CHATS on Applied Superconductivity 2021

Report of Contributions

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

Superconducting performance of as-built ITER magnet system - towards commissioning

ITER superconducting magnet system design is based on Cable-In-Conduit Conductors (CICC) cooled at cryogenic temperatures by forced circulation of supercritical helium. As part of the as-built performance assessment of the superconducting magnet system of ITER, a new 15 MA DT plasma scenario baseline was analysed. Using the updated SuperMagnet models (FLOWER 1D hydraulic network, THEA dual channel CICC model, and HEATER thermal diffusion model), the operation margins on the coil conductors and their busbars is now available and fulfil the design criteria. Additional work was carried out to initiate the commissioning preparation such as having some sensitivity analysis to guide the test to be conducted prior first plasma in December 2025.

Keywords

Category

Tools to support commissioning and operation phases of superconducting magnet systems

Primary author: GAUTHIER, Florent (ITER Organization)

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

Superconductor Thermohydraulical and Resistive Electrical Analytical Model (STREAM) applied to WEST TF Coil Quench Analysis

Thursday, September 23, 2021 1:50 PM (25 minutes)

The Toroidal Field (TF) system of the WEST tokamak comprises 18 NbTi superconducting coils, cooled in a static superfluid helium bath at 1.8 K and carrying a nominal current of 1255 A. The 19th December 2017, at the end of plasma run #52205, a quench of TFC-09 was detected first on a secondary thermohydraulical signal (helium level) and triggered the current Fast Safety Discharge (FSD).

The quench was found to be induced by a neutron and gammas flux caused by highly energetic runaway electrons (30 MeV) colliding the outboard plasma facing components. Some previous analyses [2] with SuperMagnet (CryoSoft) code confirmed a so called "smooth" quench with small initial heat deposition length (0.4 m) at low field region (external leg) and with an initial number of quenched conductor nearly equal to 100. The whole TFC-09 circular coil is modelled by a singular bath with one conductor of length equal to coil average perimeter.

A Superconductor Thermohydraulical and Resistive Electrical Analytical Model (STREAM) has been developed. This model comprises as input the Minimum Quench Energy (MQE) and an adaptation of the well known "short coil – low pressure" law for the propagation of quenched normal length. This model comprises the electrical equations (magnetic field, current sharing temperature, Joule energy, resistive voltage, resistance and current) as well as the thermodynamical and hydraulical evolution in two phases:
- The first one comprises the helium pressure evolution with an isentropic compression (closed volume) of a cold volume by a hot (and heated) volume
- The second one comprises the determination of expulsed helium mass flow in the exhaust circuit (from a given pressure threshold) with a limit at atmospheric pressure or Mach number equal 1. The evolution of helium pressure inside the coil follows, what is called, an "equi-baro-chore" evolution.

For WEST TFC09 Quench, STREAM calculated results shows good agreements with the measurements as well as the calculated SuperMagnet results. The maximal resistive voltage, Joule energy and resistance are respectively at 1400 V, 18 MJ and 5 Ω. The maximal values of helium pressure, conductor temperature and expulsed helium mass flow are respectively 0.9 to 1.0 MPa, 90 K, and 5 kg/s. This STREAM analytical model can be useful, with adaptation to Cable-In-Conduit Conductor configuration, for other tokamak magnets safe operation and protection as the execution time is reduced, compared to other existing codes.

Keywords

Fusion, Magnets, Thermohydraulics, Quench, Simulation

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D4

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

Calculation of saturated coupling loss in Rutherford cables

Tuesday, September 21, 2021 12:50 PM (25 minutes)

Inter-strand coupling loss in superconducting Rutherford cables subjected to weak transient operation is well understood, resulting in induced currents much lower than critical current of strands due to short enough twist-pitch and high enough transverse resistance. If these conditions are not fulfilled, the coupling loss saturates to hysteresis loss of an entire cable cross-section. Although such situation can barely be accepted for LTS cables due to their low temperature margin, it can actually be tolerable for high current / high field HTS cables, which are often designed using long twist-pitch or even straight strands and low transverse resistance. A dedicated study of the saturated coupling loss is performed using analytical and numerical network models. Impacts of cable design parameters (number of strands, twist-pitch, Ic, n-value, transverse resistance) and operating conditions (transient external magnetic field and transport current) on the value of critical twist-pitch and coupling loss are investigated. Particular attention is given to the rapid transient operation commonly applied in central solenoid of fusion magnets, for which the induced currents can be affected by both saturation and screening effects.

Keywords

Rutherford cables, electrical network model, coupling loss

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D2

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

JT-60SA TF Coils Quench Model and Analysis: Joule Energy Estimation with SuperMagnet and STREAM

Monday, September 20, 2021 1:50 PM (25 minutes)

In the framework of the commissioning of JT-60SA Tokamak (Japan, beginning of 2021), all the coils (TFC, CS and EF) have to be energized with a set of reduced and then nominal current after they became superconducting at 4.5 K cooling temperature with supercritical helium flow in Cable-In-Conduit Conductors (CICC).
An important Issue is to predict the Joule Energy for all the magnet systems, in particular, the Toroidal Field Coils (TFC), in case of an incidental quench arises, as well as the respectively "hot spot" temperature, the maximal conductor temperature reached during the quench development.
SuperMagnet code (CryoSoft), including THEA (Thermohydraulic 1-D CICC) and Flower (external cryogenic cooling circuit model), as well as Superconductor Thermohydraulical and Resistive Electrical Analytical Model (STREAM) have been used for these analyses and calculation.
Different TFC quench cases have been studied, in Tokamak configuration, with different quench initiation (Minimum Quench Energy) set as input at nominal current and at maximal magnetic field location (at inlet of CICC over few meters): either on only one Pancake or on each first turn of the 12 Pancakes. In this way, the determined maximal conservative Joule Energy, for one whole TFC quench is evaluated to be near 7 MJ and equal to 12 times the maximal Joule Energy per pancake. The integrated and detailed Joule Energy value depends strongly on quench initiation conditions and on the number of the entirely and rapidly quenched pancakes (quench propagation velocity with a maximum of 16 m/s).
Some further analyses have been performed on the acceptance quench test realized at the Cold Test Facility (CTF, CEA Saclay in 2018) on TFC02. This quench test has also been modelled with SuperMagnet and STREAM. The different calculation results, in particular helium temperature and pressure in upstream and downstream manifold are presented here and are in good agreement with the measurements. This analysis confirms, among others, that STREAM analytical model is valid for CICC coils cooled by forced flow of supercritical helium and can be useful for tokamak magnets protection during quench event and safe operation. This whole analysis has been useful also for the JT-60SA Tokamak magnets energization and commissioning phase.

Keywords

Fusion, Superconducting Magnets, Quench, Thermohydraulics

Category

Quench experiment, simulation and analysis for all classes of LTS and HTS magnets

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Session Classification: Quench D1

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

Preliminary design of the pressure relief system for the new EDIPO He vessel

Tuesday, September 21, 2021 1:15 PM (25 minutes)

The EDIPO test facility is undergoing a major upgrade of its magnet assembly, which will provide ground for testing both fusion and high-energy physics superconducting samples at variable temperature and with a background field of 15 T. Unlike the former magnet, which was wound with cable-in-conduit conductors cooled by a forced-flow of supercritical He, the upgraded magnet assembly will be cooled in a bath of liquid He at atmospheric pressure. Therefore, the structural design of the He vessel hosting the magnet calls for a preliminary design of its pressure relief system.
In this work, we discuss the cryogenic requirements of the He vessel, starting from a cooling configuration based on a saturated bath. We present a design based on a staged pressure relief concept, which is dealt with in two steps. In the first step, after having defined the target pressure levels, possible accidental scenarios are considered for sizing the safety relief devices. In the second step, the heat loads in normal operation are estimated for modelling the pressure relief and He recovery. For this purpose, the description of a magnet quench event is investigated, considering the fraction of the quench heat load transferred to the He bath.

Keywords

EDIPO, Helium vessel, pressure relief, safety valve, modelling

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D2

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

Analysis of current distribution and AC losses in a RW2 prototype cable for the European DEMO TF coils

Wednesday, September 22, 2021 2:40 PM (25 minutes)

Several design proposals have been envisaged for the Toroidal Field (TF) coils of the future European DEMO fusion reactor, which are based on a Nb3Sn conductor cable made with the react&wind (RW) or wind&react technologies.
Among them, Swiss Plasma Center (SPC) is proposing a RW solution combined with a layer winding technique for the coil, which is expected to permit the conductor grading as a function of the magnetic field, with a consequent remarkable saving of superconducting (SC) material.
To prevent the degradation due to bending of the fragile Nb3Sn, the proposed RW conductor cross-section has a high aspect ratio, with the SC strands located as close as possible to the section neutral axis.
The conductor cabling starts with the production of small circular SC strand bundles, which are in turn wound to form a composite Rutherford-like structure.
The conductor stability is provided by two layers of segregated stabilising copper located on the two wide sides of the SC Rutherford bundle.
A set of different solutions have been investigated as regards the two stabilising layers which, so far, basically consisted of a solid mixed matrix obtained from small rolled Cu-based assemblies.
Quite different experimental AC losses test results have been obtained from samples made of the same type of SC Rutherford bundle and different types of stabilizers, showing that further analysis and development of this cable component have to be carried out.
Recently, the use of a Rutherford bundle of clad copper strands has been considered, in order to comply with the required anisotropic properties of the stabiliser as regards both the longitudinal and transverse conductivity, to reduce the stabiliser eddy currents loss, while providing good stabilising performances.
In this work, the THELMA code is used to model short SULTAN samples of this type of RW cable, in order to analyse the effect of the new stabiliser design parameters on the total AC losses and the induced currents distribution.
To this purpose, the new geometrical model is adopted, which reproduces in a verisimilar way both the SC and stabilisers strands trajectories and reduces as much as possible their geometrical interferences, getting reasonable interstrand contact areas.
The model interstrand contact conductances are tuned using available experimental results of contact resistances measurements. Then the behaviour of different design alternatives is investigated and discussed in the paper through a parametric analysis.

Keywords

DEMO, TF coils, Nb3Sn, AC losses

Category

Electromagnetics modelling of LTS and HTS magnets

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Session Classification: Electromagnetics D3

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

AC losses in TF magnets during JT-60SA commissioning: experimental analysis and simulations

Thursday, September 23, 2021 2:15 PM (25 minutes)

During the integrated commissioning of JT-60SA tokamak, the superconducting magnets have experienced several tests such as current ramps or fast discharges. The time variations of the associated magnetic field have induced AC losses in the winding pack (WP), i.e. hysteresis and coupling losses, and in the casing, i.e. eddy currents losses, of the toroidal field (TF) coils.
From the thermo-hydraulic sensors installed in the tokamak in the inlet and outlet of the coils and of the TF casings, we have carried out enthalpy balances to estimate the total transient heat loads generated by AC losses. For JT-60SA TF, the current ramp is limited to 25 A/s, thus the associated AC losses were small compared to those of the fast discharges tests with time constants of the order of 14 s performed at several currents up to the nominal value of 25.7 kA; for this reason, we have focused our analysis on such events.
In parallel, we have computed the AC losses generated in the TF from the knowledge of the magnetic self-field map and the current profiles measured during the fast discharges. The hysteresis losses modeling is achieved using magnetization measurements of a TF strand at ENEA during production over large temperature and magnetic field ranges, the coupling losses one using magnetization measurements of a TF CICC performed at CEA, and the eddy currents losses one using the inductance model presented in JT-60SA Plant Integrated Document (PID).
We then present a comparison between these experimental and first theoretical analyses, to assess and discuss the consistency of the two approaches at the first order, i.e. at the energy balance level.
In a second step, in an attempt to deepen and increase the realism of our approach, we present and compare the results of several quasi-3D coupled thermal/thermo-hydraulic simulations performed using TACTICS code with the temperature sensors measurements during the experiment.
These simulations aim at representing the TF magnet thermal and thermo-hydraulical response to transient heat loads at a more detailed scale to better anticipate the magnet stability in future operations. In order to consider a realistic value of the TF casing/WP contact thermal resistance, which is an important driving parameter, we have performed a parametric study during which we have varied this parameter and used the enthalpy distribution between the WP and the casing as a figure of merit.

Keywords

JT-60SA, TF, AC losses

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D4

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

TACTICS: overview of a multi-physic analysis tool for fusion magnet design and application to DEMO TF coil

Tuesday, September 21, 2021 1:50 PM (25 minutes)

In the context of the different fusion machines using superconducting magnets that are currently in development or exploitation phase (DEMO, JT-60SA, ITER…), reliable numerical models are required to perform analyses of the magnet design performances. In the design phase, after a conductor and associated magnet structured is proposed, extensive analyses are carried out to verify the compliance of the design with imposed design criteria (i.e. temperature margin, hotspot temperature). These calculations are also performed during commissioning and exploitation of the machine to ensure that a given scenario will not put the magnet at risk.
To meet the need for accurate, fast, and easily usable numerical models for the analysis of magnet systems, the TACTICS code was developed. It consists of a code coupling methodology to perform a pseudo-3D transient co-simulation of coupled physics by linking different codes: THEA for the modeling of the conductors, Cast3M for the magnet structures and Simcryogenics for the cryodistribution simulation.
In this paper, the structure of TACTICS is described, detailing the different links and coupling between the codes. The latest developments will be presented, mainly regarding the numerical stability when dealing fast transients (optimization of the coupling time-step, of the meshing of the structures…). Details will be given on the generation of inputs for the different codes (electromagnetic, thermic, thermo-hydraulics, cryodistribution) and the post-processing of the results.
The last part of the paper presents the application of the tool on the latest CEA design proposals for EU-DEMO TF magnets. The design considered is WP#4 for DEMO 2018. It is an "ITER-like" design, based on the double-pancake concept, with the use of radial plates. In burn studies, the minimal temperature margin of the design will be calculated, using a model accounting for the conductors, the magnet structures and the cryodistribution by coupling the three codes included in TACTICS. The same exercise will be conducted considering a detachment of the winding pack from the casing due to the electro-mechanical forces. A fast safety discharge of the magnet will be performed, and it will be checked whether or not a quench is initiated on such scenario. Then quench simulations will be performed in order to verify if the hotspot temperature criterion is met.

Keywords

CICC, code coupling, DEMO, magnet, quench

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D2

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

Development of a multi-physic platform OLYMPE for magnet fusion design: progresses update and applications

Tuesday, September 21, 2021 2:15 PM (25 minutes)

In the framework of tokamak design studies, the magnet system dimensioning stands as a crucial point, magnets being strong drivers for reactor performances. In this aim superconducting magnets design path to manufacture and integration should prior undergo several stages of development, including the detailed analysis for defined operation cases. Those studies are linked to several physic domains (electromagnetics, mechanics, thermohydraulics, thermal) that should be interfaced together. The platform OLYMPE was developed at CEA in this objective, aiming at addressing those complex multi-physic problems in an integrated tool, which is expected to increase analyses efficiency.
The different OLYMPE submodules will be described and their dedicated simulation domain explained, together with their interconnection logic. As a matter of fact several combinations of those modules are established into converging loops and can assess the refinement of magnet design in the aim to increase design ergonomic accuracy. Namely examples will be given with following loops:
- TF system design coupled with thermohydraulics: it ensures the compliance of TF design with temperature margin criterion.
- TF system design coupled with electromagnetics: it ensures the compliance of TF design with topologically-induced magnetic field map
- Overall TF design coupled with thermohydraulics and cryogenics: it ensures the optimization of TF design and its operation conditions with overall system merits (e.g. cost factor).
- TF system design coupled with mechanics: it ensures the compliance of TF design with local stress criterion

The outcomes and methodologic merits of those loops will be illustrated by applications on DEMO configurations, and performances cross-checks or comparisons with simpler models will also be provided to quantify the accuracy enhancement.
Furthermore the management of the overall input database and the GUI interface will be presented in the aim of improving tool operability.
Finally discussions on this emerging OLYMPE tool qualities will also be exposed, including calculation performances merits and further development perspectives.

Keywords

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D2

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

Numerical analysis of quench behavior in a Cable-In-Conduit-Conductor cooled by stagnant superfluid helium

Monday, September 20, 2021 2:15 PM (25 minutes)

In a dark matter Axion research context, the MADMAX project acts as a figurehead in the physics research field. The purpose of the project is to use a dipole, composed of 18 coils, with a Figure of Merit of 100 T^2m^2. The MADMAX's coils have several specific features though, as the use of Cable-In-Conduit-Conductor (CICC) in a copper stabilizer or the use of stagnant superfluid helium inside the CICC channel. With such a small helium's cross-section and several hundreds of meters of conductor before reaching the helium bath, the quench dynamics appears then as a key issue of the design phase.

In order to solve the issue of quench propagation in the Madmax coils, we designed a MADMAX-like solenoidal prototype, for experimental quench studies, based on a numerical design phase made with THEA®. This numerical study allowed us to analyze the equations and physics behind the quench phenomenon. This numerical study was also the way to define the relevant current range for the experimental quench studies. Nevertheless, as THEA® has been rarely used with superfluid helium, its results will have to be validated by the quench testing campaign on this prototype.

The different calculations made with THEA® show that the quench propagation is divided in two different phases: a propagation with a constant speed at around 3 m/s and an acceleration phase where the propagation speed could reach 18 m/s, at the nominal current. Among the different possible phenomena, we have found that the friction forces are responsible of this two-phase propagation because they initiate the pre-heating of the magnet before the quench, reducing then the local temperature margin.

Keywords

Category

Quench experiment, simulation and analysis for all classes of LTS and HTS magnets

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Session Classification: Quench D1

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

Analytical modeling of coupling losses in CICCs, extensive study of the COLISEUM model

Wednesday, September 22, 2021 3:05 PM (25 minutes)

Magnetic field and current variations are responsible for AC losses in superconductive magnets. These losses may induce an increase of temperature within the material and negatively affect the performance of the magnet. In case of fusion energy experiments, it is essential to model and predict AC losses to ensure safe and reliable tokamak utilisation.

Developed at CEA, the new fully analytical model named COLISEUM (COupling Losses analytIcal Stages cablEs Unified Model) aims at predicting the coupling losses at various scales only from geometrical and electrical parameters. In this model, a multiplet is composed of several elements. Those elements can represents either a strand, a multiplet of strands or multiplet of multiplets. COLISEUM simulates those elements through tubes of current that are characterised by several geometrical parameters such as their twist pitch, their cabling radius or their compaction. The most recent model version addresses the coupling losses for a full Cable in Conduit Conductor (CICC), accounting contributions from the strand to the nth-stage of the cable.

In the present work, we conduct an extensive parametric study on those geometrical parameters and investigate the output of the COLISEUM model, with associated interpretations on the link between inputs relevance and resulting outputs. We compare simple COLISEUM configurations with a full numerical approach. In addition, tomographic studies, conducted at INFLPR, on real cable designs (of JT-60SA TF type) allow us to investigate and validate our theoretical results on the cabling radius.

We conducted a crosscheck between experimental AC loss measurements and the COLISEUM model on various geometries of CICCs. Samples were tested at CEA Cadarache in the JOSEFA facility using the magnetization method and in SULTAN facility using calorimetric method. We compared the measured AC losses with the losses predicted by COLISEUM using the experimental geometrical and electrical parameters as inputs for the model. It allows us to evaluate the predictive capabilities of the model for various geometries.

We discuss the possible contribution of the model to stability studies. Unifying the COLISEUM model with an analytical description of the thermal behaviour of a CICC could consolidate and broaden the range of the model for future developments.

Keywords

AC losses, Cable in Conduit Conductors CICCs, superconducting

Category

Electromagnetics modelling of LTS and HTS magnets

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Session Classification: Electromagnetics D3

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

Dynamic simulation of high transients in forced flow Supercritical helium loop for the sizing of an experimental set-up dedicated to the study of loss of vacuum.

Tuesday, September 21, 2021 2:40 PM (25 minutes)

In fusion reactors, large and complex systems of cryolines distribute supercritical helium to the different cryogenic users. Space constraints often impose to deport the pressure relief equipment several meters away from the protected volumes.
The loss of insulating vacuum is a major accidental situation for cryogenics systems. As the driving parameter for sizing the pressure relief devices is the heat flux transmitted to fluid, several studies have been carried out to measure the heat flux received by supercritical helium during the loss of the insulating vacuum. However, up to now the experiments found in the literature were performed only on storage vessels. Hence, to ensure a reliable sizing of pressure relief systems, the heat flux received by supercritical helium in case of loss of vacuum has also to be measured in forced flow configuration.
In this context, an experimental test bench with forced flow supercritical helium loop, named HELIOS, is being modified in CEA Grenoble to perform controlled loss of insulating vacuum around a cryoline and to measure the heat flux received by the fluid according to initial conditions of the flow. The new design of the HELIOS loop has been modelled with the system code CATHARE3. CATHARE 3 is the actual reference thermal-hydraulic tool to perform safety studies for the French Pressurised Water fission reactors and has been adapted to consider helium flow . The numerical model has been used to size the new experimental set-up. The modelling work also supported the assessment of the methodology to quantify the heat flux received by supercritical Helium resulting from vacuum break. Experimental results that will be measured on the HELIOS loop will be used in the qualification process of CATHARE3 with helium.

Keywords

Supercritical helium loop / Loss of insulating vacuum / Pressure Relief systems / Discharge line / Fusion reactors / Experimental setup / CATHARE-3 code

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D2

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

Dynamic simulation of the first cool down of the JT-60SA cryo-magnet system

Thursday, September 23, 2021 2:40 PM (25 minutes)

In framework of the Broader Approach research and development for fusion activities, involving Japan and Europe, the JT-60SA tokamak has been jointly constructed in Naka, Japan to support the operation of ITER and to study advanced plasma scenarios for future fusion power plants.
The integrated commissioning of the tokamak started mid 2020 with a Japanese and European team, composed of QST, F4E and Eurofusion. CEA, as member of Eurofusion consortium, has brought expertise and support in the operation of the cryo-magnetic system.
The JT-60SA superconducting magnet system is composed of 18 Toroidal Field coils, 4 Central Solenoid coil modules and 6 Equilibrium Field coils with a total mass of around 700 tons. The magnets and structures are cooled at 4.5 K by circulation of supercritical helium supplied by a powerful cryogenic system.
The cool-down from 300 K to 4.5 K took more than one month with limitation on the cool-down speed of the magnets, but also on the thermal gradients between the different coils and between coils and thermal shields surrounding coils. To avoid emissivity degradation of the Thermal Shield surfaces by condensing impurities, the Thermal Shields shall follow the magnet cool-down at a warmer temperatures.
Dynamic simulations were performed during the cool down to support the operation and to optimize the process and the magnet cool-down. The first cool-down of the JT-60SA magnet system is presented and compared with simulation results obtained with Simcryogenics models. Simcryogenics is the simulation library developed by CEA (Departement of Low Temperature Systems) on a Matlab/Simulink platform for modelling cryogenic processes. Dynamic simulation models had been developed for the JT-60SA integrated commissioning activities.

Keywords

JT-60SA, Commissioning, cool-down, cryogenic, magnets

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D4

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

Friction factor of a forced-flow cooled HTS subsize-conductor for fusion magnets

Tuesday, September 21, 2021 3:05 PM (25 minutes)

Thermal–hydraulic analyses of forced-flow cooled superconducting conductors designed for fusion magnets are typically based on 1-D mathematical models, which demand reliable predictive correlations for the transverse mass-, momentum- and energy transport processes occurring between different conductor components. Friction factor correlations, derived from pressure drop tests or Computational Fluid Dynamics (CFD) simulations of conductor samples, describe momentum transfer.
High Tc Superconductors (HTS) are promising materials to be applied in future fusion magnets, since they offer operating magnets at higher magnetic fields or higher temperatures as compared to the current conductors made of Low Tc Superconductors. Various concepts of HTS cables for fusion applications are being developed, characterized and analyzed. Recently three concepts of triplet HTS subsize-conductors for a quench experiment have been proposed by KIT. Each of them consists of three twisted CrossConductor (CroCo) strands enclosed in a stainless steel jacket, but they differ from each other in copper stabilizer geometry. In Option 1 and 2 conductors CroCo strands are contained in copper sheaths of different thickness, whereas in the Option 3 they are embedded in copper profiles with larger contact area. Hydraulic characteristics of such kind conductors was unknown. Three dedicated short dummy conductors with the geometry identical to Option 1-3 conductors were prepared by KIT to be tested for pressure drop. Option 1 and 2 samples were prepared and characterized earlier.
In the present study we present the results of the hydraulic test of the Option 3 conductor, performed using demineralized water at different temperatures, and the outcomes of the CFD simulation of flow in the Option 3 conductor using the ANSYS FLUENT commercial code. Based on these results we develop a friction factor correlation valid in a very wide range of Reynolds number which could be used in thermal-hydraulic analyses of the quench experiment.

Keywords

HTS conductors, hydraulic test, friction factor, CFD

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D2

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

Thermal-Hydraulic Analysis of the DEMO PF Coils Designed by CEA

Wednesday, September 22, 2021 12:00 PM (25 minutes)

The European DEMOnstration Fusion Power Plant (EU-DEMO) is planned as an intermediate step between the ITER experimental reactor and the future prototype fusion power plant. The core of EU-DEMO is a tokamak equipped with a fully superconducting magnet system, which includes six Poloidal Field (PF) coils. Two concepts of the PF winding packs (WP) are being developed by CEA IRFM (France) and EPFL-SPC (Switzerland) teams. Each of PF coils designed by CEA is double-pancake wound using a square NbTi Cable-in-Conduit Conductor with a central cooling channel. Our present work is focused on thermal-hydraulic analysis of the CEA design of the PF coils, based on the DEMO 2018 baseline. We performed simulations, using the THEA code by CryoSoft, of the behavior of each PF coil at normal operating conditions during the whole simplified current scenario, which consists of: Premagnetisation (10 s), Plasma Current Ramp-Up (80 s), plasma burn (7200 s, between the Start of Flat-Top (SOF) and End of Flat-Top (EOF)) and dwell (600 s) phases. The aim of this study was to estimate the minimum temperature margin for each PF coil. We took into account the realistic magnetic field profiles along each conductor and heat loads due to the AC coupling losses and time dependent hysteresis losses following changes of Jc (B,T). The obtained results serve as a verification of the proposed design with regard to the acceptance design criteria and provide information for further improvements and optimization of the PF winding packs design.

Keywords

EU-DEMO, PF coils, thermal-hydraulic analysis, temperature margin

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D3

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

OPENSC2: the thermal-hydraulic modelling of superconducting cables moves towards Open Science

Thursday, September 23, 2021 3:05 PM (25 minutes)

Within the framework of Open Science, set as a priority by the European Commission in Horizon Europe, the OPENSC2 code has been developed to grant the entire research community the possibility to simulate thermal-hydraulic transients in LTS and HTS cable-in-conduit conductors (CICC) for fusion and power applications.
A Test-Driven Development (TDD) approach has been adopted for the code development. Three test cases are considered of paramount interest: 1) An ITER-like 2-region CICC, with a thousand of mm-size LTS strands, cooled by SHe; 2) A HTS twisted-slotted-core CICC for fusion application, cooled by SHe and 3) A three-phase HTS power cable, with the supply and return lines for the LN2 coolant in a counter-current concentric configuration.
The TDD allowed to build an open-source object-oriented tool (OPENSC2): exploiting the "conductor" class, each Conductor Object (CO) is the combination of different lower-level objects (both fluid and solid components) instantiated by the class. The choice of each component drives the automatic selection of the appropriate physical equation(s) in the code: 1D transient heat conduction equations for any Solid-component Object (SO), and a full set of 1D Euler-like equations in the non-conservative variables velocity, pressure and temperature for any Fluid-component Object (FO). The SOs are thermally coupled through conduction and/or radiation to other selectable SOs along their length, and to selectable FOs. The FOs are in turn hydraulically and thermally coupled to other selectable FOs. A huge variety of constitutive relations for the transport coefficient in the FO (friction factors, heat transfer correlations) are available to the user. The SE includes not only categories of strands/tapes of pure stabilizer, strands/tapes with bulk SC material, and mixed strand/tapes, but also categories of jacket materials. Thermo-physical properties of different cryogenic fluids can be attributed to the FOs. A user-friendly GUI allows monitoring the simulations while running.
In this work, the three test cases are first discussed with their peculiarities, deriving the set of characteristics that the target object-oriented tool should comply with. The OPENSC2 tool is then introduced, showing how it allows successfully the simulation of thermal-hydraulic transients in any of the three test-cases. Benchmarks with the 4C code in the first two cases are performed to support the V&V of OPENSC2. The public repository where the tool is made available to the community is also presented, together with a proposal of a public benchmark challenge.

Keywords

HTS cables, LTS cables, Object Oriented Modeling, Theaml-hydraulics, open-source

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D4

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

Development of an integrated Cast3M mesh generator in TACTICS

Wednesday, September 22, 2021 12:25 PM (25 minutes)

In the framework of thermo-hydraulic studies for tokamaks using superconducting magnets, the TACTICS code was developed at CEA. This tool is based on the same pseudo 3D approach as the one used by similar codes such as SuperMagnet, Venecia or 4C. TACTICS thus allows the simulation of the thermal and thermo-hydraulic behavior of a superconducting coil comprising CICCs, and possibly includes the modelling of the cryodistribution. For this purpose, it couples three codes, THEA for the 1D thermo-hydraulics in the conductors, Cast3M for the 2D thermal diffusion in cross sections representing the structures (jackets, insulation and casing if any) and Simcryogenics for the cryodistribution.
During cryomagnetic system design activities, several coil options have to be studied. When preparing each TACTICS model, the Cast3M module can be the one demanding the longest development time, mainly for building the 2D geometry and the associated mesh. A methodology was thus elaborated for rationalizing the structure of input data, their entry and their processing in the Cast3M module for generating the corresponding 2D mesh.
Due to the variety of possible coil architectures affecting the structures (number of conductors, jackets features, presence of radial plates, casings geometry, layout of case cooling channels, etc.), a tree structure data was configured and a software was developed for facilitating and increasing reliability of data entry. The TACTICS Cast3M module was adapted for treating the generated input data and for building the 2D mesh with the lowest possible intervention of the user. Different levels of detail were implemented for the insulation materials inside the winding pack, and the corresponding relevance was assessed, notably regarding the temperature margin criterion.

Keywords

TACTICS, Cast3M, mesh generator, thermal, thermo-hydraulics

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D3

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

Multiphysics modelling of a sub-sized HTS fusion conductor cable concept

Monday, September 20, 2021 2:40 PM (25 minutes)

Conventional cables for fusion magnets make use of low temperature superconductors (LTS) to achieve high current densities, which are necessary to generate the magnetic field for fusion plasma confinement. Compared to LTS, high temperature superconductors (HTS) offer the possibility to increase the magnetic field strength for plasma confinement, as well as the operation at higher temperatures. The most promising HTS material for fusion applications, REBCO, is commercially available as coated conductor tapes. This conductor geometry leads to fundamentally different cable designs compared to conventional low temperature superconductor (LTS) cables for fusion application.
A common approach is to combine multiple HTS tapes to macro strands, which allow easier handling and processing during the cable fabrication. One of these concepts is the HTS CrossConductor (HTS CroCo), where HTS and intercalated copper tapes form a cross-shaped stack, embedded in a round solder matrix for high current density in the round strand cross-section. During operation, fusion cables experience high mechanical stresses through Lorentz forces and thermal expansion. Depending on the reactor type, these stresses can be static or cyclic. From the thermal-hydraulic point of view, the cable is part of the cryogenic system. In case of quench incidents, local hotspots produce an immense heat load that has to be taken away.

The quench behavior of HTS cable-in-conduit-conductors (CICC) for fusion magnets is substantially different from state-of-the-art LTS CICC. Within an international collaboration, different high-current HTS CICC will be developed, tested at high field and analyzed. KIT is preparing a HTS CICC sample for quench investigations based on HTS CroCo strands.
In this contribution, the analyses in the design phase of a HTS CICC to be tested at high Lorentz loads will be presented and include structural mechanic, thermal-hydraulic and electro-magnetic simulations. Based on previous work [1], first predictive calculations of the response of the HTS CroCo-based triplet sample at quench were refined and updated to the final sample geometry.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1] M. J. Wolf, R. Heller, W. H. Fietz, K.-P. Weiss, "Design and analysis of HTS subsize-conductors for quench investigations towards future HTS fusion magnets," Cryogenics, Volume 104, 2019

Keywords

Fusion Magnets, High Temperature Superconductors, HTS CrossConductor, Quench

Category

Quench experiment, simulation and analysis for all classes of LTS and HTS magnets

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Session Classification: Quench D1

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

H4C analysis of quench propagation experiments in HTS Cable-In-Conduit Conductors

Tuesday, September 21, 2021 12:00 PM (25 minutes)

An extensive experimental campaign, supported by the EUROfusion consortium, is ongoing at SULTAN to investigate the quench propagation in High Temperature Superconducting (HTS) Cable-In-Conduit Conductors (CICCs) and provide support for the calibration and validation of the numerical tools used for the analysis of quench propagation in HTS CICCs.
The H4C code (an upgraded version of the 4C code - a state-of-the-art numerical tool for the analysis of thermal-hydraulic transients in Low Temperature Superconducting CICCs and coils) was recently developed at Politecnico di Torino to analyze fast thermal-hydraulic and electric transients, such as the quench, in HTS CICCs.
In this work, the H4C model of the CICCs already tested in SULTAN, i.e., different designs proposed by the SPC team, is developed. The analysis of the data collected in both DC and quench tests, which are functional for constructing the input of the model, is reported first. Then the calibration of the thermal-hydraulic and electric interface parameters, such as the heat transfer coefficient among the different conductor elements and between them and the forced-flow He, is discussed. Eventually, after freezing the parameters tuned through the calibration, the validation of the model is carried out by comparing the computed voltage and temperature evolutions (up to the current dump) with the data measured at different positions along the conductor.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No. 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Keywords

Category

Quench experiment, simulation and analysis for all classes of LTS and HTS magnets

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Session Classification: Quench D2

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

Development and test of a dynamic Modelica model of the He refrigerator for superconducting magnet systems

Friday, September 24, 2021 12:25 PM (25 minutes)

The magnetic confinement of the plasma in existing and future nuclear fusion reactors is often provided by superconducting magnets. To show their superconducting properties, they must be kept sufficiently colder than the current sharing temperature during the pulsed reactor operation; therefore, they are usually cooled by supercritical He obtained by a refrigeration process. The technological complexity and cost of the He refrigerator are a significant fraction of those of the entire machine. For these reasons, a suitable dimensioning and safe operation is required and needs to be supported by adequate and reliable models. The latter, however, are currently limited to static or simplified dynamic models used for the industrial dimensioning of the refrigerators.
A new, dynamic and fast-running model of such a refrigerator is presented here, based on the object-oriented Modelica programming language. The (5 kW @ 4.5 K) He refrigerator of the ITER Central Solenoid Model Coil (CSMC), installed at the National Institutes for Quantum and Radiological Science and Technology, Naka (Japan), is chosen as reference for the model development, being its thermodynamic cycle fully representative of the refrigerators operating in many existing superconducting magnet facilities as well as in different existing and future tokamaks. The Collins cycle operated by the CSMC refrigerator features three cooling stages: the first one, assisted by liquid nitrogen precooling, from 300 K to 80 K, the second, based on two isentropic expansions in turbines, and the third, relying on isenthalpic J-T valves down to 4.5 K.
The model of each component, developed based on the CSMC design and operation data, is independently tested and then added to the "CryoModelica" library, which is also used by the 4C code for the analysis of thermal-hydraulic transients in SC magnets.
The new refrigerator model is tested both in steady-state conditions, when a constant heat source is applied to the system, and in transient mode, connecting a time varying heat source to the client. The results are shown to be coherent with what expected from the operation of the real plant in both operation-modes.
The model presented here is ready for the implementation of all the necessary controls and for its coupling to the detailed 4C magnet model. This will allow the integrated simulation of the cryoplant and the magnet for validation purposes, and, in perspective, the prediction of the refrigerator operation in support of the design and optimization of its automatic control strategies.

Keywords

Nuclear fusion, superconducting magnets, He refrigerator, thermal-hydraulic modelling, dynamic model

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D5

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

Parametric study and optimization of the cryo-magnetic system for EU DEMO at the pre-conceptual design phase

Wednesday, September 22, 2021 12:50 PM (25 minutes)

The pre-conceptual design phase of the EU DEMO magnet system relies on mechanical, electromagnetic and thermal-hydraulic analyses of different conductor designs for the Toroidal Field (TF) coils, the Poloidal Field coils and the Central Solenoid magnet. The cryo-magnetic system includes the superconducting magnets cooled by forced flow of supercritical helium at about 4.5 K, the cryo-distribution lines and valve boxes, and the cryogenic system with several cold boxes. The present analysis focuses on the cooling capacity of the TF coils with three winding pack options for the cable in conduit conductors (based on 2015 DEMO baseline), featuring pancake or layer winding approaches. Parametric studies on the cold source temperature and on the supercritical helium mass flow rate, are performed on the three conductor designs in order to identify for each one the impact of the cooling conditions onto the temperature margin with respect to the current sharing temperature. In addition, Simcryogenics, a dynamic modelling tool developed by CEA, is used to model supercritical helium loops for cooling different conductor designs. An algorithm has been developed to optimize the cold source temperature and the supercritical helium mass flow, in order to minimize the refrigeration power for each conductor design. Both parametric and optimization studies are analyzed and compared in order to estimate for each TF winding pack design the impact on the refrigeration power. The interest of such quick cross-check analyses is to identify design improvements for the conductors and the cryo-distribution, keeping acceptable temperature margins and minimizing the refrigeration power.

Keywords

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D3

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

Stability Analysis of ITER Central Solenoid During Plasma Scenario

Wednesday, September 22, 2021 1:15 PM (25 minutes)

For large scale fusion magnets of the ITER tokamak, wound with cable-in-conduit conductors, the application of sophisticated numerical models able to analyse the thermal-hydraulic behaviour during plasma scenario is of paramount importance to guarantee adequate stability margin during the operating conditions. The SuperMagnet code has been developed by CryoSoft with the intent to simulate simultaneously electrical, thermal and hydraulic aspects during the operation of superconducting coils.
In this work, the SuperMagnet code is applied to analyse the thermal-hydraulic behaviour of the Central Solenoid of the ITER tokamak under the plasma scenario. The CS magnet system is composed of six modules for a total amount of 240 pancakes. The software is able to tackle the complex structure of the CS and its cryogenic closed loop. In the present work, the circulation pump operation and the heat transfer to helium bath are investigated. The results presented here show the temperature evolution of the magnet and of the supercritical helium during plasma scenario, which allows determining the operation margin of the CS. The stability is further investigated by analysing the quench initiation and propagation in the most critical locations of the system.

Keywords

Cable-in-conduit conductor (CICC), Central Solenoid (CS), ITER, Thermal-hydraulics, SuperMagnet, Plasma Scenario.

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D3

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

Performance assessment of multi-tube He II/He II heat exchanger using a single tube sample

Friday, September 24, 2021 12:50 PM (25 minutes)

Superconducting high-field magnets working in He II are usually immersed in a pressurized static He II bath. This pressurized He II bath is then connected through a heat exchanger to a saturated He II bath acting as a cold source. Due to the peculiar He II properties (very high heat conductivity), the conventional heat exchanger designs are not suitable here. In addition, a compact design is often mandatory, as space inside cryostats is always an issue.
In a recent paper, we presented different configurations of optimized multi tube heat exchangers depending on the available horizontal or vertical space. Such an optimized compact heat exchanger prototype has been built to fulfill the cooling needs and the integration constraints of the HL-LHC superconducting D2 recombination dipole. The chosen design with hundred oxygen-free high-purity copper horizontal tubes penetrating inside the extremity of the D2 cold mass vessel is an efficient solution offering significant operating margins.
From the thermal analysis, it appears that the profile and value of the temperature difference across the heat exchanger really depends on the ratio of the transverse conductance to the longitudinal conductance, the former being determined by the conductivity of the copper and the Kapitza conductance. Therefore, optimization and prediction of the thermal performance of such a heat exchanger is only possible when these thermal properties (i.e., the conductivity and Kapitza conductance of the copper tubes) are well known. For that purpose, we built a dedicated test bench to perform these Kapitza resistance measurements on a single pipe, while the thermal conductivity and RRR measurement were measured independently in laboratory apparatus. The experimental results obtained on a single pipe were then used to infer the behavior of the overall heat exchanger. The comparison of the predictive code and the cryogenic measurements shows excellent agreement over a wide range of cryogenic operating conditions (temperatures, pressures, heating powers).
This paper presents guidelines for designing compact and efficient He II/He II heat exchanger as well as a method to predict the performance of such heat exchanger accurately.

Keywords

Superfluid, Heat exchanger

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D5

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

A Numerical Investigation on AC Losses in one module of the Central Solenoid of the ITER tokamak

Thursday, September 23, 2021 12:00 PM (25 minutes)

The investigation of electromagnetic transients in the superconducting coils of the ITER magnet system is important in order to compute the losses arising during time-varying operating conditions. The challenge of this analysis is related to the high number of degrees of freedom required to discretize large-scale magnets at the level required for AC loss computation. The Central Solenoid (CS) of the ITER tokamak is composed by six modules; each module is made up of 554 turns arranged in 40 pancakes, for a total length of about 6 km of Cable in Conduit Conductor. In this study, a methodology based on numerical simulations is proposed for the electromagnetic analysis of one module of the ITER CS. The electromagnetic THELMA code, developed at the University of Bologna (Italy), was previously used to analyse AC losses measured both in a straight ~4 m long sample of the CS conductor tested in the SULTAN facility at the Swiss Plasma Center (Villigen, Switzerland) and in the ITER Central Solenoid Insert coil, a single layer solenoid wound with a~43-m-long piece of the same conductor, tested at the premises of QST (Naka, Japan). The comparison of numerical and experimental results allowed identifying the main fitting parameter of the THELMA model, namely the interstrand conductance per unit surface.
In this work, the THELMA model is applied to the computation of AC losses in one module of the ITER Central Solenoid. The cable-in-conduit conductor is discretized at the last-but-one cabling stage and the numerical analysis is performed both at the single turn and at the single pancake level. The model results obtained at both levels of the analyses were compared to each other. A methodology was then developed in order to reduce the computational burden required by the analysis of the ~6-km-long conductor. This methodology, based on reducing the length of the analyzed cable and the number of turns involved in the computation, allows one retaining a high level of accuracy and analysing the losses in the whole CS module. The validation of the numerical approach is performed by comparison with the experimental results of the tests of the first CS module, performed at the General Atomics (GA) facility in Powey (US). The map of coupling and hysteresis loss distribution in the CS module is presented, thus identifying the most thermally stressed regions of the magnet.

Keywords

AC losses, Nb3Sn Magnets, Central Solenoid, Electrodynamic transients

Category

Electromagnetics modelling of LTS and HTS magnets

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Session Classification: Electromagnetics D4

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

Improving the SuperMagnet model; recent developments and future activities

Friday, September 24, 2021 12:00 PM (25 minutes)

Recent developments are introduced to improve the performance of the SuperMagnet model. Since an attempt to implement a momentum-conserving nodal branch, a series of study has been carried out shedding a light to the next step to the improved performance, by means of careful investigations to the numerical structure of the integrated model. From the latest quench model with adaptive time-step to the innovative coupling scheme to solve the instability, the outcomes of recent studies are presented, which are to be applied progressively for better numerical modelling of the integrated components. At the same time, some important ideas are also discussed leading the direction to the near future of the SuperMagnet code suite.

Keywords

Cryogenics, Hydraulic model, Superconducting magnet

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D5

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

Multiphysics Finite Element Modelling of "close-to-real" coil winding of a Toroidal Field Coil in a Tokamak

Wednesday, September 22, 2021 1:50 PM (25 minutes)

Finite Element Modelling (FEM) is the common practice for the design and performance evaluation of superconducting magnets. Electromagnetic models are combined with structural ones to first compute the forces that are applied to the magnet during its operation and then evaluate the stress distribution that is attained in its subcomponents. Due to the computational size of the global problem, a simplified configuration of the coil winding is usually implemented in the models: the coil is not modelled as a continuous wound cable, but each of its turns is a closed loop positioned in a grid to recreate the section and global geometry of the magnet. This results in a uniform distribution of the current in all the magnet sections and does not account for the electromagnetic effects in correspondence of the winding and layer jumps and of the coil terminations. This paper discusses the FEM procedure that has been developed with Ansys APDL to include these details in the 3-dimensional (3D) electromagnetic and structural model of a Toroidal Field Coil system (TFC) of a Tokamak. We evaluated the effect of implementing a "close-to-real" winding pack and compared the results with those from an ideal model, both in terms of electromagnetic field generated and stress levels in the magnet. In addition, we show how the detailed force distribution computed can be exploited as an input for structural sub-models to evaluate stress conditions in correspondence of the winding and layer jumps and of the coil terminations. This work has been completed as part of the EUROfusion roadmap to fusion energy in the framework of the development of the Divertor Tokamak Test facility (DTT) currently under construction at the ENEA Research Center of Frascati, Italy.

Keywords

TFC, tokamak, winding pack, Nb3Sn, CiCC, FEM

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D3

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

Design Studies, Magnetic and Structural calculations for a DEMO hybrid CS proposal

Thursday, September 23, 2021 12:25 PM (25 minutes)

The Roadmap to Fusion Electricity draws on innovative experiments pivotal for the accomplishment of the European DEMO, i.e. the demonstration fusion power plant by the EUROfusion Consortium.
At the end of the pre-conceptual design phase, the machine comprises three main magnetic systems: 6 poloidal field (PF) coils, 16 or 18 toroidal field (TF) coils and the central solenoid (CS), primary member of the ideal transformer in which the induced plasma is the secondary. A few design solutions are being studied, in order to enhance the performance of the CS in terms of magnetic flux density, structural integrity and feasibility.
The ENEA design proposal is based on a layer wound graded design, comprising for each CS module a High Field, a Medium Field and a Low Field sub-module made of Nb3Sn Cable-in-Conduit Conductors.
The option of an additional inner High Temperature Superconducting (HTS) grade, is also analyzed. Among the different CICC design options being considered, a new possibility is proposed identified with the acronym RRIS (Round-in-Round-In-Square): a circular insulated jacket is inserted in an external rectangular 316LN structure.
The proposed solution aims to obtain a cable capable of withstanding the intense electromagnetic loads generated during the DEMO plasma scenarios, preserving the CICC turn insulation integrity.
This work presents the updated solution generated via the ENEA Design Explorer algorithm, and the magneto-structural analyses for this design.

Keywords

fusion, tokamak, superconductivity, magnets, DEMO, CICC, EUROfusion, ITER

Category

Electromagnetics modelling of LTS and HTS magnets

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Session Classification: Electromagnetics D4

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

Methodological aspects of adequate modeling of the quenching process in insulated and non-insulated REBCO-tape-wound multi-double-pancake high-field magnets

Monday, September 20, 2021 3:05 PM (25 minutes)

Methodological aspects of modeling of the quench process in insulated and non-insulated ("metal-insulated") multi-double-pancake HTS REBCO-tape-wound coils are considered consistently and systematically, taking into account all important effects and inputs affecting the quench behavior and characteristics. Examples of comprehensive quench simulation in real magnetic systems are demonstrated using modern presentation tools. The presented models are not based on the finite-element method.

Keywords

No-insulation coils, quench simulation, complex simulation model, non-linearities

Category

Quench experiment, simulation and analysis for all classes of LTS and HTS magnets

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Session Classification: Quench D1

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

Thermal Analysis of He II-cooled Nb3Sn Superconducting Coil Samples for the HL-LHC Particle Accelerator Project

Monday, September 20, 2021 12:25 PM (25 minutes)

The High Luminosity upgrade of the Large Hadron Collider (HiLumi-LHC) foresees the installation
of Nb3Sn based dipoles (11T Dipole) and quadrupoles (MQXF) at select points of the
accelerator. The precise knowledge of its thermal characteristics and heat extraction performance in response to deposited loads is essential
in determining safe operating margins of the magnets. These fully
impregnated Nb3Sn coils have seen an evolution in the design and impregnation process towards production coils.
In this context, experiments measuring thermal performance of two samples from each of these type of magnets in superfluid helium have been carried out at the Central Cryogenics Laboratory at CERN. The heat load is generated either via AC losses induced by a superconducting coil external to the
samples or with a kapton covered foil-heater placed on the outer surface for two of the samples, while measuring the temperature of the cable layers in situ. The steady-state and transient behaviour of the samples have been studied. The transient thermal response of the samples is used to estimate the presence of helium within porous parts of the solid regions.
To simulate the heat flow in the combined superfluid-solid system of the experiment, a numerical model has been developed using open-source software. The robustness of the numerical solver has been validated with the experiment data, in particular across the domain of the heat loads used in the experiments and will be used to extend its application to models of the full magnet with distributed power deposition as expected during accelerator operation.

Keywords

thermal analysis, superfluid He cooling, Nb3Sn magnet samples

Category

Mechanical modelling of LTS and HTS magnets

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Session Classification: Mechanical modelling of LTS and HTS magnets

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

Comparative Thermal-hydraulic Study of High-Field Superconductors Nb3Sn and REBCO suitable for the HELIAS Stellarator Reactor

Within the EUROfusion Roadmap, the helical-axis advanced stellarator (HELIAS) is investigated as a possible long-term alternative to a tokamak fusion power plant. Its superconducting magnet system is based on modular field coils with a complex 3D shape (similar to but a lot larger than Wendelstein 7-X coils), and faces therefore several engineering challenges. The W7-X magnet system is based on the low temperature superconductor (LTS) NbTi, which cannot be used as a starting point for the development of HELIAS magnets due to the much higher magnetic field of up to 12.5 T at the conductor. HELIAS requires the use of more advanced "high-field" superconductor materials, e.g. the LTS Nb3Sn or High temperature superconductor (HTS) REBCO which lead to additional challenges. One critical aspect is the behavior of the superconductor in case of a quench. For LTS cable-in-conduit-conductors (CICC), thermal-hydraulic models for stability and quench of the conductors were developed and qualified in detail, for example during the design of the ITER magnet system and its conductors. For the HTS materials, the minimum quench energy (MQE) is orders of magnitudes higher but the normal-zone-propagation velocity is orders of magnitude smaller due to the different material properties. Additionally, the geometry and dimensions of LTS and HTS "strands" is fundamentally different, with LTS being fabricated as multi-filamentary wires of about 1 mm in diameter and most HTS REBCO-based conductors being proposed as ˜1 cm thick strands of several flat tapes (of several mm in width).
In this contribution, three different conductor options for the HELIAS magnet system, one with Nb3Sn and two with REBCO, are presented. Different winding options, e.g. layer versus pancake winding for REBCO and Nb3Sn, and related cooling options are elaborated. The THEA software is used to model the thermal-hydraulic performance of the three conductors in case of quench and to determine the MQE and hot-spot temperatures.

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Keywords

Category

Quench experiment, simulation and analysis for all classes of LTS and HTS magnets

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

Numerical Studies of High Field-Rate Losses in Cable-In-Conduit-Conductors Carrying Transport Current

Thursday, September 23, 2021 12:50 PM (25 minutes)

In large size conductors for the Central Solenoid (CS) and Poloidal Field (PF) coils of tokamaks, the AC losses set the operating limits for the magnets, especially during the plasma start up. In terms of losses, the startup of the plasma current (breakdown) can be particularly challenging, as the flux density rate can reach values as high as 10 T/s. At such high-field rates, the cable is partially saturated by the screening currents, and the classic treatment for the ac losses is no longer valid. In this work we extend the pioneering model developed by Ogasawara et al. for high field rates in cable-in-conduit conductors carrying a dc transport current. We used 1D numerical methods for calculating the coupling, hysteresis and dynamic resistance losses contributions. The losses were determined as a function of transport current and external varying field. A 2D Finite-Elements model has also been implemented by means of commercial software. A single, but field-rate dependent coupling time constant, $n\tau(dB/dt)$, has been introduced in order to account for the multiple induced currents loops typical of a multi-stage cable-in-conduit-conductor. The behavior of $n\tau$ vs. dB/dt is based on the experimental results from the most recent SULTAN tests on the rectangular DEMO Low Field conductor, in which trapezoidal field pulses have been employed. The developed 1D and 2D numerical models were applied to the computation of the ac loss of the PF and CS coils of the Divertor Tokamak Test (DTT) Facility, in its reference plasma scenario. The numerical results, that have also been compared with those obtained using the validated THELMA code, show that the energy loss is reduced with respect to the losses obtained with classical models, especially at the plasma startup, where the saturation effects become dominant.

Keywords

ac loss, saturation, high field-rate, tokamak, magnet coils

Category

Electromagnetics modelling of LTS and HTS magnets

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Session Classification: Electromagnetics D4

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

New single coupling loss time constant scaling relation for CICC conductors subjected to fusion magnet conditions

Wednesday, September 22, 2021 2:15 PM (25 minutes)

New cable concepts for the magnetic field coils of the upcoming fusion reactors are under development, with circular or rectangular cross-section. Some prototypes have been tested for DC transport current and AC loss in the Sultan facility (SPC) and for inter-strand contact resistance and AC loss at the University of Twente. The facilities both provide experimental data on the AC loss properties of the tested conductors but the conditions are different from the most severe Plasma Operating conditions. The classical single time constant based on sinewave applied fields with low frequency, leads to an over assessment of the coupling loss during plasma operation conditions. In order to provide a suitable scaling relation for the use of a simple single coupling loss time constant system, two applied magnetic field pulse profiles are considered; sinewave and trapezoidal, and the effect on the AC loss and current distribution are studied with the JackPot model. The code JackPot-ACDC provides the full current distribution versus time in all strands for applied magnetic field and transport current variations. The experimental results from interstrand contact resistance measurements carried out at the University of Twente, are used to calibrate and benchmark the simulations.
The analysis of coupling loss and current distribution shows the impact of the magnetic field changes on the conductor AC loss, translated into a single effective time constant depending on the shielding effect. One notable outcome of the study is the significantly simplified scaling of the level of coupling loss in the conductors with relevance to the magnetic field profiles under Plasma Scenario conditions. With this method, a more accurate real time calculation of the coupling loss is feasible without time demanding complex numerical computations or conservative overestimation by using the classical single time constant.

Keywords

Category

Multi-scale and multi physics design methods

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Session Classification: Multi-scale D3

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

Complementary Analysis and Modelling on superconducting JT-60SA TFC conductor

Tuesday, September 21, 2021 12:25 PM (25 minutes)

In the framework of Cold Test Facility (CTF) at CEA Saclay, JT-60SA TF coils (TFC) were tested in nominal operating conditions (25.7 kA and 5 K) followed by experimental study and numerical modelling of the quench. An additional experimental activity was conducted in order to perform further measurements on the two TFC spares. The first aim of this test program was to allow further comprehension of supercritical helium flow behavior in a Cable-In-Conduit Conductor (CICC); the second objective was to create a large database available for developing numerical models for the CICC. The study is focused on the parameters influence and coupled phenomena like interface resistances, thermal contact between pancakes or between winding and casing, heat losses and convective heat transfer. This paper presents the main results of the experimental analyses and modelling that are conducted for different hydraulic scenarios such as the influence of the cooling mass flow rate on the conductor stability. The impact of the quench initiation, detection parameters and propagation remains a central issue that is analyzed in the case of a low current quench. The numerical simulations are performed with 1D THEA code using a local approach.

Keywords

Category

Quench experiment, simulation and analysis for all classes of LTS and HTS magnets

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Session Classification: Quench D2

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

Sensitivity analysis on material properties in mechanical analysis of YBCO tapes during axial and transverse loading

Monday, September 20, 2021 12:50 PM (25 minutes)

High Temperature Superconductor (HTS) tapes are expected to enable future magnets to reach magnetic fields beyond 20 T. Detailed knowledge on how these composite coated conductors behave is needed to design reliable magnet applications. The mechanical strain causes the YBCO layer within the tape to degrade, meaning that its critical current I_c drops, leading to under-performing devices. The mechanical strain accumulates during magnet cool-down and powering of the coils. In this work, we present a 3D elasto-plastic mechanical model of a single YBCO tape implemented using the free open source FEM library Sparselizard. We present the mechanical analysis of YBCO tape during cool-down, axial, and transverse loading and the resulting stress and strain distribution within the tape layers. The definition of material properties becomes a significant uncertainty in the tape simulation. A sensitivity analysis is performed to quantify the impact of varying the elastic and plastic mechanical material properties of YBCO, copper, Hastelloy, silver, and buffer layer. The results show how sensitive the mechanical stress and strain in the YBCO layer is to the variation of individual material properties.

Keywords

Category

Mechanical modelling of LTS and HTS magnets

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Session Classification: Mechanical modelling of LTS and HTS magnets

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

Electro-mechanical modeling of the fusion cables

Monday, September 20, 2021 1:15 PM (25 minutes)

Until today several designs of the Nb3Sn Cable-In-Conduit Conductors (CICCs) have been developed for different high-performance tokamak magnets. The Nb3Sn strands composing the conductors are submitted to mechanical stresses of electromagnetic (EM) and thermal origin, inducing local deformations and affecting the strands critical current carrying capability. Even though it is possible to test the conductors to evaluate the electrical performance, it is still not possible to predict them during the conceiving phase.
The main goal of this work is to present a numerical tool able to predict the electrical performance of the conductor in operation, based on the finite element (FE) code simulations MULTIFIL. The code was adapted in the past to simulate the mechanical behavior of the fusion conductors subjected to several loadings. However in the last three years the code and the numerical approach have been largely upgraded to consider a more realistic model and simulation of the conductor. The mechanical results of code MULTIFIL are coupled with analytical and numerical electroamgnetic tools to compare the simulated electrical performance with the experimentally measured ones. More over several studies have been performed to investigate the influance of the design parameters such as the void fraction, the twist pitches and the conductor shape, on the electrical perfomance of the conductor.

Keywords

Category

Mechanical modelling of LTS and HTS magnets

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Session Classification: Mechanical modelling of LTS and HTS magnets

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

High-performance multiphysics FEM simulations in the Sparselizard open source library

Thursday, September 23, 2021 1:15 PM (25 minutes)

This talk demonstrates the capabilities of the open source FEM library Sparselizard (sparselizard.org) through mini-examples focused on the physics of interest for particle accelerator magnets. The equations and simulations are set up on the 3D geometry of CERN's Feather M2 particle accelerator magnet for the following physics:

- DC electric current flow through the magnet conductor
- Static magnetic field including saturation in the iron yoke
- Mechanical deformation due to the magnetic field forces
- Multiphysic simulation of a quench propagation in the magnet combined with conformal adaptive mesh refinement and interpolation order adaptivity (hp-FEM)
- Large scale acoustic wave propagation through the magnet with a high performance domain decomposition algorithm running on a supercomputer

Because using the Sparselizard library leads to a very compact and concise code the miniexamples can all be described in details down to every single line of code. All mini-examples will be provided online.

Keywords

Category

Electromagnetics modelling of LTS and HTS magnets

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Session Classification: Electromagnetics D4

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

Analysis of Current Distribution in Rutherford Cables for Accelerator Magnets as an Engineering Tool

Friday, September 24, 2021 1:15 PM (25 minutes)

We describe in this paper how the analysis of current distribution and redistribution in Nb3Sn Rutherford cables can be used to assist in the analysis of manufacturing issues and decision on the closure of major non-conformities. After describing the method and the model in detail, we apply it to the case of a cable defect next to the coil termination, a single strand breakage in a multi-strand cable, which could be thought as a relatively mild event. We show that in the range of parameters applicable to accelerator magnets even a minor defect can have the potential for significant performance reduction. These results have been instrumental to coming to a decision in the manufacturing flow.

Keywords

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D5

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

Welcome

Welcome the participants and presentation by M. Liao on the status of the TIER Superconducting magnets.

Session Classification: Welcome

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

CHATS-AS 2023 Announcement

Keywords

Category

Session Classification: CHATS-AS 2023 Announcement

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

CHATS-AS Closure

Keywords

Category

Session Classification: Closure