of an integrated approach which considers the magnet design variables is demonstrated via a simplified example.

2nd Session: Opportunities of Energy Saving in accelerators - Part 2 / 9

Iron-dominated cycled SC magnets for energy efficiency

Corresponding Author: luca.bottura@cern.ch

2nd Session: Opportunities of Energy Saving in accelerators - Part 2 / 10

In-vacuum magnet design and challenges

Corresponding Author: jim.clarke@stfc.ac.uk

Synchrotron light sources can extend their wavelength reach significantly by putting the undulator arrays into the beam vacuum system. The advantages are such than many light sources now utilise in-vacuum undulators when required. However, there are a number of extra physics and engineering challenges which have to be dealt with when putting magnets in-vacuum. In this talk I will explain the motivation, the additional challenges, and the realisation of in-vacuum undulators.

3rd Session: The saving prospects in European Labs, projects and machine upgrades - Part 1 / 11

The CEA-Saclay experience

Corresponding Author: pierre.vedrine@cern.ch

3rd Session: The saving prospects in European Labs, projects and machine upgrades - Part 1 / 12

Compact and low consumption magnet design - The DESY experience

Corresponding Author: bernward.krause@desy.de

During the last ten years a variety of electromagnets has been ordered to upgrade the PETRA accelerator into a synchrotron light source, to build up a new branch at the FLASH accelerator facility and to install the new European XFEL.
The talk will give an overview of the ingredients which are necessary for developing and manufacturing magnets. Two septum designs will be presented to discuss how electricity costs can be reduced without losing machine performance. Furthermore design studies of combined function magnets and a permanent magnet design that could replace a quadrupole electromagnet to save energy costs will be shown.

3rd Session: The saving prospects in European Labs, projects and machine upgrades - Part 1 / 13

Energy management at GSI and FAIR strategy on energy management

Corresponding Author: p.gardlowski@googlemail.com

GSI Helmholtzzentrum für Schwerionenforschung GmbH operates a unique large-scale accelerator for heavy ions. In the coming years the new international accelerator facility FAIR, one of the largest research projects worldwide, will be built at GSI. In the final extension FAIR consists of several heavy ion accelerator rings, experiment storage rings with up to 1,100 meters in circumference, two linear accelerators and about 3.5 kilometers high energy beam transfer lines as well as several experiment caves. In the context of rising energy prices and the responsible use of resources, GSI has taken the task to develop concepts for efficient use of energy. Actual work includes the introduction of a broad collection and analysis of energy consumption data and the development of the high efficient data center "Green IT Cube" and technologies such as load based cooling of accelerator components. The final intention of this work is to provide a modern and efficient research facility at reasonable energy costs and sustainable use of energy.

3rd Session: The saving prospects in European Labs, projects and machine upgrades - Part 1 / 14

Magnet designs for the ESRF-SR2

Corresponding Author: lebec@esrf.fr

Magnets for the ESRF storage ring upgrade (SR2) are being developed. The power consumption of the new ring should be lower than the present ESRF consumption, with much more magnets installed. On top of that, the new lattice must preserve the existing source points in the ID straight sections: longitudinal compactness is a strong constraint. Permanent magnet (PM) and electromagnet (EM) devices are being developed for this purpose. It is foreseen to install PM dipoles with longitudinal gradient. The other magnets will be normal conducting, with optimized power consumption and length. These technological choices have been driven by the magnet tuning ranges, the ESRF experience and the limited development time. For EM magnets, low power consumption goes against compactness. A compromise can be reach with longitudinally compact magnets with increased transverse dimensions. A brief review of the ESRF-SR2 magnet designs and an estimation of the energy saving (as compared to standard J=5 A/mm2 designs) will be presented.

3rd Session: The saving prospects in European Labs, projects and machine upgrades - Part 2 / 15

The PSI experience: A theory of evolution

Corresponding Author: alexander.gabard@psi.ch

From the beginning, operating costs have been a factor in the design of accelerators and beamlines at PSI. However, limited funds and increasing power costs have made this aspect even more important nowadays. Through the history of PSI, we will present the initial prerogatives for magnet design at our institute and their evolution over time, resulting in the current compact design of the magnets for the SwissFEL project and the first design concepts for the SLS 2.0 upgrade.

3rd Session: The saving prospects in European Labs, projects and machine upgrades - Part 2 / 16

CERN experience on PM based magnet design and procurement

Corresponding Author: pierre.alexandre.thonet@cern.ch

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Energy efficient magnets for FCC

4th Session: Efficient and compact magnet design examples - Part 1 / 18

Compact superconducting magnets for linear accelerators

Corresponding Author: kash@fnal.gov

New Linear Accelerators based on SCRF cavities need compact and efficient superconducting magnet packages to focus and steer electron or proton beams. These magnets should be combined with SCRF cryomodules and installed inside or between them. A recent activity in this area was directed by FNAL-KEK collaboration to splittable conduction cooled magnets. Several magnet prototypes were built and successfully tested. These magnets were designed for high energy beams used in ILC, and Project-X. Nevertheless, there is an interest to explore splittable conduction cooled magnets for new accelerators: FNAL ASTA and PIP-II, KEK STF, SLAC LCLS II. Presented results of various magnets design, fabrication, and tests. Most magnet packages combine the quadrupole magnet and two dipole correctors. The presented magnetic measurement results confirm the specified magnet package parameters.

Summary:

The splittable conduction cooled superconducting magnets provide the efficient way of integration SCRF caviries and magnets in the common cryomodule. The main advantages of the proposed approach are:
• Splittable configuration allows to install the magnet out of a very clean room;
• Conduction cooling, and cryogen-free magnet design (no LHe vessels for the magnet and current leads);
• Iron dominated magnetic design is less sensitive to the coil geometry and position.
• Coils placed far away from the magnet aperture reduce influence of superconductor magnetization effects.
• The simple magnet configuration is very efficient for serial magnet fabrication.

4th Session: Efficient and compact magnet design examples - Part 1 / 19

Electromagnetic and hybrid design experience for CLIC magnet R&D

Corresponding Author: michele.modena@cern.ch

Since 2009 CERN started R&D activities in order to identified and investigate the most challenging cases among the magnets needed for CLIC the Compact Linear Collider one of the possible Future Linear Colliders. In some specific cases the work is mainly done by our colleagues of STFC-Daresbury Lab (UK) part of the CLIC International Collaboration. In the last four years several theoretical studies, models and prototypes were realized mainly focusing two sub-system of the CLIC complex: the "2-beam Modules", the modular elements that are composing the backbone of the two linacs of CLIC, and the Machine Detector Interface (MDI) that include the final focus elements as QD0 and SD0 and the antisolenoid. In this talk we revise the status of the studied and procured magnets. Among them the Drive Beam Quadrupoles, the Main Beam Quadrupoles, the main beam Steering Correctors all challenging for the required compactness, performances and production size, and the final quadrupole QD0 and the sextupole SD0, challenging for the high performances required in terms of gradients and stability.

4th Session: Efficient and compact magnet design examples - Part 1 / 20

ZEPTO: Tunable permanent magnet dipoles and quadrupoles

Corresponding Author: ben.shepherd@stfc.ac.uk

Within the framework of the CLIC-UK collaboration between CERN and STFC, two types of permanent magnet based quadrupoles have been developed and built. These magnets have a very large tuning range (15-60 T/m and 4-43 T/m respectively). The parameters were specified for the challenging requirements of the CLIC Drive Beam Decelerator. Two prototypes have been built and successfully tested, demonstrating the tuning range, stability and field quality of these magnets. A study is also under way to develop a PM-based dipole with a tuning range of 0.8-1.6T, in line with requirements for the CLIC Drive Beam Turnaround Loop.

4th Session: Efficient and compact magnet design examples - Part 2 / 21

Development and operation of a superconducting combined-function magnet system for J-PARC neutrino beam line

Corresponding Authors: ogitsu@post.kek.jp, akira.yamamoto@cern.ch

4th Session: Efficient and compact magnet design examples - Part 2 / 22

Integrated magnet block design and production for MAX IV

Corresponding Author: martin.johansson@maxlab.lu.se

The magnet design of the MAX IV 3 GeV storage ring replaces the conventional support girder + discrete magnets scheme of previous 3rd gen. light sources with a compact integrated design having several consecutive magnet elements precision-machined out of a common solid iron block. This presentation consists of a brief description of the design, and mechanical + magnetic field measurement results from the magnet production series.

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PM materials for accelerator magnets application

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News from electrical steel producers to enable higher efficiency

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Development of energy efficient power supplies/power electronics

5th Session: Industrial perspective / **26**

Permanent (and soft) magnet materials for use in accelerators

Corresponding Author: franz-josef.boergermann@vacuumschmelze.com

Permanent magnets and soft magnetic materials with specific properties have been frequently used in various assemblies at accelerators and colliders. Among these are undulators, wigglers as well as dipoles (PM based and specific electromagnets), PM-quadrupoles and higher multipoles. From energy consumption aspects, the PM-solutions may provide a contribution to long term energy savings combined with high long term stability. New PM-materials with enhanced properties at cryogenic temperatures may open new aspects for devices at low temperatures. Actual improvements in the properties of soft magnetic materials will contribute to more effective flux guidance elements. We will present some of the recent developments in these material classes which contribute to further enhancements of such units in future accelerator and collider projects.

5th Session: Industrial perspective / **27**

Industrial challenges of compact magnet production

Corresponding Author: norbert.collomb@stfc.ac.uk

The CLIC-UK collaboration between CERN and STFC produced two prototypes of permanent magnet based quadrupoles to cover the large tuning range (15 - 60 T/m and 4 - 43 T/m respectively) required for the CLIC Drive Beam Decelerator. The space envelope and accuracies to achieve the demanding parameter challenges have been addressed during the production of the prototypes. Assembly sequencing, accuracy analysis and an investigation into industrial capabilities in both metrology and manufacture/assembly led to a proposal in the efficient and specification meeting “mass-production”. Manufacture and assembly of the prototypes

provided the identification and foundation of techniques and methodologies essential for large scale industrial manufacture.

7th Session: Beam dynamics, alignment, magnetic measurement requirements / 28

Beam dynamics requirements for future accelerators

Corresponding Author: ioannis.papaphilippou@cern.ch

7th Session: Beam dynamics, alignment, magnetic measurement requirements / 29

Magnet alignment challenges for future accelerators

Corresponding Author: helene.mainaud.durand@cern.ch

7th Session: Beam dynamics, alignment, magnetic measurement requirements / 30

Magnetic measurements challenges for very compact magnets

Corresponding Author: marco.buzio@cern.ch

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3rd Session: The saving prospects in European Labs, projects and machine upgrades - Part 1 / 34

Energy efficient beam transport by means of high current pulsed magnets

Corresponding Author: c.tenholt@gsi.de

In order to raise the focusing gradient in case of bunched beam lines, an alternative, iron free, pulsed quadrupole was designed. The transfer channels between synchrotrons as well as the final focusing for the production of secondary beams are possible applications. The construction of this quadrupole is about to be finished and thus it is almost ready to be tested. The quadrupole is running in a pulsed mode, which means an immense saving of energy by avoiding standby operation. Still the high gradients demand high currents. Hence a circuit had to be developed which is able to reclaim a significant amount of the pulsing energy for following shots. The basic design of the pulsed quadrupole is introduced also considering its differences according to common technologies. Furthermore the energy efficient circuit is explicated and the limits of adaptability are considered.

4th Session: Efficient and compact magnet design examples - Part 1 / **35**

The experience at FERMILAB: recycler ring and beam lines based on PM technology

Corresponding Author: kash@fnal.gov

Various permanent magnets were built and successfully operated at FERMILAB Accelerator Complex. The Recycler Ring and 8 Gev beam transfer line includes nearby 500 permanent magnet gradient dipoles and quadrupoles based on strontium ferrite bricks. For NLC were built and tested 6 adjustable permanent magnet quadrupoles with gradients up to 100 T/m, and wide range of integrated gradient changes. The NOVA beamline and the Main Injector ionization profile monitor permanent magnets were recently commissioned. They based on SmCo5 permanent magnets. In the presentation briefly discussed the FERMILAB experience in the area of permanent magnets design, fabrication, and operation.

5th Session: Industrial perspective / **36**

Development of electrical steel for highest efficiency applications

Corresponding Author: tim.keppert@voestalpine.com

Voestalpine is a producer of highest quality electrical steel. In recent years voestalpine proofed to be a reliable partner regarding the supply of electrical steel for the construction of magnets. From the point of the electrical steel producer the requirements of the magnet construction industry are very demanding. This contribution tries to show the difficulties that arise by the example of the MedAustron project. With the startup of the new continuous annealing line 2 voestalpine is now able to supply electrical steel for applications that require the highest efficiency available on the market. In this presentation an overview of the technical capabilities of the production of electrical steel is given. Possibilities to produce electrical steel with tailored properties concerning the coercitivity and the permeability are discussed. At the same time the physical limitations of electrical steel are discussed. Also the newest developments regarding electrical steel for higher frequency applications are discussed.

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Energy efficient magents for FCC Injector Complex

Corresponding Author: attilio.milanese@cern.ch

6th Session: Short communication from participants / 39

Discussion

7th Session: Beam dynamics, alignment, magnetic measurement requirements / 40

Nano-positioning possibilities for future accelerator magnets

Corresponding Author: kurt.artoos@cern.ch

A subject common to several future high-energy physics R&D programs is the generation of beams with very small emittance and beam size and concomitantly the alignment and stabilization of accelerator components with ultimate precision. To reach e.g. the design luminosity at the CLIC interaction point, the beam size at the interaction point (IP) shall be only one nanometre in vertical direction and 45 nanometre in horizontal direction. About 4000 Main Beam Quadrupoles (MBQ) are needed to conserve such a small beam along the accelerator and final focus (FF) magnets will focus the two beams to collide at the IP. In addition to a very stringent alignment, the quadrupole positions should be stable to sub nanometre level and this for frequencies as low as 1 Hz. An active mechanical stabilization and positioning system based on very stiff piezo electric actuators and inertial reference masses is under study for the Main Beam Quadrupoles (MBQ). The stiff support was selected for robustness against direct forces and for the option of incrementally repositioning the magnet with sub nanometre resolution. The technical feasibility and the required stability level was demonstrated on several test benches, including a type 1 MBQ prototype (100 kg) with nominal magnetic field and nominal water flow. Technical issues were however identified and the development of the actuating support, sensors, and controller is still ongoing to increase the performance, integrate the system in the overall controller, adapt to the accelerator environment, and reduce costs. This presentation will show the type of components that can be used for actuating accelerator magnets with sub nanometer resolution and the technical parameters to be dealt with. Some R&D possibilities will also be indicated.

8th Session: Summary and final discussions / 41

Summary of sessions 3&4

Corresponding Author: daniel.schoerling@cern.ch

8th Session: Summary and final discussions / **42**

Summary of sessions 5&6

Corresponding Author: jim.clarke@stfc.ac.uk

8th Session: Summary and final discussions / **43**

General discussions

8th Session: Summary and final discussions / **44**

Summary of sessions 1&2

Corresponding Author: akira.yamamoto@cern.ch

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ZEPTO: Tunable Permanent Magnet Dipoles and Quadrupoles

Author: Ben Shepherd[1]

Co-authors: Carlo Petrone [2]; Jim Clarke [1]; Michael Struik [2]; Michele Modena [2]; Neil Marks [1]; Norbert Collomb [3]

[1] *STFC*

[2] *CERN*

[3] *STFC Daresbury Laboratory*

Corresponding Author: ben.shepherd@stfc.ac.uk

Within the framework of the CLIC-UK collaboration between CERN and STFC, two types of permanent magnet based quadrupoles have been developed and built. These magnets have a very large tuning range (15-60 T/m and 4-43 T/m respectively). The parameters were specified for the challenging requirements of the CLIC Drive Beam Decelerator. Two prototypes have been built and successfully tested, demonstrating the tuning range, stability and field quality of these magnets. A study is also under way to develop a PM-based dipole with a tuning range of 0.8-1.6T, in line with requirements for the CLIC Drive Beam Turnaround Loop.

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Development of a hybrid permanent magnet quadrupole

Author: patrick ngotta[1]

Co-authors: gael le bec [1]; joel chavanne [1]

[1] *esrf*

Corresponding Author: patrick.ngotta@esrf.fr

The ESRF Insertion Devices laboratory is developing high gradient permanent magnet (PM) quadrupoles for potential use in a storage ring. This paper presents the development of a hybrid quadrupole with strong gradient (100T/m). The performance of a few PM and resistive structures are compared. One hybrid structure, composed of iron parts and rectangular PM blocks, appears to offer a good compromise between performance and technological complexity. This structure has an aperture in the horizontal plane for the X-ray beam port. It introduces field quality deterioration because of the structure asymmetry. Field quality repair work can be achieved in particular on the pole shape by optimization. Furthermore, the arrangement of the quadrupole elements allows a number of simple methods to correct the errors during the assembly.

Summary:

ESRF-II high gradient quadrupole is specified at 90 T/m which is close to the limit of conventional resistive technology. This paper introduces the development of a high gradient PM hybrid quadrupole

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Magnet designs for the ESRF-SR2

Author: Gael Le Bec[1]

Co-author: Joel Chavanne [1]

[1] *ESRF*

Corresponding Author: lebec@esrf.fr

Magnets for the ESRF storage ring upgrade (SR2) are being developed. The power consumption of the new ring should be lower than the present ESRF consumption, with much more magnets installed. On top of that, the new lattice must preserve the existing source points in the ID straight sections: longitudinal compactness is a strong constraint. Permanent magnet (PM) and electromagnet (EM) devices are being developed for this purpose. It is foreseen to install PM dipoles with longitudinal gradient. The other magnets will be normal conducting, with optimized power consumption and length. These technological choices have been driven by the magnet tuning ranges, the ESRF experience and the limited development time. For EM magnets, low power consumption goes against compactness. A compromise can be reach with longitudinally compact magnets with increased transverse dimensions. A brief review of the ESRF-SR2 magnet designs and an estimation of the energy saving (as compared to standard J=5 A/mm2 designs) will be presented.

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A capital-cost and energy reducing configuration for dipoles in multi-stacked race-track bends.

Author: Neil Marks[1]

[1] *STFC, Daresbury Laboratory; U. of Liverpool.*

Some existing facilities (1) and the recent proposal for the LHeC collider (2,3), have utilised a race-track configuration, with 180 degree bends, to circulate beam for a small number of turns (typically 3 revolutions) through superconducting energy-recovery linacs. Particles of differing energies are defected in these bends and this is accomplished by positioning the beams at different vertical positions, with different strength dipole magnets stacked vertically at the appropriate height for each beam. Conventionally, these dipoles are separately, individually, powered. However, the paper will

present a revised geometry that allows coils to be shared between two adjacent vertically stacked dipoles, so contributing to the required Ampere-turns in both magnets. The resulting configuration reduces the total coil volume and hence the energy losses of the complete assembly. As an example, such a modified structure for the LHeC, configured according to the linac-ring option, would reduce the dipole coil volume and power loss by circa one third.

(1) CEBAF: see https://www.jlab.org/12-gev-upgrade

(2) A. Bogacz, Thomas Jefferson National Accelerator Facility, CERN-ECFA-NuPECC Workshop, June 2012.

(3) LHec; A Large Hadron Electron Collider at CERN; sections 8.1.2, Fig 8.5; and 9.2.1 p335.

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Compact Superconducting Magnets for Linear Accelerators

Author: Vladimir Kashikhin[1]

Co-authors: Akira Yamamoto [2]; Michael Tartaglia [1]; Nikolai Andreev [1]; Nobuhiro Kimura [3]; Yuriy Orlov [1]

[1] *Fermilab*

[2] *High Energy Accelerator Research Organization (JP)*

[3] *KEK*

Corresponding Author: kash@fnal.gov

New Linear Accelerators based on SCRF cavities need compact and efficient superconducting magnet packages to focus and steer electron or proton beams. These magnets should be combined with SCRF cryomodules and installed inside or between them. A recent activity in this area was directed by FNAL-KEK collaboration to splittable conduction cooled magnets. Several magnet prototypes were built and successfully tested. These magnets were designed for high energy beams used in ILC, and Project-X. Nevertheless, there is an interest to explore splittable conduction cooled magnets for new accelerators: FNAL ASTA and PIP-II, KEK STF, SLAC LCLS II. Presented results of various magnets design, fabrication, and tests. Most magnet packages combine the quadrupole magnet and two dipole correctors. The presented magnetic measurement results confirm the specified magnet package parameters.

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- Splittable configuration allows to install the magnet out of a very clean room;
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- Iron dominated magnetic design is less sensitive to the coil geometry and position.
- Coils placed far away from the magnet aperture reduce influence of superconductor magnetization effects.
- The simple magnet configuration is very efficient for serial magnet fabrication.

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Industrial challenges of compact magnet production

Author: Norbert Collomb[1]

Co-authors: Ben Shepherd [2]; Jim Clarke [2]; Neil Marks [2]

[1] *STFC Daresbury Laboratory*

[2] *STFC*

Corresponding Author: norbert.collomb@stfc.ac.uk

The CLIC-UK collaboration between CERN and STFC produced two prototypes of permanent magnet based quadrupoles to cover the large tuning range (15 - 60 T/m and 4 - 43 T/m respectively) required for the CLIC Drive Beam Decelerator. The space envelope and accuracies to achieve the demanding parameter challenges have been addressed during the production of the prototypes. Assembly sequencing, accuracy analysis and an investigation into industrial capabilities in both metrology and manufacture/assembly led to a proposal in the efficient and specification meeting "mass-production" . Manufacture and assembly of the prototypes provided the identification and foundation of techniques and methodologies essential for large scale industrial manufacture.

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The Loss Budget of the SIS100 Fast Ramped Superferric Magnets

Author: Egbert Fischer[1]

Co-authors: Alexander Bleile [1]; Anna Mierau [2]; Pierre Schnizer [3]

[1] *GSI*

[2] *GSI Helmholtzzentrum für Schwerionenforschunb mbH*

[3] *GSI Helmholtzzentrum für Schwerionenforschung mbH*

Corresponding Author: e.fischer@gsi.de

The superconducting magnets of the SIS100 heavy ion accelerator are to be built based on a compact window-frame design. Beside the optimisation of the magnetic field characteristics the minimisation of the AC losses was a central part during the R&D phase. Now the first dipole was built and tested. We presend the obtained loss results for typical operation modes and compare them with previous estimations and extrapolate these to the expected power consumption required for thequadrupole and corrector magnet. This will allow estimating the expected total energy consumption.

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Integrated magnet block design and production for MAX IV

Author: Martin Johansson[1]

[1] *MAX IV Laboratory*

Corresponding Author: martin.johansson@maxlab.lu.se

The magnet design of the MAX IV 3 GeV storage ring replaces the conventional support girder + discrete magnets scheme of previous 3rd gen. light sources with a compact integrated design having several consecutive magnet elements precision-machined out of a common solid iron block. This presentation consists of a brief description of the design, and mechanical + magnetic field measurement results from the magnet production series.

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Permanent (and soft) magnet materials for use in accelerators

Author: Franz-Josef Börgermann[1]

[1] *Vacuumschmelze GmbH & Co KG*

Corresponding Author: franz-josef.boergermann@vacuumschmelze.com

F.-J. Boergermann, C. Brombacher, K. Uestuener, F. Fohr, Vacuumschmelze GmbH & Co KG, Hanau, Germany

"Permanent magnets and soft magnetic materials with specific properties have been frequently used in various assemblies at accelerators and colliders.
Among these are undulators, wigglers as well as dipoles (PM based and specific electromagnets), PM-quadrupoles and higher multipoles.
From energy consumption aspects, the PM-solutions may provide a contribution to long term energy savings combined with high long term stability.
New PM-materials with enhanced properties at cryogenic temperatures may open new aspects for devices at low temperatures.
Actual improvements in the properties of soft magnetic materials will contribute to more effective flux guidance elements.
We will present some of the recent developments in these material classes which contribute to further enhancements of such units in future accelerator and collider projects."

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Saving opportunities in accelerator magnets

Author: Davide Tommasini[1]

[1] *CERN*

An accelerator magnet is usually excited either by water cooled copper coils powered with an effective current density in the range of 3-6 A/mm2 or by using superconducting coils, depending on the required field amplitude. Exceptions are often due to technical reasons (special constraints, easier construction, more reliability). Up to now, only in rare cases (in particular in experimental magnets) the energy consumption is an important design factor. The situation is however rapidly evolving and many research institutes are either revising the existing installations or planning the new ones with special attention towards energy consumption.
This talk will review several "saving opportunities"presently considered in this domain.

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Power converters design optimization - need for an integrated approach with the magnet designer

Author: Davide Aguglia[1]

[1] *CERN*

This talks presents the basics of the design of a power converter for DC and pulsed magnet. Particularly the impact of the magnet design (inductance, voltage and current adaptation given by the number of turns, etc.) on the converter design is illustrated. Compromises between efficiency, cost

and technologies are presented. Finally, the need and benefits of an integrated approach which considers the magnet design variables is demonstrated via a simplified example.

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Magnet Energy Recovery; a way towards more compact and efficient systems

Author: Konstantinos Papastergiou[1]

[1] *CERN*

Magnet energy recovery on a cycle-by-cycle basis shows potential for great energy savings and improvement of the grid power quality. Reducing the magnet duty cycle allows more compact mechanical layout and greater efficiency. To achieve such a benefit a system integration study is essential before starting the parallel development of magnets and power conversion/energy recovery systems.

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Energy management at GSI and FAIR, strategy on energy management,

Author: Jan Lindenberg[1]

[1] *G*

GSI Helmholtzzentrum für Schwerionenforschung GmbH operates a unique large-scale accelerator for heavy ions. In the coming years the new international accelerator facility FAIR, one of the largest research projects worldwide, will be built at GSI. In the final extension FAIR consists of several heavy ion accelerator rings, experiment storage rings with up to 1,100 meters in circumference, two linear accelerators and about 3.5 kilometers high energy beam transfer lines as well as several experiment caves.
In the context of rising energy prices and the responsible use of resources, GSI has taken the task to develop concepts for efficient use of energy. Actual work includes the introduction of a broad collection and analysis of energy consumption data and the development of the high efficient data center "Green IT Cube"and technologies such as load based cooling of accelerator components.
The final intention of this work is to provide a modern and efficient research facility at reasonable energy costs and sustainable use of energy.

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The GSI experience: Energy efficient beam transport by means of high current pulsed magnets

Author: Carmen Tenholt[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

In order to raise the focusing gradient in case of bunched beam lines, an alternative, iron free, pulsed quadrupole was designed. The transfer channels between synchrotrons as well as the final focusing

for the production of secondary beams are possible applications. The construction of this quadrupole is about to be finished and thus it is almost ready to be tested. The quadrupole is running in a pulsed mode, which means an immense saving of energy by avoiding standby operation. Still the high gradients demand high currents. Hence a circuit had to be developed which is able to reclaim a significant amount of the pulsing energy for following shots. The basic design of the pulsed quadrupole is introduced also considering its differences according to common technologies. Furthermore the energy efficient circuit is explicated and the limits of adaptability are considered.

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CERN plans towards energy efficiency

Author: Serge Claudet[1]

[1] *CERN*

High energy accelerators are usually great energy consumers and could not escape from being concerned by energy efficiency aspects. After recalling the context, major actions towards energy efficiency will be presented, with plans for the future.

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In-vacuum magnet design and challenges

Author: Jim Clarke[1]

[1] *STFC*

Synchrotron light sources can extend their wavelength reach significantly by putting the undulator arrays into the beam vacuum system. The advantages are such than many light sources now utilise in-vacuum undulators when required. However, there are a number of extra physics and engineering challenges which have to be dealt with when putting magnets in-vacuum. In this talk I will explain the motivation, the additional challenges, and the realisation of in-vacuum undulators.

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Electro-magnetic and hybrid design experience for CLIC magnet R&D

Author: Michele Modena[1]

[1] *CERN*

Corresponding Author: michele.modena@cern.ch

Since 2009 CERN started R&D activities in order to identified and investigate the most challenging cases among the magnets needed for CLIC the Compact Linear Collider one of the possible Future Linear Colliders. In some specific cases the work is mainly done by our colleagues of STFC-Daresbury Lab (UK) part of the CLIC International Collaboration.
In the last four years several theoretical studies, models and prototypes were realized mainly focusing two sub-system of the CLIC complex: the “2-beam Modules”, the modular elements that are composing the backbone of the two linacs of CLIC, and the Machine Detector Interface (MDI) that include the final focus elements as QD0 and SD0 and the antisolenoid.

In this talk we revise the status of the studied and procured magnets. Among them the Drive Beam Quadrupoles, the Main Beam Quadrupoles, the main beam Steering Correctors all challenging for the required compactness, performances and production size, and the final quadrupole QD0 and the sextupole SD0, challenging for the high performances required in terms of gradients and stability.

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Nano-positioning possibilities for future accelerator magnets

Author: Kurt Artoos[1]

Co-author: Stef Janssens [1]

[1] *CERN*

Corresponding Author: kurt.artoos@cern.ch

A subject common to several future high-energy physics R&D programs is the generation of beams with very small emittance and beam size and concomitantly the alignment and stabilization of accelerator components with ultimate precision. To reach e.g. the design luminosity at the CLIC interaction point, the beam size at the interaction point (IP) shall be only one nanometre in vertical direction and 45 nanometre in horizontal direction. About 4000 Main Beam Quadrupoles (MBQ) are needed to conserve such a small beam along the accelerator and final focus (FF) magnets will focus the two beams to collide at the IP. In addition to a very stringent alignment, the quadrupole positions should be stable to sub nanometre level and this for frequencies as low as 1 Hz. An active mechanical stabilization and positioning system based on very stiff piezo electric actuators and inertial reference masses is under study for the Main Beam Quadrupoles (MBQ). The stiff support was selected for robustness against direct forces and for the option of incrementally repositioning the magnet with sub nanometre resolution. The technical feasibility and the required stability level was demonstrated on several test benches, including a type 1 MBQ prototype (100 kg) with nominal magnetic field and nominal water flow. Technical issues were however identified and the development of the actuating support, sensors, and controller is still ongoing to increase the performance, integrate the system in the overall controller, adapt to the accelerator environment, and reduce costs.
This presentation will show the type of components that can be used for actuating accelerator magnets with sub nanometer resolution and the technical parameters to be dealt with. Some R&D possibilities will also be indicated.

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The experience at FERMILAB: recycler ring and beam lines based on PM technology

Author: VLADIMIR KASHIKHIN[1]

Co-authors: Bruce Brown [1]; David Harding [1]; George Velev [1]; Ioanis Kourbanis [1]; Oliver Kiemschies [1]

[1] *Fermilab*

Corresponding Author: kash@fnal.gov

Various permanent magnets were built and successfully operated at FERMILAB Accelerator Complex. The Recycler Ring and 8 Gev beam transfer line includes nearby 500 permanent magnet gradient dipoles and quadrupoles based on strontium ferrite bricks. For NLC were built and tested 6 adjustable permanent magnet quadrupoles with gradients up to 100 T/m, and wide range of integrated gradient changes. The NOVA beamline and the Main Injector ionization profile monitor permanent magnets were recently commissioned. They based on SmCo5 permanent magnets. In the presentation briefly discussed the FERMILAB experience in the area of permanent magnets design, fabrication, and operation.

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Compact and Low Consumption Magnet Design- The DESY Experience

Author: Bernward Krause[1]

[1] *DESY*

Corresponding Author: bernward.krause@desy.de

During the last ten years a variety of electromagnets has been ordered to upgrade the PETRA accelerator into a synchrotron light source, to build up a new branch at the FLASH accelerator facility and to install the new European XFEL.

The talk will give an overview of the ingredients which are necessary for developing and manufacturing magnets. Two septum designs will be presented to discuss how electricity costs can be reduced without losing machine performance. Furthermore design studies of combined function magnets and a permanent magnet design that could replace a quadrupole electromagnet to save energy costs will be shown.

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Development of electrical steel for highest efficiency applications

Author: Timothy Keppert[1]

[1] *Voestalpine Stahl GmbH*

Corresponding Author: tim.keppert@voestalpine.com

Voestalpine is a producer of highest quality electrical steel. In recent years voestalpine proofed to be a reliable partner regarding the supply of electrical steel for the construction of magnets. From the point of the electrical steel producer the requirements of the magnet construction industry are very demanding. This contribution tries to show the difficulties that arise by the example of the MedAustron project. With the startup of the new continuous annealing line 2 voestalpine is now able to supply electrical steel for applications that require the highest efficiency available on the market. In this presentation an overview of the technical capabilities of the production of electrical steel is given. Possibilities to produce electrical steel with tailored properties concerning the coercitivity and the permeability are discussed. At the same time the physical limitations of electrical steel are discussed. Also the newest developments regarding electrical steel for higher frequency applications are discussed.

6th Session: Short communication from participants / 66

A capital-cost and energy reducing configuration for dipoles in multi-stack race-track bends

Corresponding Author: neil.marks@stfc.ac.uk

Some existing facilities (1) and the recent proposal for the LHeC collider (2,3), have utilised a racetrack configuration, with 180 degree bends, to circulate beam for a small number of turns (typically 3 revolutions) through superconducting energy-recovery linacs. Particles of differing energies are defected in these bends and this is accomplished by positioning the beams at different vertical positions, with different strength dipole magnets stacked vertically at the

appropriate height for each beam. Conventionally, these dipoles are separately, individually, powered. However, the paper will present a revised geometry that allows coils to be shared between two adjacent vertically stacked dipoles, so contributing to the required Ampere-turns in both magnets. The resulting configuration reduces the total coil volume and hence the energy losses of the complete assembly. As an example, such a modified structure for the LHeC, configured according to the linac-ring option, would reduce the dipole coil volume and power loss by circa one third.

Summary:

(1) CEBAF: see https://www.jlab.org/12-gev-upgrade
(2) A. Bogacz, Thomas Jefferson National Accelerator Facility, CERN-ECFA-NuPECC Workshop, June 2012.
(3) LHec; A Large Hadron Electron Collider at CERN; sections 8.1.2, Fig 8.5; and 9.2.1 p335.

6th Session: Short communication from participants / **67**

Development of a hybrid permanent magnets quadrupole

Corresponding Author: patrick.ngotta@esrf.fr

The ESRF Insertion Devices laboratory is developing high gradient permanent magnet (PM) quadrupoles for potential use in a storage ring. This paper presents the development of a hybrid quadrupole with strong gradient (100T/m). The performance of a few PM and resistive structures are compared. One hybrid structure, composed of iron parts and rectangular PM blocks, appears to offer a good compromise between performance and technological complexity. This structure has an aperture in the horizontal plane for the X-ray beam port. It introduces field quality deterioration because of the structure asymmetry. Field quality repair work can be achieved in particular on the pole shape by optimization. Furthermore, the arrangement of the quadrupole elements allows a number of simple methods to correct the errors during the assembly.

Summary:

ESRF-II high gradient quadrupole is specified at 90 T/m which is close to the limit of conventional resistive technology. This paper introduces the development of a high gradient PM hybrid quadrupole

6th Session: Short communication from participants / **68**

The loss budget of the SIS100 fast ramped superferric magnets

Corresponding Author: a.mierau@gsi.de

The superconducting magnets of the SIS100 heavy ion accelerator are to be built based on a compact window-frame design. Beside the optimisation of the magnetic field characteristics the minimisation of the AC losses was a central part during the R&D phase. Now the first dipole was built and tested. We presend the obtained loss results for typical operation modes and compare them with previous estimations and extrapolate these to the expected power

consumption required for the quadrupole and corrector magnet. This will allow estimating the expected total energy consumption.

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The PSI Experience: A Theory Of Evolution

Author: Alexander Gabard[1]

[1] *Paul Scherrer Institute*

Corresponding Author: alexander.gabard@psi.ch

From the beginning, operating costs have been a factor in the design of accelerators and beamlines at PSI. However, limited funds and increasing power costs have made this aspect even more important nowadays. Through the history of PSI, we will present the initial prerogatives for magnet design at our institute and their evolution over time, resulting in the current compact design of the magnets for the SwissFEL project and the first design concepts for the SLS 2.0 upgrade.

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Why are particle accelerators so inefficient?

Author: Philippe Lebrun[1]

[1] *CERN*

High-energy accelerators/colliders have developed into large machines consuming high electrical power up to the 100 MW range, thus making the energy bill a major component of their operating costs and eventually of their acceptability by society. With several new projects under study beyond the Large Hadron Collider (LHC), and projections of rising electricity prices by energy agencies, this trend is expected to grow into a critical issue for future machines. While a minimum power duty can be estimated from the beam parameters of both circular and linear accelerators/colliders, they all share low grid-to-beam efficiency entailing much higher power requirements from the electrical networks. We analyse the sources of energy dissipation, from the closest to the farthest from the beams, and discuss the power efficiency of some existing machines and future projects. This methodology also enables to identify possible paths for improvement.