CAS course on ”Normal- and Superconducting Magnets”, 19 November - 02 December 2023, St. Pölten, Austria

Report of Contributions

https://indico.cern.ch/e/1227234

Contribution ID: **1** Type: **not specified**

Arrival day and registration

Sunday 19 November 2023 15:00 (6 hours)

Contribution ID: **2** Type: **not specified**

Opening

Monday 20 November 2023 08:30 (1 hour)

Presenter: TECKER, Frank (CERN)

Contribution ID: **3** Type: **not specified**

Overview Design of accelerator magnets

Monday 20 November 2023 09:30 (1 hour)

The design, construction, and operation of accelerator magnets, particularly those employing superconductor technology, pose
challenges in all domains of physics and engineering. These challenges include: Material science aspects, such as the development of superconducting wires and cables, the specification of austenitic and magnetic steel, and the choice of radiation-resistant insulation. Mechanical engineering challenges, such as finding the appropriate force-restraining structure for the coils, the right level of prestress in the coil/collar assembly, the design of manufacturing tooling, coldmass integration, and welding techniques, cryostat integration, and magnet installation and interconnection, all made more difficult by the very tight tolerances required by the optics of the particle beam. The physics of superfluid helium and cryogenic engineering for helium distribution lines, refrigeration, and process control. Vacuum technology for insulation and the beam vacuum. The beam vacuum system must provide an adequate beam lifetime in a cryogenic
system, where heat flow to the 1.9˜K helium circuit must be minimized. The science and technology of magnetic measurements of the field homogeneity and magnetic axis. Metrology for magnet alignment in the tunnel. Electrical engineering challenges for power supplies (high current, low voltage), water-cooled cables, current leads using high Tc superconductors, superconducting busbars, diodes operating at cryogenic temperatures, magnet protection and energy extraction systems, and powering interlocks.

In particular, the quench simulation requires bringing together simulations, tests, and measurements to check the validate the empirical parameters used in the simulations. This, in turn, requires modern frameworks for model-based systems engineering (MBSE).

Presenter: RUSSENSCHUCK, Stephan (CERN)

Contribution ID: **4** Type: **not specified**

Field description for magnets I

Monday 20 November 2023 11:00 (1 hour)

Instead of asking what are vector fields, or what is the difference between the magnetic field intensity H
and the magnetic flux density B, it is more meaningful to ask what they do or describe: Vector fields are mappings that assign to each point of the domain, one and only one bound vector from the domain's tangent space. Electric fields, represented by the gradient of a scalar field, require a three-dimensional affine (point) space and a scalar product of its associated linear (vector) space. Magnetic fields need an orientation for all operations involving cross-products.
The constitutive (material) equations also require a metric, which can be seen from their physical units, for example, Vs/Am for the permeability.
it is clear that a rich mathematical structure is required, and violation of this structure may lead to confusion and pitfalls in analytical and numerical
field computations, such as force and energy calculations, Faraday paradoxes etc.

Presenter: RUSSENSCHUCK, Stephan (CERN)

Contribution ID: **5** Type: **not specified**

Field description for magnets II

Monday 20 November 2023 12:00 (1 hour)

Instead of asking what are vector fields, or what is the difference between the magnetic field intensity H
and the magnetic flux density B, it is more meaningful to ask what they do or describe: Vector fields are mappings that assign to each point of the domain, one and only one bound vector from the domain's tangent space. Electric fields, represented by the gradient of a scalar field, require a three-dimensional affine (point) space and a scalar product of its associated linear (vector) space. Magnetic fields need an orientation for all operations involving cross-products.
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field computations, such as force and energy calculations, Faraday paradoxes etc.

Presenter: RUSSENSCHUCK, Stephan (CERN)

Contribution ID: **6** Type: **not specified**

Beam dynamics + resulting magnet specifications I

Monday 20 November 2023 14:30 (1 hour)

The main purpose of the lecture is to explain the real use of all main magnet types in different accelerators. For this a one hor primer on linear beam optics is included. Folloing the theoretical model application examples of dipole, quadrupoles, sextupoles, solenoids and other magnets are given.

Presenter: SCHMICKLER, Hermann

Contribution ID: **7** Type: **not specified**

Beam dynamics + resulting magnet specifications II

Monday 20 November 2023 15:30 (1 hour)

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Presenter: SCHMICKLER, Hermann

Contribution ID: **8** Type: **not specified**

One slide - one minute

Monday 20 November 2023 17:00 (1 hour)

Contribution ID: **9** Type: **not specified**

Welcome Drink

Monday 20 November 2023 18:00 (1h 30m)

Contribution ID: **10** Type: **not specified**

Field description for magnets III

Tuesday 21 November 2023 08:30 (1 hour)

Instead of asking what are vector fields, or what is the difference between the magnetic field intensity H
and the magnetic flux density B, it is more meaningful to ask what they do or describe: Vector fields are mappings that assign to each point of the domain, one and only one bound vector from the domain's tangent space. Electric fields, represented by the gradient of a scalar field, require a three-dimensional affine (point) space and a scalar product of its associated linear (vector) space. Magnetic fields need an orientation for all operations involving cross-products.
The constitutive (material) equations also require a metric, which can be seen from their physical units, for example, Vs/Am for the permeability.
it is clear that a rich mathematical structure is required, and violation of this structure may lead to confusion and pitfalls in analytical and numerical
field computations, such as force and energy calculations, Faraday paradoxes etc.

Presenter: RUSSENSCHUCK, Stephan (CERN)

Contribution ID: **11** Type: **not specified**

Magnetic field simulation by finite element methods

Tuesday 21 November 2023 09:30 (1 hour)

Stephan Russenschuck, Maxwell equations in global form, oriented manifolds, Ampere's law, Faraday's law, Gauss'law, conservation of charge. Maxwell equation in local form, Vector fields, application to NC magnets, material relations, boundary and interface conditions, space curves and their applications, CCT magnets, the directional derivative, grad, curl, and div, coordinate-free definition of the differential operators, Maxwell's house. Harmonic fields in 2D, solution of the boundary value problem in magnetostatics, co-homology, Green's function, the field of line currents, ideal distribution of currents in SC magnets, Forier and Taylor series, complex notation, holomorphic extension, Helmholtz coils, the magnetic double layer, the magnetic scalar potential of a current loop, the magnetic moment, forces and energy in non-linear circuits., Technology, Topical, Magnets, Superconductivity,

Presenter: DE GERSEM, Herbert

Contribution ID: **12** Type: **not specified**

Introduction to code for practical exercises

Wednesday 22 November 2023 08:30 (1 hour)

Presenter: MILANESE, Attilio (CERN)

Contribution ID: **13** Type: **not specified**

Introduction to practical exercises

Tuesday 21 November 2023 12:00 (1 hour)

Presenters: FISCARELLI, Lucio (CERN); GARCÍA-TABARÉS, Luis; BUZIO, Marco (CERN); EISTERER, Michael; YANG, Yifeng (University of Southampton (GB))

Contribution ID: **14** Type: **not specified**

RT magnet design, fabrication, testing I

Tuesday 21 November 2023 14:30 (1 hour)

This course focuses on resistive magnets. After an introduction, with examples of the variety of normal conducting magnets installed in accelerators, the main requirements and interfaces are formalized and described. The design principles –both of the yoke and of the coil –are then presented, with general formulae and covering more in detail the case of dipoles and quadrupoles. The last part is dedicated to fabrication and acceptance tests, where real life examples are provided.

Presenter: MILANESE, Attilio (CERN)

Contribution ID: **15** Type: **not specified**

Superconductivity

Tuesday 21 November 2023 15:30 (1 hour)

The lecture presents the basic phenomenology of superconductivity. It starts with the defining properties: zero resistivity and perfect flux expulsion (Meissner effect). The latter evidences a thermodynamic phase not only perfect conductivity. Without any knowledge of the underlying mechanism, one can derive the condensation energy of the superconducting state, flux penetration at the surface and the respective magnetic penetration depth. By assuming a condensate of charged particles having a unique wave function one can further derive fluxoid quantization and the value of the respective flux quantum. This motivates the breakdown of the Meissner state at high fields in type-II superconductors as well as the occurrence of vortices. The Ginzburg-Landau theory, which describes the resulting mixed state quantitatively, is introduced. Finally, limitations for the loss free currents in superconductors are discussed together with the required vortex pinning mechanism.

Presenter: EISTERER, Michael

Contribution ID: **16** Type: **not specified**

RT magnet design, fabrication, testing II

Tuesday 21 November 2023 17:00 (1 hour)

This course focuses on resistive magnets. After an introduction, with examples of the variety of normal conducting magnets installed in accelerators, the main requirements and interfaces are formalized and described. The design principles –both of the yoke and of the coil –are then presented, with general formulae and covering more in detail the case of dipoles and quadrupoles. The last part is dedicated to fabrication and acceptance tests, where real life examples are provided.

Presenter: MILANESE, Attilio (CERN)

Contribution ID: **17** Type: **not specified**

Modelling and simulating accelerator magnets

Tuesday 21 November 2023 11:00 (1 hour)

In this lecture, we show how to set up a finite element model of an accelerator magnet. We discuss the challenges in simulating accelerator magnets and come up with a list of requirements for commercial or freeware simulation tools. The challenges include detailed geometries, nonlinear and hysterestic materials, superconductivity, composite materials, complicated eddy-current effects, multi-physics and multi-scale phenomena, uncertainties and large-scale computing.

Presenter: DE GERSEM, Herbert

Contribution ID: **18** Type: **not specified**

RT magnet design, fabrication, testing III

Wednesday 22 November 2023 09:30 (1 hour)

This course focuses on resistive magnets. After an introduction, with examples of the variety of normal conducting magnets installed in accelerators, the main requirements and interfaces are formalized and described. The design principles –both of the yoke and of the coil –are then presented, with general formulae and covering more in detail the case of dipoles and quadrupoles. The last part is dedicated to fabrication and acceptance tests, where real life examples are provided.

Presenter: MILANESE, Attilio (CERN)

Contribution ID: **19** Type: **not specified**

SC magnet design - EM part I

Wednesday 22 November 2023 11:00 (1 hour)

After a brief recap of the derivation of field harmonics, this lecture delineates the process of creating multipoles with current lines, focusing particularly on dipoles and quadrupoles. The presentation covers the derivation of ideal dipolar and quadrupolar fields, as well as more realistic cases such as sector coils and canted cos-theta configurations.

Presenter: FARINON, Stefania (INFN e Universita Genova (IT))

Contribution ID: **20** Type: **not specified**

SC magnet design - mechanical I

Wednesday 22 November 2023 12:00 (1 hour)

Superconducting magnets create very high magnetic fields thanks to their intrinsically large current densities. As a consequence, large electromagnetic forces are created. Obviously, support structures are needed to hold these forces without degradation. Futhermore, as a specific feature of superconductors, proper support of the coils is necessary to avoid premature quenches. This lecture starts with a review of the basic concepts for mechanics applied on superconducting magnets, to review later the recommended support structures depending on the field level and type of magnets.

Presenter: TORAL, Fernando (CIEMAT - Centro de Investigaciones Energéticas Medioambientales y Tec. (ES))

Contribution ID: **21** Type: **not specified**

Hands-on - Block 1 - Superconducting magnet design (SCD)

Wednesday 22 November 2023 14:30 (2 hours)

Presenters: Dr TODESCO, Ezio (CERN); TORAL, Fernando (CIEMAT - Centro de Investigaciones Energéticas Medioambientales y Tec. (ES)); IZQUIERDO BERMUDEZ, Susana (CERN)

Contribution ID: **22** Type: **not specified**

Hands-on - Block 1 - Superconducting magnet design (SCD)

Wednesday 22 November 2023 17:00 (1 hour)

Presenters: Dr TODESCO, Ezio (CERN); TORAL, Fernando (CIEMAT - Centro de Investigaciones Energéticas Medioambientales y Tec. (ES)); IZQUIERDO BERMUDEZ, Susana (CERN)

Contribution ID: **23** Type: **not specified**

Technical superconductors (LTS)

Thursday 23 November 2023 08:30 (1 hour)

The lecture starts by introducing the basic requirements on superconducting wires and tapes for applications. The difference between the technical critical current and the original definition of the critical current in terms of the critical state is discussed. The concept of stabilized multifilamentary wires is introduced. Details and particular properties of three superconducting materials (NbTi, MgB2, Nb3Sn) used for LTS wires are given. Possibilities of optimizing flux pinning or enhancing the upper critical field are outlined. Production techniques for Nb3Sn wires with their advantages and disadvantages are presented. The influence of stress and strain on the wire performance is discussed with a particular focus on Nb3Sn.

Presenter: EISTERER, Michael

Contribution ID: **24** Type: **not specified**

SC magnet design - EM part II

Thursday 23 November 2023 09:30 (1 hour)

The lecture shows the methodology for assessing the maximum performance of dipole and quadrupole magnets. This involves introducing and explaining concepts such as critical surface, filling ratios, peak field on coils, load line, and short sample. It also delves into additional considerations regarding the influence of the iron yoke and current grading.

Presenter: FARINON, Stefania (INFN e Universita Genova (IT))

Contribution ID: **25** Type: **not specified**

Technical superconductors (HTS)

Thursday 23 November 2023 11:00 (1 hour)

After a short introduction aiming at reviewing the physical parameters of superconducting materials, families of the cuprates (REBCO, BSCCO 2212 and BSCCO 2223), MgB2 and Iron Based Superconductors are described. Emphasis is put on their structure, on their physical properties, including vortex pinning characteristics, and on the manufacturing processes that enable production of wire and/or tape. Electrical properties of these superconducting materials and geometries of cables to date conceived for transferring high currents are also presented. Finally, benefits and potential future large-scale applications of High Temperature Superconductors are discussed.

Presenter: Dr BALLARINO, Amalia (CERN)

Contribution ID: **26** Type: **not specified**

SC magnet design - mechanical II

Thursday 23 November 2023 12:00 (1 hour)

Superconducting magnets create very high magnetic fields thanks to their intrinsically large current densities. As a consequence, large electromagnetic forces are created. Obviously, support structures are needed to hold these forces without degradation. Futhermore, as a specific feature of superconductors, proper support of the coils is necessary to avoid premature quenches. This lecture starts with a review of the basic concepts for mechanics applied on superconducting magnets, to review later the recommended support structures depending on the field level and type of magnets.

Presenter: TORAL, Fernando (CIEMAT - Centro de Investigaciones Energéticas Medioambientales y Tec. (ES))

Contribution ID: **27** Type: **not specified**

Hands-on block 1

Thursday 23 November 2023 14:30 (2 hours)

Contribution ID: **28** Type: **not specified**

Hands-on block 1

Thursday 23 November 2023 17:00 (1 hour)

Contribution ID: **29** Type: **not specified**

Quench detection & magnet protection

Friday 24 November 2023 08:30 (1 hour)

When a superconducting magnet has a local irreversible transition above the critical surface (quench), protection systems must be activated to avoid overheating the conductor or creating too large voltages in the coil between the resistive part the the superconductive one. Here we will deal with protection of high field main accelerator magnets, characterised by a large current density and long lengths, not allowing energy extraction. We will describe the physics ruling the hotspot temperature, with a flarameteric dependence on the magnet design, and the scaling laws for the quench detection. Finally we will describe the two main systems that are sued to protect the magnets, namely the quench heaters and the CLIQ, recently introduced at CERN.

Presenter: Dr TODESCO, Ezio (CERN)

Contribution ID: **30** Type: **not specified**

Hands-on block 2

Friday 24 November 2023 09:30 (1 hour)

Contribution ID: **31** Type: **not specified**

Hands-on block 2

Friday 24 November 2023 11:00 (2 hours)

Contribution ID: **32** Type: **not specified**

Medaustron Visit

Friday 24 November 2023 14:30 (4h 30m)

Contribution ID: **33** Type: **not specified**

Electrical Insulation for Magnets

Saturday 25 November 2023 08:30 (1 hour)

Magnets for particle accelerators are electrical machines subjected to severe operating conditions such as extreme temperatures, radiations, high mechanical stresses, and in certain cases high voltages. A robust electrical insulation is vital to guarantee a high reliability and availability of the accelerator machines. This lecture aims to provide an overview of the most common electrical insulation systems for magnets, the testing techniques and the basics that drives the design choices. In addition, it is discussed the breakdown mechanisms that characterize the main dielectric media: gas (and vacuum), liquids and solid dielectrics.

Presenter: PICCIN, Roland (CERN)

Contribution ID: **34** Type: **not specified**

Magnetic measurement systems overview

Saturday 25 November 2023 09:30 (1 hour)

This lecture provides a broad overview of the topic of measurement of the field generated by accelerator magnets. First, the need of magnet testing is put in context by comparing it with numerical modelling and beam-based measurements. Then the most commonly used measurement principles are reviewed including induction, Lorentz force and magnetic resonance-based instruments. A few metrological aspects are highlighted, such as the role of calibration references and the possible impact of recent SI system updates. Finally, some examples are given on the topic of magnetic sensor fiducialization, i.e. calibration of its geometrical position.

Presenter: BUZIO, Marco (CERN)

Contribution ID: **35** Type: **not specified**

Rotating coils, flux metric method, wire systems

Saturday 25 November 2023 11:00 (1 hour)

The measurement of the magnetic field is often the final verification of the design and fabrication process of a magnets for particle accelerators.
In most cases, when seeking high accuracy, the measurement technique and its realization can result in a considerable effort. The lecture describes
the most used field-measurement techniques based of flux-metric methods:
i)the rotating coil method gives a complete two-dimensional description of the magnetic field in terms of normal and skew multipoles;
ii) static coils are employed in case of fast-ramped or curved magnets;
iii) the single stretched wire is the reference instrument to measure field
integrals and to find the magnetic axis.

Presenter: FISCARELLI, Lucio (CERN)

Contribution ID: **36** Type: **not specified**

Low-emittance ring magnets

Saturday 25 November 2023 12:00 (1 hour)

Low emittance rings are accelerator facilities of increasing importance nowadays. Both damping rings for linear colliders and storage rings of 4th generation light sources belong to this category. Magnets for these type of rings share demanding and specific features: high field strength, good field quality, narrow tolerance alignments. There are some particular magnets to which special attention will be given: permanent magnets, combined function magnets and longitudinally variable field dipoles. An overview of the largest ongoing low emittance rings will be done, with detailed explanation on the magnets.

Presenter: TORAL, Fernando (CIEMAT - Centro de Investigaciones Energéticas Medioambientales y Tec. (ES))

Contribution ID: **37** Type: **not specified**

Hands-on block 2

Saturday 25 November 2023 14:30 (2 hours)

Contribution ID: **38** Type: **not specified**

Hands-on block 2

Saturday 25 November 2023 17:00 (1 hour)

Contribution ID: **39** Type: **not specified**

Poster Session

Thursday 23 November 2023 18:00 (1h 30m)

Contribution ID: **40** Type: **not specified**

Mapping techniques (Hall Probes)

Monday 27 November 2023 08:30 (1 hour)

Field maps, i.e. cartographic descriptions of the magnetic field, are used to assess the field quality in accelerator magnets, for various applications. Due to their capability to measure static magnetic fields, and their comparatively small active areas of less than 1 mm2, mapping techniques are based on Hall probes as magnetic field sensors.
This lecture begins with an introduction to the Hall effect and semiconductor-based Hall sensor technology. It then discusses the physical effects that limit the performance of Hall sensor measurements in single- and three-component measurements and explains remedies. Further details on calibration procedures for Hall sensor measurements at room and cryogenic temperature are discussed in the third section. Additional challenges for Hall probe mapper systems are discussed. The last section of this talk deals with a post processing technique that drastically shortens the measurement time, increases the measurement precision, and avoids approximation errors. This post processing technique is based on a boundary element method for the field reconstruction of measured boundary data and leverages on the smoothing property of Kirchhoff's integral equation.

Presenter: Mr LIEBSCH, Melvin (TE-MSC-MM)

Contribution ID: **41** Type: **not specified**

Hysteresis and dynamic effects in SC magnets

Monday 27 November 2023 09:30 (1 hour)

After a short digression about the physics of magnetisation in ferromagnetic materials as iron, we will discuss the magnetisation in the superconductors, and its relation to the stability of the superconductor and to the strand architecture. We then discuss the impact of the magnetisation on field quality ; we then outline the ramp rate effects, and its impact on the cable design. We conclude on how to estimate the losses due to all these phenomena.

Presenter: Dr TODESCO, Ezio (CERN)

Contribution ID: **42** Type: **not specified**

Heat transfer, cryostat, conduction cooling I

Monday 27 November 2023 11:00 (1 hour)

For one-of-a-kind superconducting-, or small numbers of, superconducting-magnets one usually can afford to be more relaxed on energy consumption and cryogen consumables than for the magnets making up the core of a multi-km long particle accelerator. From the point of view of thermal design conceptions of accelerator magnets we'll address the energetic notions that come into play when having to decide for a new project. The experience gained with the present LHC design will be addressed together with some of the drawbacks that emerged. We'll conclude with the, in my personal opinion, consequent thermal design directions that ought to be taken for new accelerator projects which enhance sustainability and lighten the dependence on cryogen resources.

Presenter: VAN WEELDEREN, Rob (CERN)

Contribution ID: **43** Type: **not specified**

Material for magnets & measurements I

Monday 27 November 2023 12:00 (1 hour)

Magnetic materials, both hard and soft, are used extensively in several components of particle accelerators. Magnetically soft iron-nickel alloys are used as shields for the vacuum chambers of accelerator injection and extraction septa; Fe-based material is widely employed for cores of accelerator and experiment magnets. Weakly magnetic austenitic stainless steels are largely applied for structural and vacuum systems. After a review of the magnetic properties of materials and the different types of magnetic behaviour, this first lecture will deal with metallurgical aspects of magnetism. The influence of the metallurgy and metalworking processes of materials on their microstructure and magnetic properties is studied for different categories of magnetic materials relevant for accelerator technology. Their metallurgy is extensively treated. Hard magnetic material will also be covered. In the second lecture, the selection of materials for functional and structural components of accelerator and fusion magnets is addressed with examples taken from normal and superconducting magnets. The talk will address the material challenges of magnet construction, requiring a wide application of tightly specified grades, featuring a controlled microstructure and adequate mechanical, physical, magnetic and vacuum properties over a large temperature range. A broad spectrum of relevant examples will be presented, issued from the experience maturated within decades of building of large magnet systems that must guarantee a reliable, long-lasting service with limited interventions. The requirements, and in turn the metallurgical processes applied to achieve the final stringent properties will be discussed - dictated by mechanical, magnetic or vacuum compatibility constraints and often by a combination of them. A case study will be developed, highlighting the challenges of application of a stainless steel solution for the upgrade of the detector structure of the Compact Muon Solenoid (CMS), which is one of the two large experiments at the CERN Large Hadron Collider (LHC), involving the construction of a High Granularity Calorimeter in the framework of the High Luminosity LHC upgrade. This requires a cost-effective production of 600 tons of austenitic stainless steel plates with a tight specification in terms of magnetic permeability, to be processed through a tailored steelmaking route. Methods for characterizing and measuring the properties of feebly magnetic materials will also be addressed.

Presenter: Dr SGOBBA, Stefano (CERN)

Contribution ID: **44** Type: **not specified**

Hands-on block 3

Monday 27 November 2023 14:30 (2 hours)

Contribution ID: **45** Type: **not specified**

Hands-on block 3

Monday 27 November 2023 17:00 (1 hour)

Contribution ID: **46** Type: **not specified**

Material for magnets & measurements II

Tuesday 28 November 2023 08:30 (1 hour)

Magnetic materials, both hard and soft, are used extensively in several components of particle accelerators. Magnetically soft iron-nickel alloys are used as shields for the vacuum chambers of accelerator injection and extraction septa; Fe-based material is widely employed for cores of accelerator and experiment magnets. Weakly magnetic austenitic stainless steels are largely applied for structural and vacuum systems. After a review of the magnetic properties of materials and the different types of magnetic behaviour, this first lecture will deal with metallurgical aspects of magnetism. The influence of the metallurgy and metalworking processes of materials on their microstructure and magnetic properties is studied for different categories of magnetic materials relevant for accelerator technology. Their metallurgy is extensively treated. Hard magnetic material will also be covered. In the second lecture, the selection of materials for functional and structural components of accelerator and fusion magnets is addressed with examples taken from normal and superconducting magnets. The talk will address the material challenges of magnet construction, requiring a wide application of tightly specified grades, featuring a controlled microstructure and adequate mechanical, physical, magnetic and vacuum properties over a large temperature range. A broad spectrum of relevant examples will be presented, issued from the experience maturated within decades of building of large magnet systems that must guarantee a reliable, long-lasting service with limited interventions. The requirements, and in turn the metallurgical processes applied to achieve the final stringent properties will be discussed - dictated by mechanical, magnetic or vacuum compatibility constraints and often by a combination of them. A case study will be developed, highlighting the challenges of application of a stainless steel solution for the upgrade of the detector structure of the Compact Muon Solenoid (CMS), which is one of the two large experiments at the CERN Large Hadron Collider (LHC), involving the construction of a High Granularity Calorimeter in the framework of the High Luminosity LHC upgrade. This requires a cost-effective production of 600 tons of austenitic stainless steel plates with a tight specification in terms of magnetic permeability, to be processed through a tailored steelmaking route. Methods for characterizing and measuring the properties of feebly magnetic materials will also be addressed.

Presenter: Dr SGOBBA, Stefano (CERN)

Contribution ID: **47** Type: **not specified**

NC dynamic effects, reproducibility

Tuesday 28 November 2023 09:30 (1 hour)

This lecture concerns the techniques to measure and model mathematically non-linear effects in iron-dominated magnets, with the aim to control the magnetic field with a high precision, 100 ppm or better, as typically required in particle accelerators. The topics covered include a review of the physical phenomenology of magnetic saturation, hysteresis and eddy currents in material samples and accelerator magnets, as well of the most popular models to represent them; a discussion on the available instrumentation and measurement techniques; and a survey of open-loop and closed-loop (feedback-based) magnetic field control methods, with a critical comparison about their cost and effectiveness.

Presenter: BUZIO, Marco (CERN)

Contribution ID: **48** Type: **not specified**

Heat transfer, cryostat, conduction cooling II

Tuesday 28 November 2023 11:00 (1 hour)

For one-of-a-kind superconducting-, or small numbers of, superconducting-magnets one usually can afford to be more relaxed on energy consumption and cryogen consumables than for the magnets making up the core of a multi-km long particle accelerator. From the point of view of thermal design conceptions of accelerator magnets we'll address the energetic notions that come into play when having to decide for a new project. The experience gained with the present LHC design will be addressed together with some of the drawbacks that emerged. We'll conclude with the, in my personal opinion, consequent thermal design directions that ought to be taken for new accelerator projects which enhance sustainability and lighten the dependence on cryogen resources.

Presenter: VAN WEELDEREN, Rob (CERN)

Contribution ID: **49** Type: **not specified**

NC Modelling & measurement of non-linear effects

Tuesday 28 November 2023 12:00 (1 hour)

This lecture concerns the techniques to measure and model mathematically non-linear effects in iron-dominated magnets, with the aim to control the magnetic field with a high precision, 100 ppm or better, as typically required in particle accelerators. The topics covered include a review of the physical phenomenology of magnetic saturation, hysteresis and eddy currents in material samples and accelerator magnets, as well of the most popular models to represent them; a discussion on the available instrumentation and measurement techniques; and a survey of open-loop and closed-loop (feedback-based) magnetic field control methods, with a critical comparison about their cost and effectiveness.

Presenter: BUZIO, Marco (CERN)

Contribution ID: **50** Type: **not specified**

Hands-on block 3

Tuesday 28 November 2023 14:30 (2 hours)

Contribution ID: **51** Type: **not specified**

Hands-on block 3

Tuesday 28 November 2023 17:00 (1 hour)

Contribution ID: **52** Type: **not specified**

Social Event

Tuesday 28 November 2023 21:00 (3 hours)

Contribution ID: **53** Type: **not specified**

Hands-on block 4

Wednesday 29 November 2023 14:30 (2 hours)

Contribution ID: **54** Type: **not specified**

Hands-on block 4

Wednesday 29 November 2023 17:00 (1 hour)

Contribution ID: **55** Type: **not specified**

Metrology, alignment & fiducialisation

Thursday 30 November 2023 08:30 (1 hour)

Fiducialisation is an essential part of the alignment process for an accelerator component that need to be aligned within tolerances greater than the component mechanical assembly precision. This step establishes the relationship between the physical object as it has been built and the theoretical slot it should occupy inside the machine. It defines how the functional features, such as lamination, blades, electrodes, or flanges, are related to the theoretical beam axis, and how the component should be aligned. Furthermore, fiducialisation transfers this internal information to reference targets outside the component, easily visible and measurable during the alignment process in the tunnel. It is part of the error budget among the different sources along the whole process. The lecture will introduce the requirements, concepts and technologies used at CERN, and give an overview of the most important and critical aspects from the production up to the final alignment.

Presenter: BESTMANN, Patrick (CERN)

Contribution ID: **56** Type: **not specified**

SC magnet fabrication + testing I

Thursday 30 November 2023 09:30 (1 hour)

The production of superconducting magnets for accelerators is a complex and not yet fully industrialised process. Ensuring the reliable performance of these magnets in accelerators requires meticulous engineering across a diverse range of specialties. In this lecture, after a brief historical overview of accelerator magnets design and construction, we review the main manufacturing steps for the construction of an accelerator magnet, from the strand to the cryostat. We take as examples the NbTi 8.3 T dipoles for the LHC and the Nb3Sn 11.3 T quadrupoles for HL-LHC, putting in evidence the differences in between the two technologies. The main features of the magnets are reviewed, showing how the design and component quality impact on construction and why the final product calls for a total-quality approach. Finally, we briefly review why, what, and how we test superconducting magnets, underlining the close connection with the design validation and with the manufacturing process.

Presenter: IZQUIERDO BERMUDEZ, Susana (CERN)

Contribution ID: **57** Type: **not specified**

Injection & extraction devices

Thursday 30 November 2023 11:00 (1 hour)

A brief introduction to injection and extraction devices for synchrotron particle accelerators. An overview will be given of the magnets, but also the electric field devices commonly used. The talk will highlight the link between these devices and the required power converters. It will conclude with the consequences of the device choice on the accelerator protection elements.

Presenter: BORBURGH, Jan (CERN)

Contribution ID: **58** Type: **not specified**

SC magnet fabrication + testing II

Thursday 30 November 2023 12:00 (1 hour)

The production of superconducting magnets for accelerators is a complex and not yet fully industrialised process. Ensuring the reliable performance of these magnets in accelerators requires meticulous engineering across a diverse range of specialties. In this lecture, after a brief historical overview of accelerator magnets design and construction, we review the main manufacturing steps for the construction of an accelerator magnet, from the strand to the cryostat. We take as examples the NbTi 8.3 T dipoles for the LHC and the Nb3Sn 11.3 T quadrupoles for HL-LHC, putting in evidence the differences in between the two technologies. The main features of the magnets are reviewed, showing how the design and component quality impact on construction and why the final product calls for a total-quality approach. Finally, we briefly review why, what, and how we test superconducting magnets, underlining the close connection with the design validation and with the manufacturing process.

Presenter: IZQUIERDO BERMUDEZ, Susana (CERN)

Contribution ID: **59** Type: **not specified**

Hands-on block 4

Thursday 30 November 2023 14:30 (2 hours)

Contribution ID: **60** Type: **not specified**

Hands-on block 4

Thursday 30 November 2023 17:00 (1 hour)

Contribution ID: **61** Type: **not specified**

Powering infrastructures

Friday 1 December 2023 08:30 (1 hour)

Power converters play a central role in particle accelerators where both their performances are directly linked. As accelerator complexes develop towards higher beam energies and a more sustainable nature, in response to the needs of physics research and of reducing the environmental impact, power converters are required to be on the forefront of technology. They have proliferated into accelerator complexes where thousands of them are used in modern complexes as at CERN. They must, therefore, achieve high reliability and in many cases cutting-edge precision. Hence, powering normal and superconducting magnets for accelerators is a driving force for the development of high-performance power converters.
This lecture intends to introduce the requirements of power converters for magnets used in particle accelerators. After showing the power conversion principles, it describes the role of power converters, the challenges and constraints when powering superconducting magnets. The principles of redundancy and modularity are discussed in this lecture in addition to the power converter control and high precision definition. More sustainable installations would need a better management of electromagnetic energies used in accelerator complexes. This lecture shows, therefore, the latest tendencies in terms of energy storage for power converters and lists the key circuit parameters to be taken into consideration to properly specify a power converter. Finally, it describes a variety of ancillary systems and infrastructure to connect the power converters to the magnets in particle accelerators.

Presenter: YAMMINE, Samer (CERN)

Contribution ID: **62** Type: **not specified**

Permanent magnets

Friday 1 December 2023 09:30 (1 hour)

This lecture presents permanent magnets for accelerator applications. Fundamental concepts such as magnetization, remanence, coercitive field and demagnetizing field are introduced. The main materials used in accelerators are neodymium-iron-boron (Nd2Fe14B) and samarium-cobalt (Sm2Co17). The manufacturing process of these materials, as well as their main properties, are presented. A few permanent magnet designs are described: Halbach magnets, permanent magnet dominated and iron dominated designs. The field can be tuned by trimming coils or by movable parts. Permanent magnets are widely used for building undulators. They are of interest for building compact, high gradient magnets, as well as for building low or zero power magnets for storage rings or transfer lines.

Presenter: LE BEC, Gael (ESRF)

Contribution ID: **63** Type: **not specified**

Superferric magnets

Friday 1 December 2023 11:00 (1 hour)

A brief introduction to the superferric magnets is given, what are they and why we use them.
An overview of the use of superferric magnets in synchrotrons by selected examples from past to actual projects. A special focus is dedicated to HL-LHC high Orde Correctors with a detailed description of the design and performance, highlighting the contribution of the superferric configuration.
The potential contribution of superferric magnets for increasing sustainability of research infrastructure is finally discussed.

Presenter: Dr STATERA, Marco (INFN Milano - LASA)

Contribution ID: **64** Type: **not specified**

Magnets for medical applications

Friday 1 December 2023 12:00 (1 hour)

This lecture is an overview of Magnets for Medical Applications using Particle Accelerator.
In the first part of the lecture we will give an introduction to different accelerators employed in hadron therapy to cure cancer as cyclotrons and synchrotrons. in the second part of the lecture, we will present the MedAustron experience including some of the aspects related to commissioning with beam and operating magnets for clinical operations.
The MedAustron Particle Therapy Accelerator located in Austria delivers proton beams in the energy range 60-250 MeV and carbon ions 120-400 MeV/n for tumour treatment in three irradiation rooms. Proton beams up to 800 MeV are also provided to a separate room dedicated to research. Over the last years, in parallel to clinical operations, we have completed the installation and commissioning of the whole accelerator including a proton gantry beamline and the first world-wide rotator.

Presenter: PIVI, Mauro (MedAustron)

Contribution ID: **65** Type: **not specified**

Insertion devices

Friday 1 December 2023 14:30 (1 hour)

Insertion devices are installed in storage rings and linac-driven light sources to produce radiation or to enable an interaction of the particle beam with the radiation field. The intended use case for the generated radiation drives the design requirements for the insertion device. This lecture is intended to give an idea of how undulator radiation and FEL gain depend on the properties of the insertion devices and what consequences this has for the design of these magnets. It gives an overview of the technological choices for insertion devices and deals with the particular challenges for their construction and quality assurance.

Presenter: BERNHARD, Axel (KIT)

Contribution ID: **66** Type: **not specified**

Collider magnets (incl. muon collider)

Friday 1 December 2023 15:30 (1 hour)

The Muon Collider, one of the options considered for the future of particle physics at the energy frontier, poses many challenges to accelerator technology. The magnets for the muon beam production, acceleration and collision are one of the most demanding systems, for many reasons. Firstly, collider performance in terms of energy and luminosity translates in the demand for high fields, high field rates, and large apertures, thus challenging magnet science and engineering well beyond state-of-the-art. At the same time, the operating environment is very harsh: the decay of highly energetic muons, whose products are difficult to shield, results in large heat and radiation loads to be managed efficiently. Finally, a Muon Collider, as any other future collider at the energy frontier, needs to be affordable and produce sustainable science. The magnets, the single system with the largest cost and power figures, are naturally at the center of the attention also from this point of view. We base this note on analytical and scaling relations to indicate what and how the magnet challenges of the Muon Collider can be mastered, and what needs to be done. Most interesting, addressing magnet technology challenges for a Muon Collider will benefit any future collider at the energy frontier, as well as many other fields of scientific and societal application of magnet technology.

Presenter: BOTTURA, Luca (CERN)

Contribution ID: **67** Type: **not specified**

Closing

Friday 1 December 2023 17:00 (1 hour)

Presenter: TECKER, Frank (CERN)

Contribution ID: **68** Type: **not specified**

Departure day

Saturday 2 December 2023 08:30 (2h 30m)

Contribution ID: **69** Type: **not specified**

Hands-on - Block 2 - Resistive magnet design (NCD)

Wednesday 22 November 2023 14:30 (2 hours)

Presenters: Dr BALLARINO, Amalia (CERN); MILANESE, Attilio (CERN); BORBURGH, Jan (CERN); BAUCHE, Jeremie (CERN); THONET, Pierre Alexandre (CERN)

Contribution ID: **70** Type: **not specified**

Hands-on - Block 3 - Magnetic measurements (MM)

Wednesday 22 November 2023 14:30 (2 hours)

Presenters: Dr BALLARINO, Amalia (CERN); BUZIO, Marco (CERN); RUSSENSCHUCK, Stephan (CERN)

Contribution ID: **71** Type: **not specified**

Hands-on - Block 4 - Superconductivity experiments (SCE)

Wednesday 22 November 2023 14:30 (2 hours)

Presenters: Dr BALLARINO, Amalia (CERN); GONZALEZ GOMEZ, Luis Antonio (CERN); GARCÍA-TABARÉS, Luis (CIEMAT); EISTERER, Michael; YANG, Yifeng (University of Southampton (GB))

Contribution ID: **72** Type: **not specified**

Hands-on - Block 2 - Resistive magnet design (NCD)

Wednesday 22 November 2023 17:00 (1 hour)

Presenters: Dr BALLARINO, Amalia (CERN); MILANESE, Attilio (CERN); BORBURGH, Jan (CERN); BAUCHE, Jeremie (CERN)

Contribution ID: **73** Type: **not specified**

Hands-on - Block 3 - Magnetic measurements (MM)

Wednesday 22 November 2023 17:00 (1 hour)

Presenters: Dr BALLARINO, Amalia (CERN); BUZIO, Marco (CERN); RUSSENSCHUCK, Stephan (CERN)

Contribution ID: **74** Type: **not specified**

Hands-on - Block 4 - Superconductivity experiments (SCE)

Wednesday 22 November 2023 17:00 (1 hour)

Presenters: Dr BALLARINO, Amalia (CERN); GONZALEZ GOMEZ, Luis Antonio (CERN); GARCÍA-TABARÉS, Luis; EISTERER, Michael; YANG, Yifeng (University of Southampton (GB))

Contribution ID: **75** Type: **not specified**

Seminar: Simulation, AI & beyond

Wednesday 22 November 2023 18:00 (1 hour)

Presenter: ROTHSCHEDL, Dominik (Dwh GmbH)