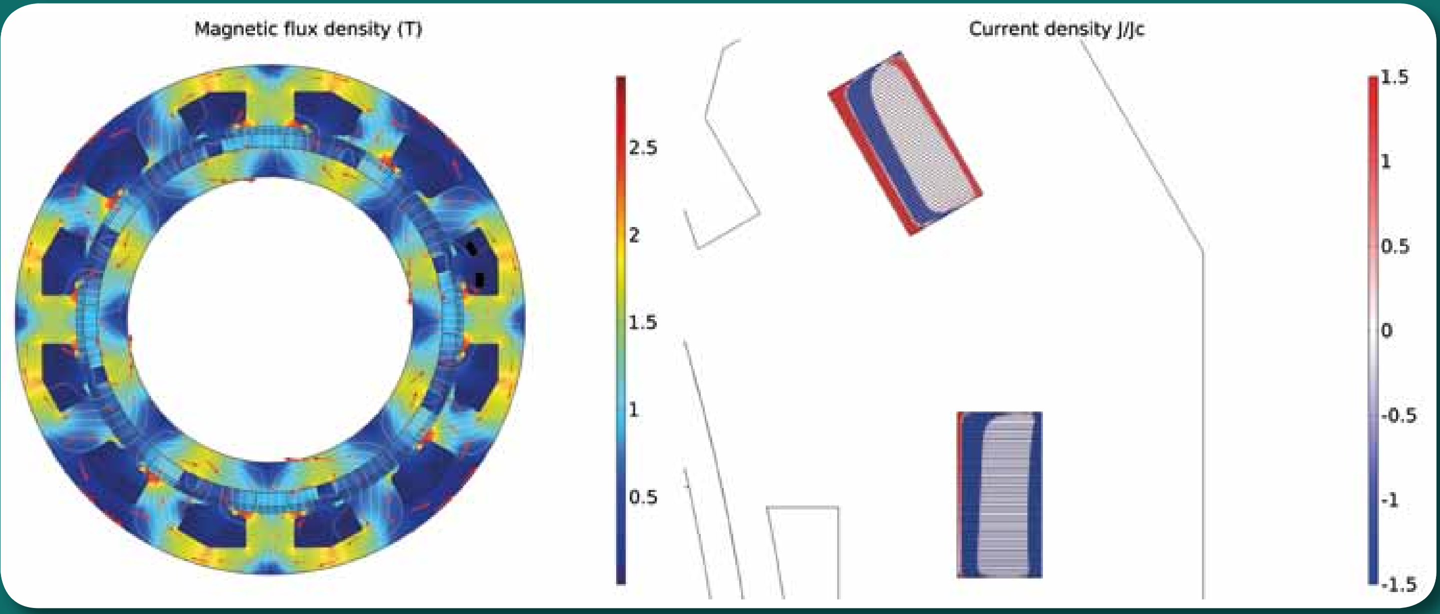
Karlsruhe Institute of Technology

ITEP – Institute for Technical Physics

Results of Research and Development
2019 Annual Report

INSTITUTE FOR TECHNICAL PHYSICS



Imprint

Karlsruhe Institute of Technology (KIT)
Institute for Technical Physics
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen,
Germany

Phone +49 721/608-23 501
www.itep.kit.edu

BG-zertifiziert nach NLF / ILO-OSH 2001

Texts:
Tabea Arndt, Christian Day, Walter Fietz, Jörn Geisbüsch, Thomas Giegerich, Francesco Grilli, Steffen Grohmann, Roland Gyuráki, Stefan Hanke, Jens Hänisch, Bernhard Holzapfel, Frank Hornung, Marion Kläser, Thomas M. Kochenburger, Ralph Lietzow, Ingeborg Meyer, Mathias Noe, Simon Otten, Alan Preuß, Sonja Schlachter, Stylianos Varoutis, Pattabhi Vishnuvardhan-Gade, Klaus Weiss, Michael Wolf

Translation: KIT Translation Service

Photos and charts: Karlsruhe Institute of Technology (KIT)

Cover photo:
Coupled electromagnetic design of a fully superconducting Machine (left) and simultaneous exact calculation of the magnetic field distribution in the individual tape conductors of the coil (right)

Gestaltung: modus: medien + kommunikation gmbh
www.modus-media.de

July 2020

Contents

PREFACE

The Institute of Technical Physics (ITEP) sees itself as a national and international competence centre for fusion, superconductivity and cryotechnology with the research fields

- Superconductor and cryomaterials
- Power engineering applications of superconductivity
- Superconducting magnet technology and
- Technologies of the Fusion Fuel Cycle

The work of the ITEP is anchored in the long-term programmes “Fusion”, “Storage and Networked Infrastructures” and “Matter and Universe” of the Karlsruhe Institute of Technology (KIT) and the Helmholtz Association of German Research Centres.

Very large and unique experimental facilities, laboratories and the corresponding technical infrastructure are available to deal with the complex and mostly multidisciplinary tasks. These are, for example, a laboratory for the development of superconducting energy technology components, a laboratory for the development of superconducting materials, the high-field magnet laboratory for the development of superconducting magnets of high fields, the cryogenic high-voltage laboratory for the investigation of the high-voltage strength of cryogenic insulating materials and the cryogenic material laboratories for the investigation of electrical and mechanical properties at very low temperatures.

In 2019, our institute achieved very good scientific results, a large number of successful development projects and some special challenges and events, which are briefly described below. We would like to highlight two important developments.

After more than 11 years of affiliation with the ITEP, the Tritium Laboratory Karlsruhe was assigned to the IEKP as of April 2019. Due to the focus of the TLK on the KATRIN project and a secured financing, this reallocation was supported by all participants. We wish the TLK and all employees all the best and much success.

Within the framework of a Helmholtz recruitment initiative, a new professorship "Superconducting Magnetic Technology" with Dr. Arndt from Siemens Corporate Technology could be filled competently and on a long-term basis. This means that all important fields of application for superconductivity are now covered by one instiutute and, uniquely in Europe, the entire value chain from materials to high-current applications can be researched at the ITEP. Prof. Dr. Arndt is a member of the collegial institute management of the ITEP.

Fig. 1: Prof. Dr. Arndt accompanies the new professorship "Superconducting Magnet Technology" at ITEP

In the research field of **superconductor and cryomaterials,** the investigation and further development of YBa2Cu3O7 tape conductors is an important focus. In 2019, fundamental investigations on the dependence of critical quantities on oxygen loading were investigated. Optimal settings for this important process step could be determined in a very large parameter range. Within the scope of an enabling research project of FUSION, specific production processes and a selection of alloys were investigated for structural materials for magnets, which allow higher strength and improved fracture behaviour for use in magnets at cryogenic temperatures. First materials with improved mechanical properties at cryogenic temperatures could be produced by cold and hot forming. A new phase equilibrium facility CryoPHA-EQTS for the investigation of mixture cooling circuits was successfully put into operation and first mixtures up to a temperature of 85 K were investigated. In the development of high current conductors, 40 kA were achieved in an arrangement of 12 CrossConductor conductors. Furthermore, the upscaling of the manufacturing process patented at ITEP was improved. For the first time longer samples were manufactured in a roll-to-roll process.

A new joint project was started in the **Energy Applications research field to develop a superconducting** industrial busbar with a current strength of 200,000 amperes. Our task here is, among other things, the planning, preparation and execution of tests on scaled components. In the modelling and simulation of high-temperature superconductors, a detailed electromagnetic simulation of a fully superconducting machine was coupled for the first time in an EIU project with a detailed simulation of the superconductor for the exact determination of the alternating current losses. The calculation time and accuracy is thus significantly improved. See also the title page of the annual report. In the TELOS joint project for the development of electric aircraft, a superconducting busbar was further developed and, in particular, the contacting was significantly improved. As an essential part of the Energy Lab 2.0, the new Building 668 was handed over and the laboratory infrastructure was set up. This includes, among other things, a 1 MVA Power-Hardware-in-the-Loop test stand and a 60 kW flywheel energy storage.

An important task in the research field of **superconducting magnet technology** is the development of high-temperature superconducting magnets. Here, the process patented at the ITEP for the production of cross conductors suitable for high current could be further developed. For the first time, roll-to-roll production was demonstrated and a high-current demonstrator was successfully tested at 40 kA. Furthermore, in our test facility HOMER II, the use of high field coils with a layer winding of YBCO tape conductors in a background field of 20 T a maximum field of 26.5 T was achieved. Within the scope of a German-Chinese project funded by the DFG (German Research Foundation), several non-insulated coils were manufactured for a superconducting wind power demonstrator using direct current and successfully tested at their operating point of 30 K.

In the research field of **Fusion Fuel Cycle Technologies** we develop fundamentally new vacuum technologies and processes for tritium extraction and recovery. Together with an industrial partner, the world's largest NEG pump to date, which works with a new getter material, was developed and tested at the ITEP. A new equipment for material characterization for the process of temperature-vibration-absorption to shift the concentration between different hydrogen isotopologues in a mixture was successfully put into operation and first results show the absorption behaviour of hydrogen in palladium at different conditions. Furthermore, all currently discussed divertor configurations were compared with each other using a uniform approach. The extraction efficiency was calculated with varying pump efficiency. The results show that new divertor geometries have a significantly higher efficiency than the previously proposed references for ITER and DEMO. For the first time worldwide a tritium compatible mercury liquid ring pump was characterized. The mercury diffusion pump built at ITEP and optimized for high pressures was put into operation and is working.

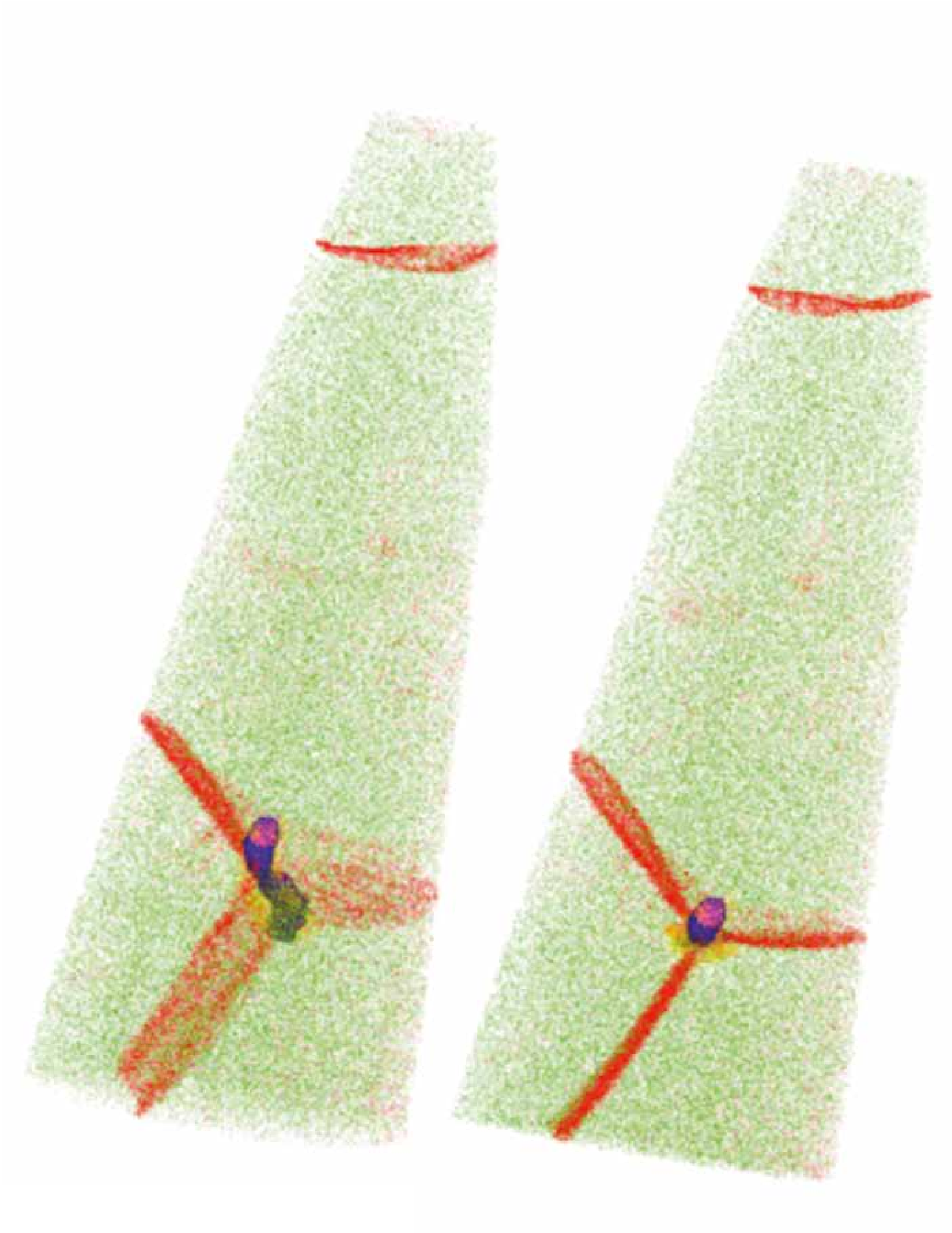
In 2019, a total of 36 doctoral students were **supervised** by ITEP staff and 11 master students.

We would like to express our special thanks to all employees of the ITEP and all cooperation partners from universities, research institutes and industry for the very trusting as well as extraordinarily fruitful and successful cooperation in 2019.

Yours Sincerely

Mathias Noe   Bernhard Holzapfel

Tabea Arndt



Atom probe tomography of an internally oxidized Nb_3Sn low-temperature superconductor prepared via powder-in-tube (PIT) method. Green: superconducting matrix, red: Cu segregation at the grain boundaries. Along the crossing line of three grain boundaries, oxide precipitates (yellow and purple) are highlighted through an iso-area envelope. The sample dimensions are ca. 80 nm x 200 nm. Sample and analysis provided by Bruker EAS, ITEP, and KNMF.

Results from the Research Areas

Superconductor and Cryogenic Materials

Coordination: Professor Dr. Bernhard Holzapfel

The understanding of superconducting materials and the characterization of material properties at cryogenic temperatures as well as the realization of conductor concepts are core and backbone of any superconducting energy or magnet application. Therefore, we are currently working on the following research topics in the research field of superconducting and cryomaterials:

- Superconducting Materials
- Cryogenic structural materials
- Cryogenic material properties
- Conductor development

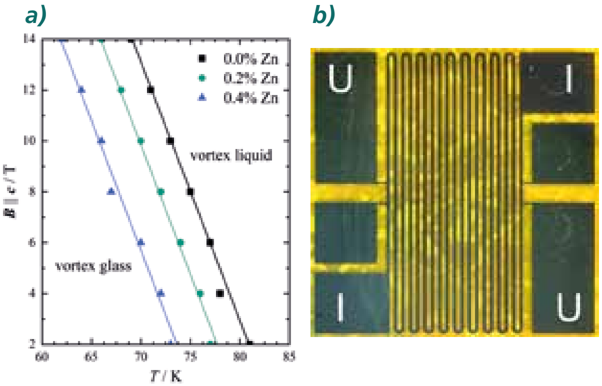


Figure 1: (a) Glass-liquid transition of $YBa_2(Cu_{1-x}Zn_x)_3O_{7-δ}$ layers as a function of Zn content. (b) Meander structure for the higher-resolution electrical transport measurements.

Superconducting Materials

The main activities in this research topic include fundamental material science questions, such as the improvement of the electrical transport properties of established superconducting materials, as well as application-oriented studies on new, promising superconductors and the industry-oriented technological development of HTS coated conductor production.

Materials Research

High-temperature superconductors. The oxygen content of $REBa_2Cu_3O_{7-δ}$ layers (RE rare earth) is an essential parameter for the quality of the superconducting properties. Therefore, the oxygen loading process for layers with different microstructures (grown with chemical solution deposition, CSD, and/or pulsed laser deposition, PLD) was investigated in detail this year. To optimize this process, electrical relaxation was measured on CSD samples to determine the kinetics of oxygen diffusion. Oxygen diffusion occurs in two clearly distinct regimes (high and low temperatures) with different activation energies. The transition temperature between the two regimes depends characteristically on the rare earth and possible nanoparticle additions. It can be correlated with the so-called Ortho-I-Ortho-II transition between different oxygen ordering structures. This information can also be used to make the oxygen loading process as cheap and fast as possible.

Not only the content of oxygen in the layer, but also the details of the loading process decisively determine the superconducting properties, since during the oxygen loading, different defect structures, including stacking faults and RE_2O_3 particles may develop depending on oxygen pressure, temperature and holding time. This was investigated on $GdBa_2Cu_3O_7$-2.5wt%$BaHfO_3$ nanocomposites grown with pulsed laser deposition, where the critical current density could be increased by a factor of 2 by optimizing the oxygen loading.

Magnet applications require pinning landscapes in $REBa_2Cu_3O_{7-δ}$ coated conductors specially designed for low temperatures. Since the coherence length $ξ_{GL}$ is particularly small in this temperature range, atomic defects are especially promising to further increase the pinning force densities. To better understand the underlying pinning effects, glass-liquid phase transitions, Figure 1a, and pinning force distributions of $YBa_2(Cu_{1-x}Zn_x)_3O_{7-δ}$ layers were investigated [Ackermann et al., J. Phys. Conf. Ser. 2020]. For this purpose, the approximately 250 nm thick layers were structured in a meandering pattern, Figure 1b, and electrically characterized. The Zn doping reduced T_c by about 15 K/%, which is well comparable with literature values. The pinning force distribution in these layers was mostly independent of temperature. The activation of the pinning centers therefore occurs exclusively in a narrow temperature range just below T_c.

Fe-based superconductors. The microstructure of $Ba(Fe_{0.92}Co_{0.08})_2As_2$ layers produced by pulsed laser deposition was investigated by scanning transmission electron microscopy (STEM) on cross-sectional samples (Figure 2). In the case of CaF_2 substrates, the superconducting layers grow epitaxially on the substrate with homogeneous thickness (Figure 2a). Planar defects (mostly stacking defects) are visible as dark horizontal lines and could improve the superconducting properties by reducing microstrain. In addition, iron-rich precipitates and other foreign phases (e.g. BaF_2) form in the layers (Figure 2b). The composition was determined from high-resolution STEM images and energy dispersive X-ray spectroscopy (Figure 2c). These precipitates, whose growth depends strongly on the deposition parameters, could also be detected and determined in X-ray diffraction and showed up in surface topographical images by atomic force microscopy.

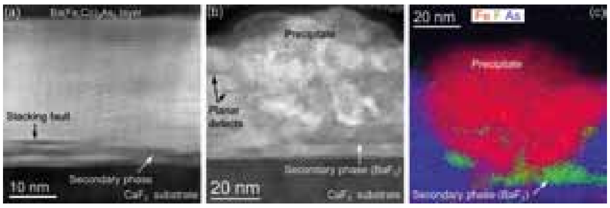


Figure 2: STEM cross-sectional images of a $Ba(Fe,Co)_2As_2$ layer. (a) Epitaxial growth of the layer on the substrate with defects and foreign phases at the interface. (b) Locally larger precipitates in the layer, mainly consisting of iron, as detected by chemical analysis using STEM-EDXS (c). The arsenic signal marks the $Ba(Fe,Co)_2As_2$ main phase.

In order to investigate possible increase of the current carrying capacity, 35 to 110 nm thick $Ba(Fe_{0.92}Co_{0.08})_2As_2$ nanocomposite layers with $BaHfO_3$ nanoparticles were produced using a quasi-multilayer technology in pulsed laser deposition [Meyer et al., et al., J. Phys. Conf. Ser. 2020]. Complete $Ba(Fe_{0.92}Co_{0.08})_2As_2$ layers and incomplete $BaHfO_3$ layers alternate. The critical temperatures drop slightly from 23 K to 19 K with increasing BaHfO3 content. The critical current density Jc, however, increases significantly with increasing $BaHfO_3$ content and reaches almost 106 A/cm2 in self-field at the highest investigated BaHfO3 content of 1 mol%. The pinning densities Fp also increase 10-fold and reach 50 GN/m³ at 11 T and 1 mol% $BaHfO_3$, Figure 3.

$Ba(Fe_{0.92}Co_{0.08})_2As_2$ films as well as a $REBa_2Cu_3O_7$-$BaHfO_3$ nanocomposite films could also be investigated in pulsed fields up to 65 T at the Los Alamos high-field laboratory regarding their critical fields and critical current densities. Meanders were structured similar to those shown in Figure 1b but on a smaller area, and current-voltage characteristics were measured during the magnetic pulse using a novel technique developed in Los Alamos [Leroux et al. Phys. Rev. Appl. 11, 054005

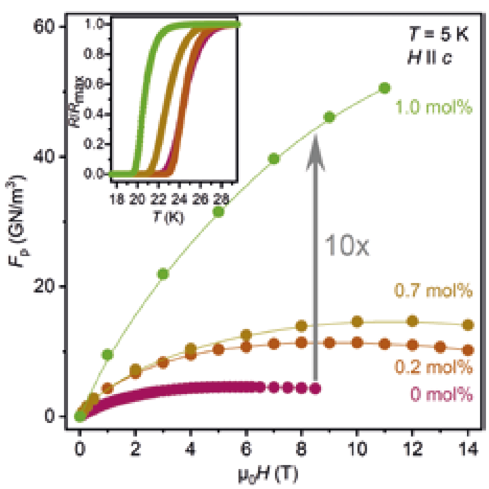


Figure 3: Magnetic field dependence of the pinning force density of $Ba(Fe_{0.92}Co_{0.08})_2As_2$-$BaHfO_3$ nanocomposite layers for different BaHfO3 concentrations Inset: Normalized resistance of the layers near the critical temperature.

(2019)]. Further measurement trips for these investigations are planned for 2020.

In HiperFBS, a bilateral DFG-funded project with the Institute of Electrical Engineering of the Chinese Academy of Sciences Beijing, which started in April 2019, tapes and wires made of Fe-based superconductors for high-field applications are being developed. Within this framework, several tapes of the cooperation partner were measured with regard to their microstructure and current carrying capacity. Further bilateral collaborations on Fe-based superconductors exist with the group of Kazumasa Iida at Nagoya University and the group of Xiaoli Dong at the Institute of Physics, Chinese Academy of Sciences Beijing. Within the scope of these activities, the anisotropy of the electrical transport properties of NdFeAs(O,F) and (Li,Fe)OHFeSe layers in magnetic fields up to 14 T were investigated in detail.

Nb_3Sn. In the research cooperation between BRUKER, CERN, and KIT on Nb_3Sn low temperature superconductors, the focus in 2019 was on the targeted generation and characterization of nanoscale precipitates (see Figure 4) in the superconducting phase. As has been shown, these precipitates act as artificial pinning centers and have the potential to increase the current carrying capacity of existing conductor concepts by more than 70% [Bühler et al., IEEE Trans. Appl. Supercond. 2020]. The resulting microstructure was analysed by scanning and transmission electron microscopy as well as atomic probe tomography. In parallel, prototypes of novel conductor concepts were produced for evaluation, which, in addition to producing fine precipitates, aim at grain refinement in the Nb_3Sn microstructure.

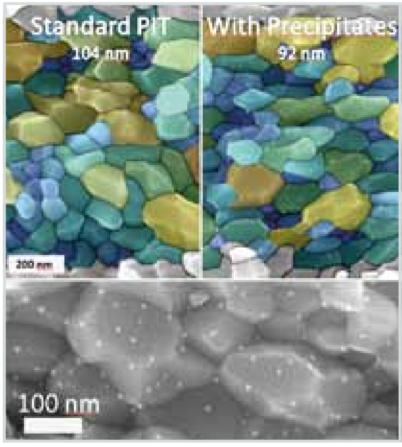


Figure 4: Fracture surfaces through the Nb_3Sn microstructure. Above: coloured according to grain size (left: reference, right: sample with nanoscale precipitates), bottom: magnification.

Technology development

HTS coated conductor production. In our cooperation with Deutsche Nanoschicht GmbH, we were able to significantly improve coating and pyrolysis compared to 2018 by rebuilding and optimizing the reel-to-reel oven. X-ray analysis after crystallization showed that this year's samples show significantly higher intensities of the desired (00l) orientation and on the other hand much less misaligned (200) and (103) components. Thus, for the first time, it has now been possible to implement the entire CSD process for the continuous production of superconducting YBCO coated conductors. However, the still very low critical current density values necessitate further optimization.

Characterization. Within the framework of several EU projects (ASuMED, SuperWind) and bilateral cooperations, the current carrying capacity of REBa2Cu3O7 coated conductors of various manufacturers (THEVA, SuperOx, SuperPower, Shanghai Creative SC) was measured in fields up to 6 T and currents up to 1000 A [Lao et al., Rev. Sci. Instr. 90, 015106 (2019)]. Furthermore, novel THEVA coated conductors with reduced substrate thickness of 50 µm could be tested at the Grenoble high-field laboratory in fields up to 20 T. The superconducting properties are comparable to the thicker tapes, except for field orientations parallel to the ab-planes, which can be explained by the large Lorentz forces. In FastGrid (EU project), bending tests at 77 K were performed on THEVA coated conductors optimized for superconducting fault current limiters. Minimum possible bending radii of 1.25 cm (tension) and 0.5 cm (compression) without degradation are promising.

Contact: Jens.Haenisch@kit.edu

Cryo-Structural Materials

High strength structural materials for cryogenic magnet applications are mandatory for fusion technology and are funded within the Enabling Research project. Further, additive manufacturing exhibits a significant potential for cryogenic applications. Fatigue tests on additive manufactured 316LN samples adds to the work performed so far. Fundamental investigation to understand the deformation mechanism at cryogenic temperatures of special Senkov alloy is continued within a DFG project.

Enabling Research Project "High Strength Materials". The successfully obtained project within this research topic is funded by EUROfusion and started in January 2019. Basic background is the improvement of cryogenic mechanical properties of austenitic steels (316LN) by specific deformation processes. The work is done within the CryoMaK laboratory managed by the ITEP and is divided in three work packages. Within the first work package the possibility to adapt the microstructure by successive cold and hot forging is investigated. Steel samples were produced by the company COMTES (Czech Republic). By selective variation of process parameters, the grain size was successfully reduced from about 80 µm to 19 µm. Compared to room temperature the mechanical properties at 77 K were significantly enhanced. For a comprehensive characterization of the mechanical properties, further experiments (tensile and fracture experiments at liquid Helium) are in preparation. The second work package deals with the potential of cryogenic rolling as a deformation process to adapt the microstructure. This process was conducted by the Technical University of Kosice (Slovakia). Plates of 15 mm thickness were deformed by rolling about 30% and 30%. The process was conducted with non-cooled plates at room temperature as well as with 77 K pre-cooled plates and first results were compared. These showed a clear increase of the mechanical properties regarding the toughness in rolling direction. Especially the 77 K pre-cooled plates exhibit an enormous increase of the yield stress of about 100%. Investigations are ongoing to describe the impact of rolling deformation on the microstructure. In addition, further tests regarding fracture behavior are foreseen. Within the frame of the third work package in 2020 these deformation

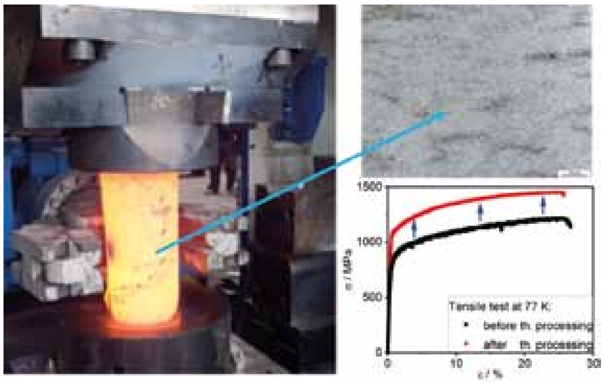


Figure 5: Forged 316LN with microstructure (grain size about 20 µm) and mechanical tensile test.

process should be transferred to alternative alloys and the potential to manufacture components for cryogenic application will be analyzed.

Additive Manufacturing of 316L. Following the successful manufacturing by Powder Bed Fusion together with first tensile tests at cryogenic temperatures the fracture behavior was investigated especially by fatigue performance at low temperatures. These tests revealed a problem of the manufacturing process. During the laser melting of the powder material defects in the size of the powder particle (about 40 µm) are introduced.

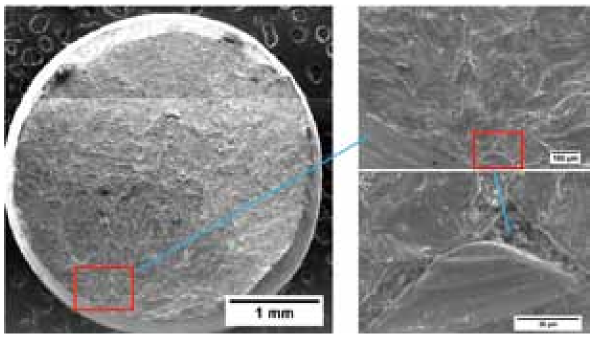


Figure 6: Fracture surface after fatigue test of additive manufactured 316L. Failure initiated at shown defect.

This leads to a premature failure during cycling loading. Detailed studies of these macroscopic defects are performed in collaboration with the Institut für Angewandte Materialien (Werkstoffkunde) aiming to adapt the production process.

DFG Project „High Entropy Alloys". After the successful synthesis of the room-centered-cubic High-Entropy alloy HfNbTaTiZr, called Senkov-alloy, further investigations regarding the origin of their low temperature characteristic were performed. Mechanical compression experiments were done at cryogenic temperature and the development of the microstructure analyzed.

Band structures within the grains are seen and their angular alignment need further assessment to describe a deformation mechanism. This work will be continued in 2020 together with the Institut für Angewandte Materialien (Werkstoffkunde).

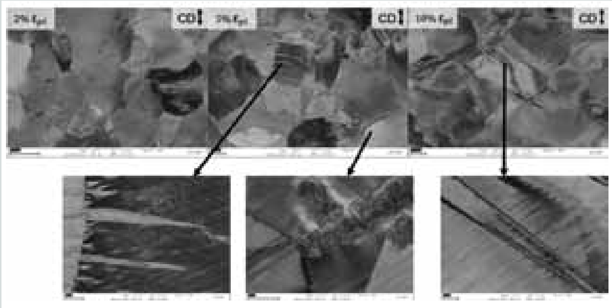


Figure 7: Senkov-samples after successive deformation under compression (2%, 5%, 10%). Development of band structures within grains.

Contact: Klaus.Weiss@kit.edu

Cryogenic fluid properties

In the frame of our technology development of cryogenic mixed-refrigerant cylces (CMRC) for high-temperature superconductor (HTS) applications, a first doctoral thesis [1] was completed in co-operation with the Institute of Technical Thermodynamics and Refrigeration (ITTK). The technology and the application limits are based on the physical properties of cryogenic fluid mixtures, which are not sufficiently investigated yet. For this purpose, the cryogenic phase equilibria test stand CryoPHAEQTS was commissioned, where properties of all cryogenic fluid mixtures can be investigated at temperatures down to 15 K and pressures up to 150 bar. The experimental data will be used to develop equations of state, which are needed to describe real fluid properties for process design and optimization.

In the frame of a further doctoral thesis, the development of a numerical modelling framework for CMRC heat exchangers was completed. First prototypes of micro-structured CMRC heat exchangers were developed in co-operation with the Institute of Micro Process Engineering (IMVT) and tested successfully.

Contact: steffen.grohmann@kit.edu

[1] Kochenburger, T.: Kryogene Gemischkältekreisläufe für Hochtemperatursupraleiter-Anwendungen. Dissertation, Karlsruher Institut für Technologie, 2019, isbn: 978-3-8439-3987-4.

Conductor and Wire Concepts

In 2019, a technology transfer preparatory grant enabled the significant improvement of HTS CrossConductor (HTS CroCo) fabrication by implementing novel fabrication technologies. The HTS DC demonstrator could be operated continuously at a current of 36 kA for more than 39 minutes. Many research projects requested the laser-patterning of specialized geometries and within an European project with CERN, additional Roebel-cables were manufactured.

Technology Transfer Preparatory Grant „CroCo4Industry". Multiple improvements of different aspects of HTS CroCo fabrication were achieved and novel approaches could be followed with the support of a KIT technology transfer preparatory grant. Generally, the maturity of the fabrication could be improved and key steps towards the marketability of HTS CroCos were taken. First the fabrication setup was relocated to its new, permanent position in building 408 and fabrication tolerances were reduced significantly. Figure 8 shows a polished cross-sectional view of one recent sample made of tapes of 2 mm and 3 mm width. These band-widths correspond to the smallest currently commercially available REBCO tapes. Consequently, absolute tolerances correspond to largest relative tolerances. The cross-shaped geometry of the tape-stack and the overall round solder shell is very well achieved, deviations from the ideal shape are below 0.1 mm. Measurements of the critical current in a liquid nitrogen bath confirm the expected critical currents as calculated from individual tapes' data.

Figure 8: Polished cross-sectional image of a HTS CroCo conductor made of 2 mm and 3 mm wide tapes. The cross-shaped tape stack and the round solder shell is very well formed.

Further focus was put on the realization of a setup for the reel-to-reel fabrication of untwisted HTS CroCos in a reel-to-reel process. The preparation of HTS CroCo conductors in a continuous process from multiple REBCO tape spools to a final HTS CroCo drum is considered a key step towards marketability. For cost reasons, only two to four superconducting tapes were used, the remaining tapes were copper tapes. Figure 9 shows a snapshot of the HTS CroCo drum during the fabrication process with multiple turns of the fabricated HTS CroCo on the drum.

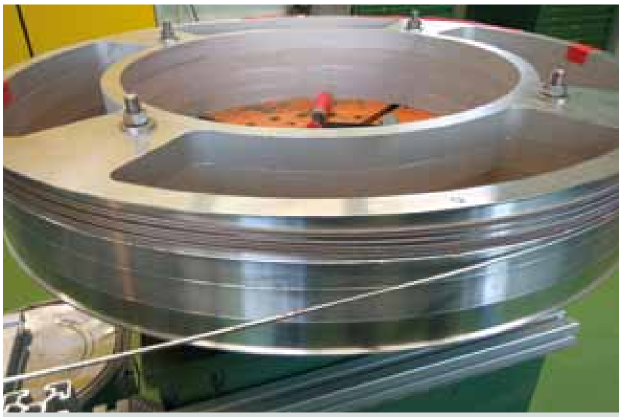


Figure 9: Reel-to-reel fabrication of HTS CroCos.

Super-DC-Demonstrator. Two test campaigns of the superconducting high-current-cable demonstrator setup were carried out in 2019. Due to an improvement of the contact resistances, a critical current of 33 kA was achieved. The electric fields of the individual twelve HTS CroCos were calculated and compared to expected values. The measured and calculated values show a very good agreement as shown in Figure 10(a). Additionally, the stability of the setup during constant-current operation was tested and a current of 36 kA was driven through the demonstrator for more than 39 minutes without quench (i.e., a loss of superconductivity due to a self-amplifying temperature increase). For currents of 37 kA and above, no stable operation could be obtained and the increasing voltage triggered the quench detection system and current shut-down. Figure 10(b) shows the time-evolution of the voltage of HTS CroCo No. 12, this was the HTS CroCo with the highest voltage in the superconducting part of the setup.

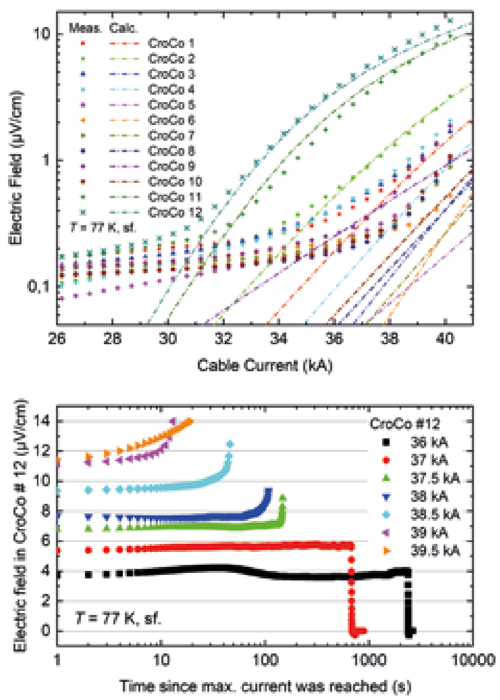


Figure 10: (a) Measured electric field of the twelve HTS CroCo strands (symbols) and expected field (dashed lines) as a function of the total cable current. (b) time dependence of the electric field of HTS CroCo 12 for different constant currents.

In a second test campaign, a novel close-to-application contact concept was implemented and tested. The contact scheme made use of a common connector part to which all HTS CroCo strands were soldered. This lead to an order-of-magnitude reduction of lead resistances compared to previous tests. The improved current distribution between the individual conductors lead to an increased critical cable current of 38 kA and a reduced transition width between the twelve strands as visualized in Figure 11.

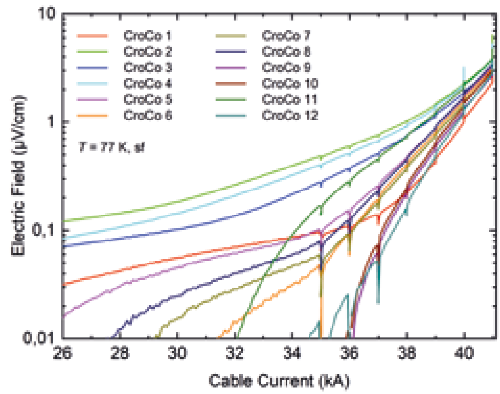


Figure 11: Electric field of the twelve HTS CroCos of the Super-DC-demonstrator as a function of the cable current in a test campaign with improved close-to-application termination scheme.

Roebel cable for "EuCARD2-FUM". Within the EU-project EuCARD2-FUM, different REBCO tapes from Bruker company were punched to the required Roebel geometry. The company performed the post-punching silver-coating and electrolytic surrounding copper plating. On a semi-automatic cabling machine, Roebel-cables were formed at ITEP and delivered to CERN. CERN fabricated successfully the FEATHER.M2.3-4 test coils form such Roebel cables and achieved magnetic fields of 4.2 T at 4.5 K.

Contact: Michael.Wolf@kit.edu

Installation of a 60 kW-3.6 kWh flywheel mass storage for the Energy Lab 2.0 at KIT

Results from the Research Areas

Energy Applications of Superconductivity

Coordination: Prof. Dr.-Ing. Mathias Noe

In the research field Energy Applications of Superconductivity the ITEP's scientific and technical staff is doing R&D in the following topics:

- Superconducting network components
- New applications of superconductivity
- Modelling of superconductors and components
- Real-time system integration

Superconducting network components

The focus in the topic of superconducting network components is on the development of new types of equipment for electrical energy systems. The researchers achieved the following results in 2019.

EU project FASTGRID. The goal of the EU project FASTGRID (www.fastgrid-h2020.eu/) is to significantly improve superconducting strip conductors for use in DC current limiters, towards higher switching capacities and higher currents. Compared to the current state of the art, this requires modifications to the conductor geometry.

For this purpose, a large number of experiments and simulations of the switching behavior were carried out at the ITEP in 2019. The difference between the AC and DC switching behavior of the superconducting tape conductor was compared and the necessity of sufficient conductor stabilization was demonstrated. Despite extensive investigations and modifications to the conductor and test setup, it has not yet been possible to achieve the targeted high switching capacities in a reproducible manner.

In addition, a comprehensive life cycle analysis for the manufacturing process of a superconducting tape conductor was carried out in a doctoral thesis supervised jointly with the Institute for Technology Assessment and Systems Analysis (ITAS). The manufacturing process was recorded and analysed in detail in order to be able to estimate various environmental factors. The investigation shows the great influence of the substrate. Since most manufacturers are currently reducing the substrate thickness further, this proportion will continue to decrease. Compared to copper and aluminum, the environmental influences during the production of superconducting tapes are lower.

BMWi joint project DEMO200. On 1.7.2019, the DEMO200 joint project funded by the BMWi was started. Together with our partners Vision Electric Superconductors, Messer, Trimet, d-nano and Theva, the aim is to develop the technology for a compact and efficient industrial DC high curent busbar with a current of 200,000 amperes and to demonstrate its functionality in a test.

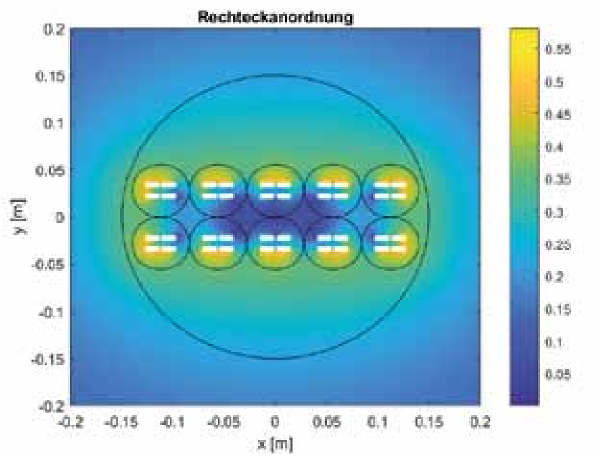


Fig. 1: Magnetic field calculation for the arrangement of about 500 superconducting tapes for a bus bar with 200 kA

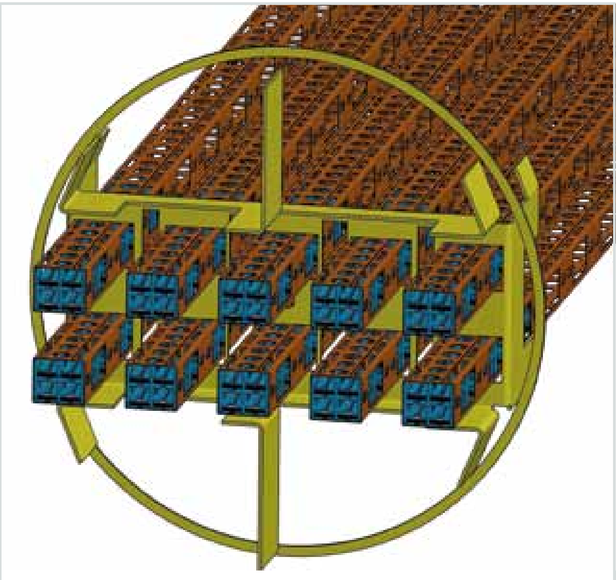


Fig. 2: Structural arrangement of ten 20 kA modules for a superconducting 200 kA busbar

In the project, the ITEP has taken on the task of characterising the superconducting tape conductors, helping to develop the basic geometry and the contacts and conducting a test on a scaled busbar element. Figure 1 shows magnetic field calculations to optimize the arrangement and the superconductor requirements. To achieve 200 kA, currently about 500 ribbon conductors must be connected in parallel.

Figure 2 shows a possible arrangement of the conductors, dividing the busbar into 10 submodules of 20 kA each.

Contact: Mathias.Noe@kit.edu

New Applications of Superconductivity

The main focus of this research topic is essentially on electric or hybrid electric aircraft propulsion systems. The work is carried out within the project TELOS (funded by the German Ministry of Economics and Technology) with partners such as Airbus and Siemens and in close cooperation with Siemens in the context of various doctoral theses. Thematically, the work of the research topic ranges from the development of tools for the analytical design and optimization of hybrid electric aircraft drives, via the design and construction of a rotating electric machine based on superconducting MgB2 stator windings to the development of a power distribution system based on high-temperature superconductors (TELOS). Furthermore, within the EU project ASUMED, methods for 2D modelling of individual windings in a motor winding and for 3D modelling of motor components are being developed. Although these activities also relate thematically to electric aircraft engines, they are formally assigned to the research topic "Modelling of Superconductors and Components". In the following, the work carried out in 2019 is presented in detail.

As part of a PhD thesis in close cooperation with Siemens a detailed motor design was carried out for rotating electrical machines based on superconducting stator windings made of magnesium diboride. For this purpose, a transient electromagnetic FEM model, a thermal CFD model and a structural-mechanical model of the motor were developed. To evaluate the properties of MgB2 conductors, commercial 114-filament conductors were characterized with respect to their current carrying capacity at different temperatures and magnetic fields.

In the framework of the project TELOS, development work continued on a 2-pole DC-HTS power distribution system for hybrid-electric aircraft propulsion systems with a power in the 40 MW range. It is designed as a modular busbar system, with special attention being paid to contacts and branches. For the individual elements of the busbar system, a 3D-printed carrier structure made of a non-conductive polyamide material was developed and tested. The carrier structure is able to compensate for thermal length changes of 5 mm per meter of cable length and to absorb the high Lorentz forces acting on the superconductors at currents above 10 kA. In combination with the cooling medium it ensures sufficient electrical insulation between the two poles and between the poles and the inner cryostat tube.,

For the connection of the busbars, contacts for superconductor tape stacks have been developed within the TELOS project, which enable a low-resistance redistribution of the current between the individual tapes of the stacks. Such joints were tested with regard to current carrying capacity and longitudinal and transverse resistances. The longitudinal resistances within a superconductor plane are about 30 nΩ for overlap lengths of 24 mm in stacks of 10 tapes of 12 mm width (see Figure 1 and Table 1). The transverse resistances between the 1st and 10th level are in the range of only 200 nΩ despite the tape structure with insulating buffer layers. For the total resistances of such contacts, values are in the range of 5 nΩ or less, so that the losses for currents of 13.3 kA are less than 1 Watt.

Figure 3: Schematic representation of a joint between two stacks with 10 REBCO tapes each.

to \ from	SC01+	SC01-	SC02+	SC02-	SC05+	SC05-	SC10+	SC10-
SC01+		33,0 nΩ	23,9 nΩ	46,7 nΩ	109,5 nΩ	92,9 nΩ	169,2 nΩ	198,2 nΩ
SC01-			55,8 nΩ	77,4 nΩ	131,9 nΩ	116,3 nΩ	195,9 nΩ	218,5 nΩ
SC02+				26,8 nΩ	94,0 nΩ	77,4 nΩ	154,1 nΩ	184,1 nΩ
SC02-					73,1 nΩ	55,7 nΩ	140,4 nΩ	167,2 nΩ
SC05+						26,7 nΩ	97,6 nΩ	124,0 nΩ
SC05-							112,1 nΩ	140,3 nΩ
SC10+								35,5 nΩ
SC10-								

Table 1: El. resistance between tapes of two joined stacks consisting of 10 REBCO Tapes each either within a stack plane (SCi+ ↔ SCi-, green filling) or between different planes of the stacks (SCi+/- ↔ SCj+/-),

For conduction cooled current leads from 300 K to 20 K, loss calculations were carried out which showed that, with a suitable choice of material, they do not have to be designed for the maximum current during flight due to the strongly varying load profile. By reducing the cross section, not only the total losses are reduced, but also the weight can be reduced considerably.

Since the construction of a hydrogen infrastructure is not possible within the current TELOS project for reasons of time and cost, a cryogenic demonstrator is being built in the area of the CuLTKa facility, that allows gaining of knowledge about flow resistances, temperature and pressure conditions on the basis of gaseous helium. After completion of the design phase, construction drawings were prepared for this demonstrator and various components were manufactured or procured externally. In the area of the CuLTKa facility, the carrier frame for the KRYO demonstrator was built. Parallel to this work, the inner cryostat tubes were equipped with the carrier structure and dummy tapes and tested with regard to their dielectric strength. In several tests it could be shown that at voltages up to about 4 kV no flashovers occur between the two poles of the cable or between the poles and the grounded cryostat tube.

To design and optimize the entire drive train of a hybrid-electric drive system, an analytical component model for the drive unit including the power electronics was created. This model is currently being extended by models for power distribution, propeller/fan, transmission, battery and cooling unit, so that the interactions of the individual systems can be taken into account in the overall optimization.

Contact: Sonja.Schlachter@kit.edu

Modelling of Superconductors and Compo-nents

The focus of the research work was the experimental investigation of the electrothermal behaviour of "pancake coils" when local heating occurs. For this purpose, two pancake coils were manufactured, one with and one without electrical insulation between the windings. In order to simulate a local weak point at constant cur-rent below the critical current, a heating resistor was placed on the surface of the coils, which was used to create an area with reduced critical current density by locally increasing the temperature of the superconduc-tor. In addition, to electrical measurements of coil ter-minal voltage, current and developed magnetic field, fluorescent thermal imaging was used over the entire coil surface to analyze temperature changes and cur-rent redistribution. Fig. 4A shows the temperature dis-tribution in the insulated coil after the occurrence of a local defect, The temperature increase associated with a transition to normal conduction occurred only in the windings directly in contact with the defect, because there was no alternative electrical path and the thermal conductivity was reduced by the capton insulation layer. In a similar measurement on the non-isolated coil shown in Fig. 4B, a much longer heating period was required to destabilize the coil. In this coil, the local heat input caused a redistribution of the currents within the coil - due to the comparatively low contact re-sistance to adjacent windings - and finally led to the normal transition from the centre of the coil. This was the weakest point of the coil during the design phase, since both a stronger magnetic field and an ohmic cur-rent flow helped to reduce the critical current density of the superconductors locally.

In order to investigate and understand the time-variable properties and the overcurrent behavior, a multiphysics model based on a distributed circuit model is designed and implemented in MATLAB, which takes into account the local contact resistance, the self- and mutual in-ductance and the resistance of the supercon-ducting tape in the normal conducting state

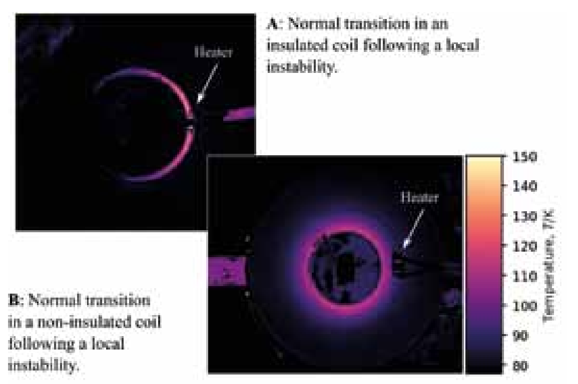


Fig. 4: Thermal imaging for visualization and calculation of temperatures in HTS coils.

Within the EU project ASUMED, a finite element method model based on the T-A formulation was implemented in COMSOL Multiphysics and used to calculate the losses in the stator windings of fully superconduc-ting machines. The model allows the calculation of the time-dependent magnetic field distribution throughout the machine and the details of the current density deve-lopment in the individual superconducting windings within the same model. The T-A formulation (in its form with homogenized conductors) has been used to calcu-late the shielding currents and field drift in large HTS magnets, such as the 32 T-magnet of the National High Magnetic Field Laboratory, whose HTS insert consists of tens of thousands of turns (Fig. 5).

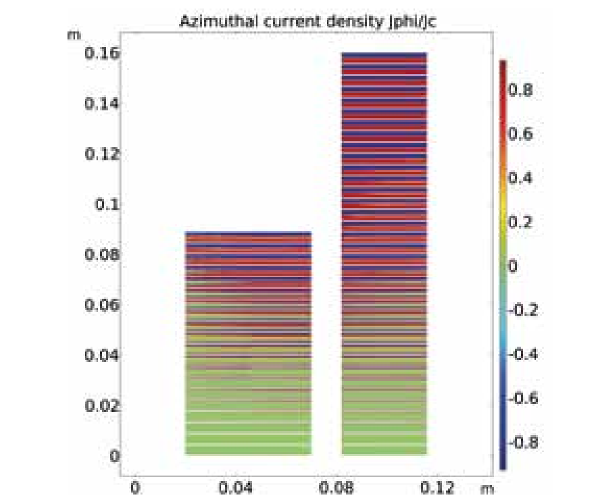


Fig. 5: Sshielding currents in the HTS insert of the 32 T NHMFL magnet, calculated with the homogenized T-A formulation).

In a collaboration with EPF Lausanne, Switzerland, a combination of very fast pulsed high current measurements and numerical simulations was used to extract the resistivity of the REBCO layer of HTS-coated conductors for current densities exceeding the critical current at various temperatures. The aim is to assess whether and to what extent a simpler description of the REBCO resistivity than the well-known "power-law model" can be used to simulate HTS tapes in supercritical situations. Figure 6 shows a typical (I,T) surface

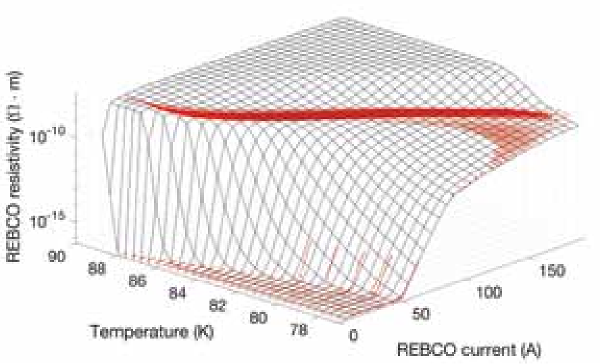


Fig 6: Typical rho (I,T) surface for the REBCO material of a commercial tape conductor, reconstructed from measured data points (red points) using a regularization method (grid)

for the REBCO material of a commercial ribbon conductor, reconstructed from experimentally measured data points using a regularization procedure.

Contact: Francesco.Grilli@kit.edu

Real-time System Integration

In the research topic "Real-time System Integration", far-reaching developments have taken place over the past year in the fields of infrastructure and laboratory set-up, as well as in the research areas of sector coupling, applied superconductivity, energy storage systems and grid studies.

The development of the MVA Power Hardware-in-the-Loop (PHIL) laboratory environment has significantly progressed. All 200 kVA modules have been delivered, installed and commissioned. The power supply unit and primary distribution were already approved at the beginning of the year, followed later by the cooling system. The output distribution was set up. In addition, a controllable resistive load, which can - if required - absorb the total power of the system, was purchased. The design of inductive and capacitive loads and other equipment was completed and orders have been placed. The components of the real-time system and the measurement technology were also successfully integrated into the system, so that the first "closed-loop" operation of parts of the system was achieved at the end of the year (see Fig. 7). The group is working in a focused manner with industry partners to ensure that all operating modes of the PHIL system become ready for use early in 2020.

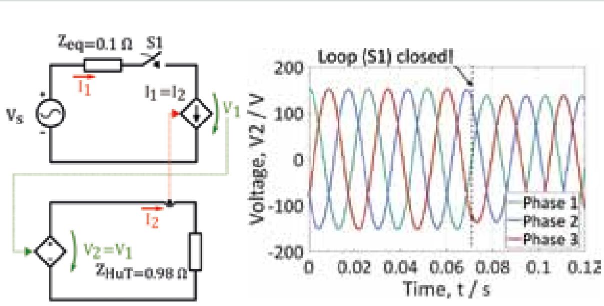


Fig. 7: PHIL test setup: First "closed-loop" operation of a 200 kVA module in the MVA PHIL laboratory.

In the BMWi joint project FlyGrid, in which possible applications of a 500 kW flywheel energy storage system (FESS) in distribution grids are investigated, advantages of such system were studied in the grid of a major southern German distribution system operator (DSO). This led to installation site suggestions to ensure locally the best use of the equipment. For this purpose, an investigation of the voltage sensitivities based on load flow calculations of the entire system with 1264 nodes was carried out. Based on local measurement data, the results were verified using data analysis methods. For example, "Mutual Information" as a correlation measure was used to estimate the relationship between voltage and power. Real-time simulations of the power grid environment at selected locations with a time resolution of <50 μs were utilized to test for transient effects in the PHIL laboratory. The installation and connection of the FESS at the Energy Lab 2.0 is currently being prepared. Figure 8 shows the grid support provided by the equipment at a selected installation site.

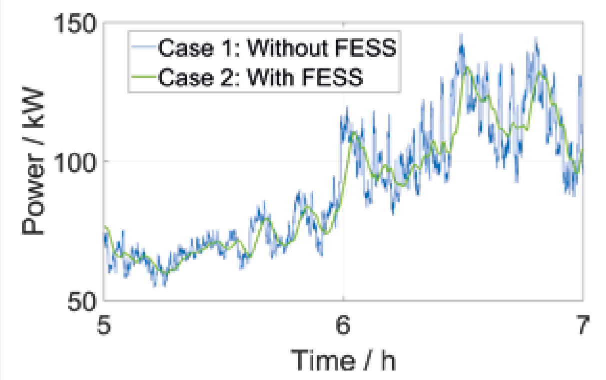


Fig. 8: FlyGrid FESS: Application of the component for power smoothing and hence for improved integration of renewable generation.

A modular FESS with an initial unit of 60 kW and a total energy storage capacity of 3.6 kWh has been set up and is ready for operation. In order to study the aggregation of storage solutions in the future, further storage components, such as battery systems and supercapacitors, were procured. Electrical storage components hardware can be integrated in the laboratory using an existing Imperix system.

In the BMBF joint project Sector Coupling (SEKO), the goal at ITEP is to set up test stands with a micro gas turbine and a combined heat and power plant (CHP). While a suitable CHP was already acquired, the configuration and assembly of the micro gas turbine system has been well advanced in 2019. Detailed physical simulations of components, such as the turbine, internal combustion engine and generator, as well as investigations into the control of the systems were carried out. These simulations will be ported to a real-time environments in the next step.

In phase 1 of the Kopernikus project ENSURE, the evaluation of the use of a superconducting 380 kV cable was completed. This study proposed a detailed design for

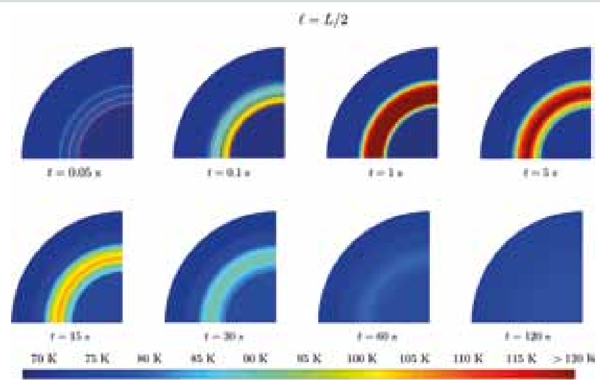


Fig. 9: Simulation of a concentric three-phase cable consisting of HTS tapes: Temperatures inside the cable at different times at half of the cable length l = L / 2 = 500 m.

use in the 380 kV three-phase AC transmission grid. General aspects of the application are explained and superconductor technology is compared to other technologies regarding different performance criteria. To support such studies, detailed physical simulations of equipment employing high-temperature superconductivity (HTS), such as cables and fault current limiters, were implemented (see Fig. 9) and also performed in real-time.

Contact: Joern.Geisbüsch@kit.edu

Highlight: The completion of building 668 and commissioning of the 1 MVA Power-Hardware-in-the-Loop test facility are major infrastructural achievements that took place in 2019.

After two years of construction work, the new laboratory building (Fig. 10) was handed over for use to the IAI and ITEP in June 2019. The building hosts the Smart Energy System Simulation and Control Center (SEnSSiCC) of the Energy Lab 2.0. The main components are a data analysis and simulation laboratory, a control and visualization laboratory, a modular microgrid and a 1 MVA Power-Hardware-in-the-Loop (PHIL) test facility, which is operated by ITEP.

Fig. 10: Exterior of the new laboratory building 668 hosting the microgrid and the Power-Hardware-in-the-Loop laboratory.

The total power output of one mega-volt-ampere (MVA) of the PHIL system is achieved by five 200 kVA modules, which were installed by the Austrian power electronics company Egston during the last year. An important milestone in commissioning was reached with the first closed loop operation at the start of December 2019. The PHIL laboratory equipped with an OPAL RT real-time grid simulator is now available for a wide range of power grid investigations. Initially the focus is on storage integration and sector coupling, especially combined heat power (CHP) plants.

Furthermore, a 60 kVA flywheel energy storage system (Fig. 11) was commissioned in 2019. The commissioning is about to be followed by extensive investigations of the device in the PHIL laboratory in spring 2020. A micro CHP unit utilizing a piston engine and a micro gas turbine are also being set up. First investigations of these plants are scheduled in 2020. Main objectives are to provide validated and real-time capable models of the components and to improve grid integration of the systems by developing grid-supportive controls.

Contact: Joern.Geisbüsch@kit.edu

Fig. 11: Installation of a 60 kW, 3,6 kWh flywheel energy storage system at the Energy Lab 2.0 site of the KIT.

HTS insert coil in front of HOMER II during installation

Results from the Research Areas

Superconducting Magnet Technology

Coordination: Dr. Walter Fietz

On the basis of experience from numerous large-scale experiments like the ITER TFMC construction and test, following topics were formed in the area Superconducting Magnet Technology:

- Coil technology
- HTS fusion magnets and current leads
- Rotating machines
- Industrial applications

To push the NMR technique towards higher resolution, the research topic "coil technology" tackles the realization of highest magnetic fields. Therefore, an insert coil with High Temperature Superconductors (HTS) was developed, which generates in the background field of HOMER II a magnetic field above 26 Tesla in a 68 mm bore.

In the research topic "HTS fusion magnets and current leads", the application of HTS materials for future fusion magnet systems is in focus. Beside the design principle of such magnets for Tokamak and Stellarator machines, the development and test of high current HTS conductors is a focal point.

In the research topic "rotating machines", superconducting stator-systems for efficient wind turbines have been designed and different variations of coil designs have been developed and fabricated. In parallel, completely superconducting engines for future electric airplanes have been modeled.

In the research topic "industrial applications" the transfer of the know-how generated in the research area Superconducting Magnet Technology. Cooperation in the field of NMR and superconducting induction heaters are examples for this.

Contact: Walter.Fietz@KIT.edu

Coil Technology

The work in the 'Superconducting High Field Magnets' group was distinguished this year by the successful operation of the upgraded superconducting high field experiment facility, HOMER II. At last the technological development of high-field insert coils made from second generation high temperature superconductors (2G-HTS) could be translated into practice.

The HOMER II facility, operational since 2006, in its basic configuration constructed from the metallic superconductors NbTi and NbSn produces a magnetic field of 20 T in a relatively large bore of 185 mm. The acknowledged goal was to increase the field to at least 25 T by means of an additional superconducting insert coil constructed from HTS which can withstand the high field strength. In contrast to almost all other laboratories worldwide, the technically demanding design of the HTS insert consisting of five nested individual layer-wound sections was implemented (see figure 1). This choice was made considering the technology transfer with our long-standing industrial partner Bruker BioSpin who require this type of HTS insert coil for the further development of their world leading High Field NMR Spectrometer (see also paragraph 'Industrial Applications').

In total, almost 1.6 km of 2G-HTS REBCO-type tape conductor was wound for the five serially connected sections of the insert coil. The available free bore for experiments is a comparatively large 68 mm diameter.

Details of the successful operation in which fields of up to 26.5 T were reached are found in the Highlight section.

All test runs were successfully completed without quench, degradation or other undesirable results. The field contribution of the HTS insert coil is, however, force-limited, which means the current carrying capability of the HTS was far from exceeded. The mechanical stress from the electromagnetic Lorentz force in the HTS at 26.5 T is 510 MPa, i.e. the load on the HTS

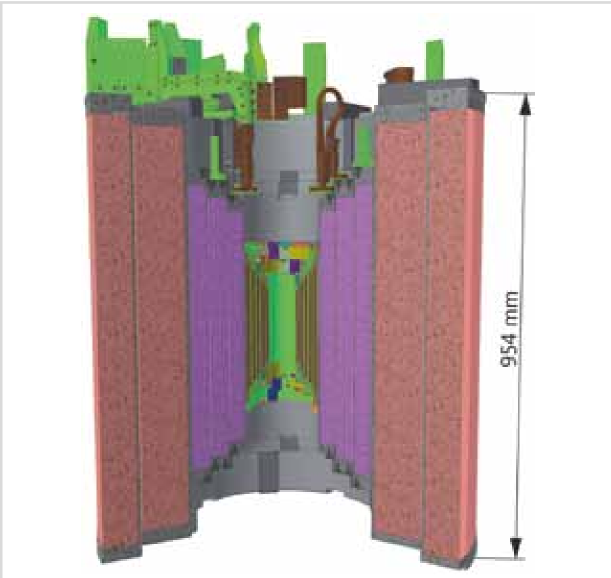


Fig. 1: Cross section of the complete magnet system of the upgraded HOMER II experimental facility comprising two NbTi and three NbSn magnet sections (outer to inner) and a central five section REBCO insert coil with a free bore of 68 mm diameter.

tape conductor with a cross-sectional area of 1 mm2 is calculated to be 51 kg. By reaching 26.5 T in a 68 mm bore, HOMER II is one of the world wide leading pure superconducting high field experimental facilities.

In conclusion, two possible options to further upgrade HOMER II towards 30 T were identified. One is the upgrading of the existing HTS insert with two further sections and a remaining free bore of 30 mm, the other, in the case of the availability of longer HTS lengths, the construction of a new HTS insert coil comprising three layer-wound sections with a free bore of 68 mm.

Contact: Frank.Hornung@kit.edu

HTS fusion magnets and Current Leads

Comparison of the suitability of Nb_3Sn and REBCO as superconductors for HELIAS. In the frame of the EUROfusion Roadmap, the HELIAS (helical-axis advanced stellarator) concept as a possible long-term alternative to the Tokamak fusion reactor is investigated. The complex three-dimensional shape of the magnetic coils poses several technical challenges. Since the magnetic field in HELIAS will be much higher than in W7-X, the available NbTi technology cannot be directly transferred. Rather, a different superconductor material must be used, i.e. Nb_3Sn or the high-temperature superconductor (HTS) REBCO. Therefore, researchers at ITEP compared in 2019 the advantages and disadvantages of a coil configuration with Nb_3Sn or REBCO, discussed possible winding and cooling options - pancake winding versus layer winding - and developed a first rough design of a coil conductor with Nb_3Sn and REBCO. Two REBCO conductor concepts were included in this design: CORC and CroCo. Previous IPP studies served as reference parameters for the HELIAS coils.

Due to the 3D shape of the winding package of the magnetic coils, a square or round shape of the conductor is recommended. In case of a solution with Nb_3Sn it has to be considered that the superconductor requires an annealing treatment, which has to be done either before (react&wind – RW) or after (wind&react – WR) the winding, which leads to problems with the mechanical load (for RW) or with the application of the electrical insulation (for WR). A solution with REBCO offers the advantages that no annealing treatment is required and that the material is not sensitive to mechanical stress (strain). However, the low quench propagation speed is a general challenge using REBCO cable solutions.

First drafts of a conductor concept using Nb_3Sn or REBCO were developed (Figure 2) and evaluated with respect to stability and hotspot temperature during quench. It is shown that the Nb_3Sn option has a similar safety margin as it is realized at ITER. In the case of the REBCO option, it is shown that the CORC variant is designed with too little copper, which leads to very high hotspot temperatures. The CroCo option is closer to the targeted limit in the case of a hotspot, but the strain limit is likely to be exceeded. Figure 3 shows the expected temperature in the superconducting cable and steel sheath for the Nb_3Sn and REBCO solutions CORC and CroCo during a detected quench and subsequent safety discharge as a function of time.
Further investigations are necessary, also with regard to the feasibility of these HELIAS coils.

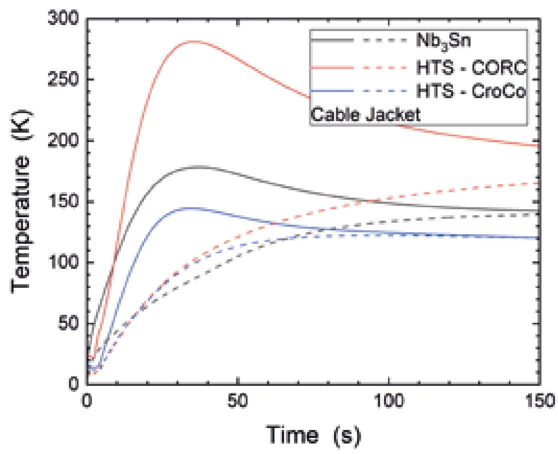


Fig. 3: Temperature in the superconductor cable and in the steel sheath for the Nb_3Sn and the REBCO solutions CORC and CroCo, respectively, during a detected quench and subsequent safety discharge as a function of time

Design and quench analysis of CroCo triplet samples for a quench experiment. Within the framework of a European-Chinese cooperation, the quenching behavior of HTS conductors in an external magnetic field is to be investigated. For this purpose, samples are to be designed and built by three European laboratories, which are then tested in the SULTAN test facility at the SPC in Switzerland. The ITEP planned to contribute three different conductor designs, consisting of three CroCo strands embedded in a stainless-steel sheath and cooled with supercritical helium at 4.5 K, but differing in the amount of stabilizing copper and the geometric design. While the design of the samples to

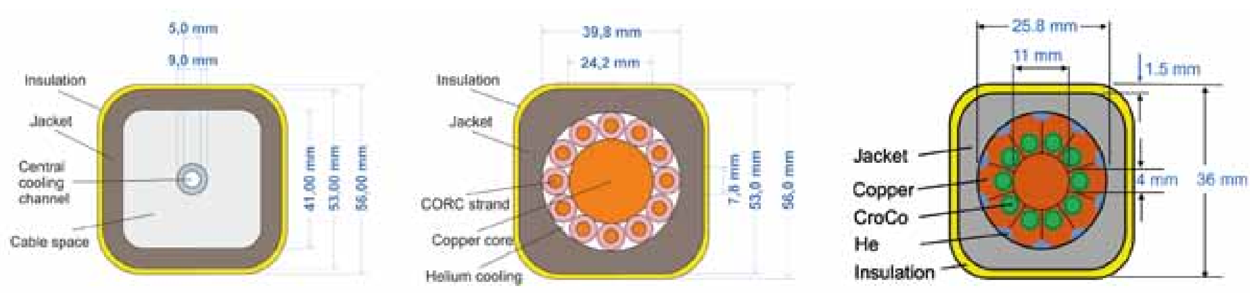


Fig. 2: Preliminary designs of conductor concepts: Nb_3Sn (left) and REBCO-CORC (middle) + REBCO-CroCo (right)

be tested was started, quench calculations were performed with the calculation code THEA to compare the different designs. In all designs a CroCo strand carries a maximum of 5 kA. Figure 4 shows the schematic structure of the three CroCo conductors.

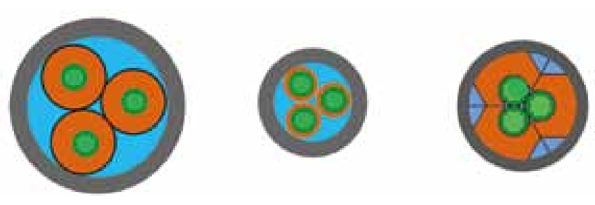


Fig. 4: Schematic representation of three CroCo conductor concepts for a quench experiment in SULTAN: reference design (left), design with low copper content (middle) and design with copper profiles (right)

Conductor option 1 as a reference (2 mm thick copper sheath around each CroCo strand) has a current density in the copper of approximately 118 A/mm2. Conductor option 3 (CroCo strand without copper sheath and soldered into copper profiles) results in the lowest temperature in case of a quench and the smallest temperature difference between strand and conductor sheath, which is due to the better thermal connection between copper and sheath. In conductor option 2 (1 mm thick copper sheath around each CroCo strand)

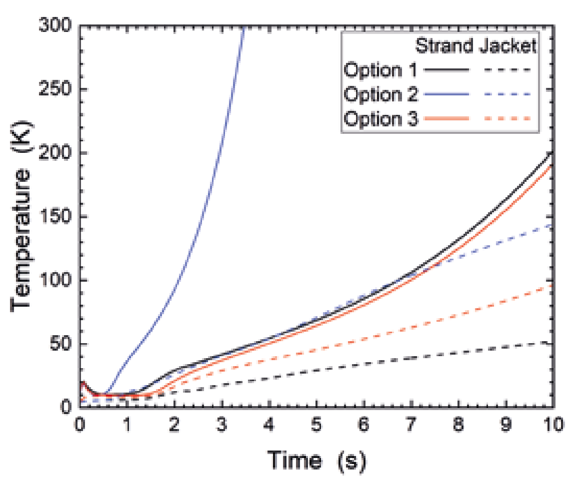


Fig. 5: Temperature curve for CroCo strand and conductor sheath as a function of time for the three conductor options

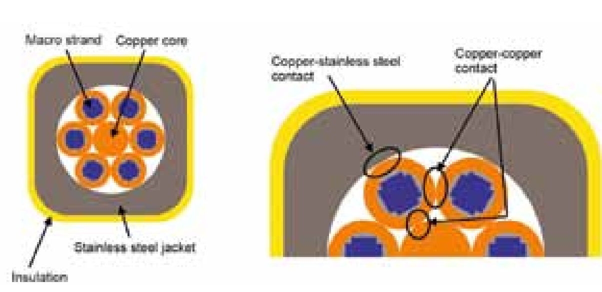


Fig. 6: Schematic representation of the contacts present in an HTS-CICC

the temperature rises very quickly because there is little stabilizing copper. Different THEA models were used to investigate the influence of current redistribution on the quench curve. It was found that simple models treating the CroCo strands as one element sufficiently reflect the temperature behavior, while the detailed models provide more accurate information about the current redistribution. Figure 5 shows the temperature curve for CroCo strand and conductor sheath as a function of time for the three conductor options.

Determination of the thermal contact resistance between pressed copper-copper and copper-stainless steel surfaces for HTS-CICC high current conductors. One of the main areas of current research is the investigation of the quench behavior of high current HTS conductors. One of the key parameters is the thermal contact resistance, which determines the heat transfer between HTS strands and between strands and stainless-steel sheathing. Figure 6 shows schematically the contacts present in an HTS-CICC.

The thermal contact resistance can be determined by measuring the heat conduction through the contact, whereby n square copper or stainless steel plates are stacked on top of each other to increase the accuracy of the measurement.

The thermal conductivity values of the copper or stainless-steel plates were then subtracted from the measurement result to finally obtain the thermal contact resistance. Figure 7 shows the resulting thermal resistance Rth of a 1 mm wide contact as a function of temperature for copper-copper and copper-stainless steel contacts.

Especially the temperature dependence of the thermal resistance agrees well with the values expected from the theory. Nevertheless, further investigations are still necessary, in particular the dependence of the thermal resistance on contact pressure should be investigated.

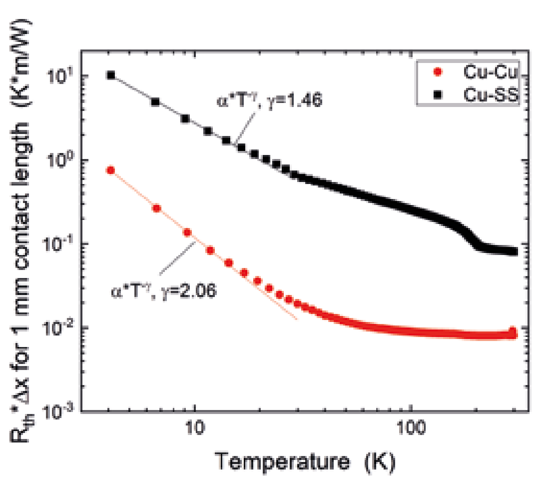


Fig. 7: Thermal resistance Rth of a 1 mm wide contact as a function of temperature for copper-copper and copper-stainless steel contacts

Contact: Walter.Fietz@kit.edu

HTS CrossConductor for Fusion Magnets The HTS CrossConductor, a HTS high-current conductor developed at KIT, was further improved with the help of a technology-transfer-preparatory grant, details on this project are given in the research topic "conductor and wire concepts". For a fusion magnet, the realization of windings of this type of HTS cable concept is of particular interest. Figure 8 shows several turns of HTS CroCo made of 2-mm and 3-mm-wide tapes, which were fabricated in a reel-to-reel process and spooled directly on a drum of 100 cm diameter. For electrical testing in a liquid nitrogen bath, the conductor was wound on a wooden plate at a diameter of 60 cm. Figure 9 shows the electric field as a function of the current through the conductor at T = 77 K and self-field conditions. From this measurement, a critical current of 292 Ampere was extracted. After several warm-up, straightening, re-winding and cool-down cycles, no degradation was observed. These successful experiments mark an important milestone on the path towards a cabled-high-current HTS fusion magnet conductor.
Contact: Michael.Wolf@kit.edu

Fig. 8: Several HTS CroCo windings (made from Cu and HTS tapes of 2 mm and 3 mm width) spooled on a drum of 100 cm diameter

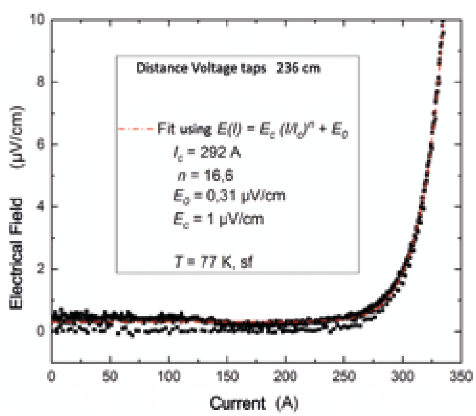


Fig. 9: Electric field as a function of the current in a HTS CroCo sample wound to a diameter of 60 cm.

Cryogenic component test for fusion magnets. Fusion magnets are operated at strong magnetic fields and high electric currents. Therefore, strong Lorentz forces act onto the conductor within a magnet. Because of their excellent properties in high magnetic fields, fusion magnet conductors made from high temperature superconductors REBCO are proposed. This conductor consists of an arrangement of so-called HTS CroCos, a high current cable concept developed at ITEP, as shown in Fig. 2 and Fig. 4.

As a simplified experimental investigation regarding the impact of the Lorentz force on these conductors, transversal pressure experiments on HTS CroCo triplets, representing the smallest relevant cable, were carried out in the CryoMaK laboratory. The degradation of the triplet exposed to this force was examined. The compressive load was applied in liquid nitrogen by a MTS 100 kN test rig. After each rising load step the critical current of each CroCo was determined. Fig. 10 depicts the sample holder, placed in the liquid nitrogen bath.

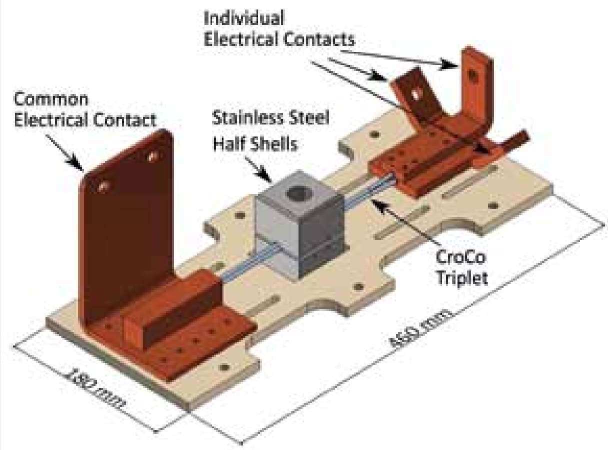


Fig. 10: Sample holder used for tranversal compression investigation with the MTS 100 test rig

Four sample configurations were examined, extracted from two extrema possible in tape orientation, one with tape edges and one with tape faces pressing together.

Each of these configurations were examined with and without copper jacket for mechanical and electrical stabilization. These four sample configurations together with the relating measurement results are visualized in Fig. 11. These results show clearly, that the triplets with tape edges pressing together react more sensitive on the transversal loading than the one with the tape faces pressing together. In both cases the copper jacketing has a positive effect, on the acceptable maximum load, as well as the less steep degradation. Therefore, for high current operation a copper jacketing in this cable layout is mandatory.

By adapted jacket geometries possible overstresses due to point contacts can be prevented, as well as an accumulation by separate electromagnetic forces on the conductor located at the edge. With this, the maximum tolerable compressive load will be increased. An example of such profiles was already presented above in 'Design and quench analysis of CroCo-triplet samples for a quench experiment' in Fig. 4.

Contact: Klaus-Peter.Weiss@kit.edu

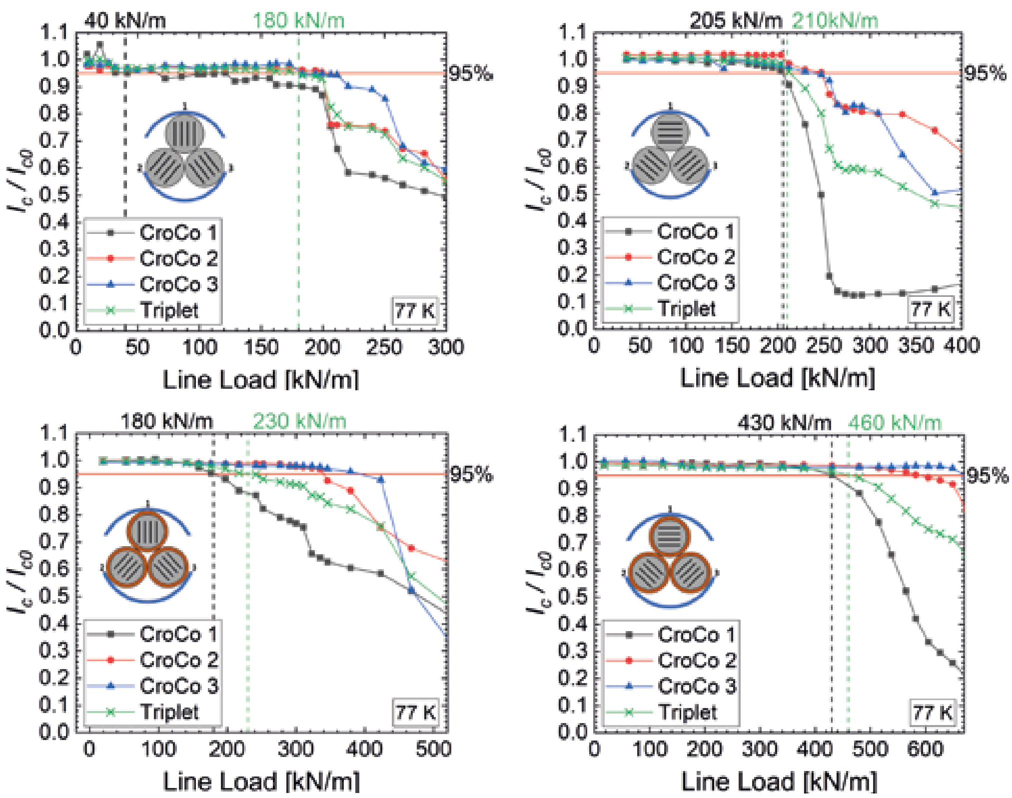


Fig. 11: Sample configuration, as well as the related transversal compression test results

Rotating Machines

Presently, international research and development in rotating machines focuses on the applications „electric aircraft“ and „wind turbines“. For the first focus, generators of high rotational speed (e.g. of the 10 MW-class) as well as fast spinning propulsion motors (usually of the 1 MW-class) are of interest. For the application in wind turbines, the rotational speed is strongly reduced, but a high number of poles is required. ITEP is doing research and development in both fields of application.

Superconducting generators for wind turbines. Generators to be used in offshore wind power generation have to be robust, lightweight, efficient and reliable in a power rating 10 MW+ – preferably connected in a direct-drive configuration to avoid gear-boxes and their maintenance needs. The high current densities of superconductors may result in compact and lightweight machines. The required cooling technology is often perceived (from a non-rational bias) as being challenging. The small rotational speed and the small frequencies of a wind turbine may suggest to use superconductors in the stator beneficially (, too). This approach avoids the complex task of cold rotational feedthroughs. Therefore, a superconducting stator system has been designed and prepared in close collaboration within the project "SuperWind".

The coils (see Figure 12) have been prepared in the so-called „non-insulation" technique and have been finally tested.

As a result, the coils could be operated as planned and the properties were in line with expectations. The time constant due to the radial resistance in between the non-insulated windings determined the ramp-up of the magnetic field after reaching the nominal excitation of 450 A (see Figure 13). Transient Operation and effects (over-currents and varying temperature) have been withstood without any harm.

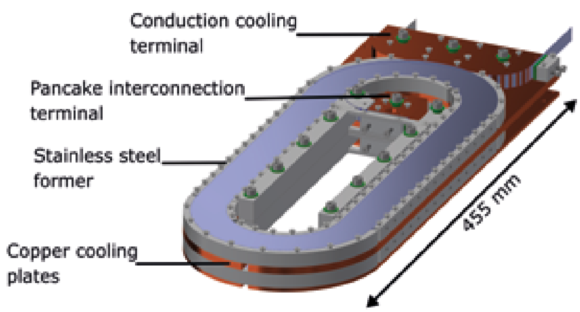


Fig. 12: Double pancake for a stator pole

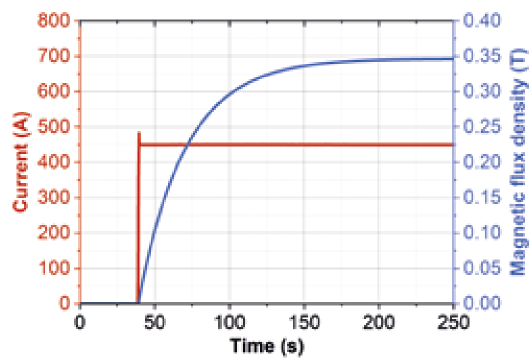


Abb. 13: Excitation of a non-insulated double pancake coil

Superconducting Motors for Electric Aircrafts. The challenging requirements of aviation concerning power-to-mass ratio of all components (for motors and generators targeting >20 kW/kg) are in favor of a fully-superconducting concept of a machine. Therefore, a numerical model has been developed that completely describes the electromagnetic features of such a machine. This encompasses even the local current loading of the individual superconducting tapes. (see Figure 14). This expertise in modelling provides the base for the final design of such a propulsion motor and for the erection of the prototype in the framework of the project „ASuMED" by the partners in the project in 2020.

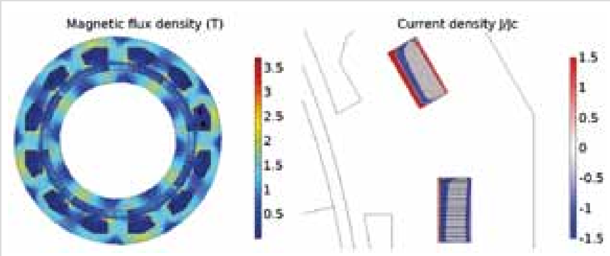


Fig. 14: Magnetic flux in the cross section of the machine (left) and the local relative current loading in the stator (right).

Contact: Tabea.Arndt@kit.edu

Industrial applications

NMR Magnet Technology – Cooperation with Bruker BioSpin AG Switzerland. The cooperation between ITEP and Bruker BioSpin has a long tradition since 1985. The magnetic systems of the 750 MHz, 800 MHz, 900 MHz and 1000 MHz high-resolution NMR spectrometers were jointly developed. Whilst before only the low temperature superconductors (LTS) had been used, the magnet development in the 1200 MHz project was extended to the high temperature superconductors (2G HTS) due to the physical properties of the LTS.

In the complementary project to the NMR magnet technology the HFM team supports the industrial partner in additional measures with the quality assurance, optimization and the world-wide commercial launch of the NMR spectrometers. The focus is on characterization and qualification of commercial technical superconductors as well as prototype superconductors by high-resolution E(I) measurements in the experimental facilities JUMBO and HOMER I at magnetic field strengths up to 20 T and temperatures of 4.2 K and 2.2 K, as well as angle-dependent investigations of high-temperature superconductors. Further emphasis is placed on the investigation of the superconducting properties of the superconducting joints built from the conductors and optimization of their resistivity in the p -range depending on the external magnetic field and transport current. Tests on novel 2G HTS windings manufactured by Bruker (conductor lengths greater than 100 m) in the HOMER I experimental facility of the high-field laboratory up to the operating conditions of an HTS coil in a 1200 MHz magnetic system showed the potential of these conductors and windings. Our results were applied in the NMR magnet system development with frequencies above 1000 MHz. Bruker delivered the world's first 1100 MHz NMR spectrometer to St. Jude's Children Research Hospital in Memphis, Tennessee, in summer 2019. The 1200 MHz systems have reached their target field and are about to be delivered.

In general, the superconductors and superconducting joints investigated differ in their basic structure, material composition, manufacturing process, dimensions and physical properties, which requires a large number of test configurations and test programs. The results of the experiments and their evaluation are partnership know-how and are subject to absolute confidentiality.

Contact: marion.klaeser@kit.edu

BMWi Project: RoWaMag -– Robust and low-maintenance magnetic heater. In 2018 the ITEP, together with the HTS-conductor tape manufacturer THEVA GmbH and the family company Bültmann GmbH, applied to the BMWi for sponsorship of the RoWaMag project. After this was approved, the kick-off meeting with all participating project partners and the BMWi took place on 9.05.2019 at Bültmann GmbH.

Hot forming is an universal procedure for the production of semi-finished metal goods and metal products by, for example, extrusion, forging or hot rolling. It uses the low high temperature strength of metallic materials. It is an extremely energy-intensive procedure because heat and mechanical deformation energy must be applied. The inductive heating of materials has an efficiency of 50 %. Magnet heaters based on high temperature superconductors (HTS) demonstrate a considerably higher efficiency of more than 70 %. Therefore significant energy savings can be made by using a HTS-magnet heater and, as a consequence, reduced CO_2 emissions in this sector.

In the first project phase, the specifications for the magnet heater were established by Bültmann. The achievable magnet field in the heating area, the geometric boundary conditions, operating and maintenance conditions, as well as the price of the HTS magnets including cryogenic system are all included in the design. Theva carried out the first calculations for the coil construction based on this data. The heat input for different cryogenic system concepts could be determined depending on the coil composition. The findings resulted in a preferred design concept for the cryogenic system that also enables upscaling of the principle for larger magnet heaters.

Figure 15 illustrates the concept in a block diagram. The HTS magnet is surrounded by a cooling shield built inside a vacuum container. A two-stage cryo cooler is used. The first stage of the cooler is connected to the cooling shield and conducts the heat due to the support structure and the radiated heat away from the vacuum container. The heat produced in the current leads due to conduction and Joule heating from the operating current of approximately 500 A is also removed by the first stage of the cooler at about 80 K. The second stage cools the HTS magnets. It removes the heat of the support structure between the cooling shield and the magnets, the thermal radiation from the shield and the heat from the current leads to the coil, at a temperature of about 25 K.

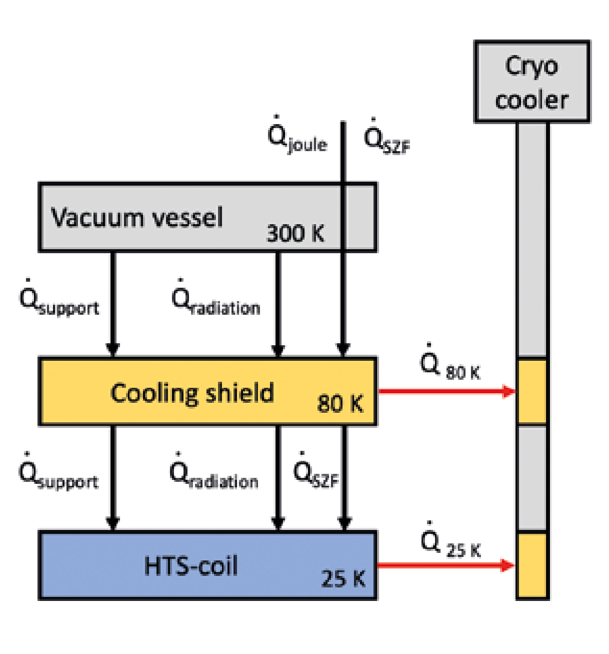


Abb. 15: Cooling concept of the HTS magnet

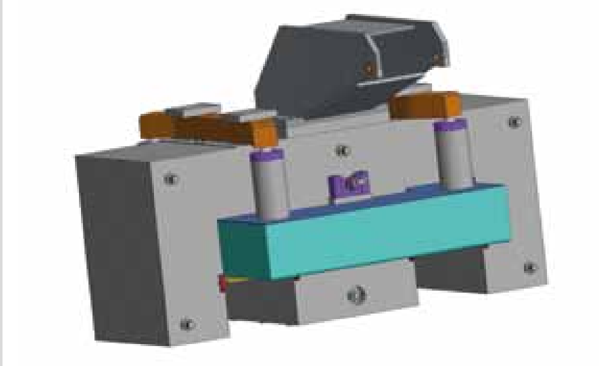


Abb. 16: Design of the yoke with cryostat

The next stage is the constructive translation of the design into a magnet system. Here the challenge, alongside the principal necessary functionality and robustness of the system, is to develop one product that will be economically competitive and can be reliably and safely operated for at least 10 years. A first design is shown in figure 16.

Contact: ralph.lietzow@kit.edu

Highlight: 26.5 T reached in a HTS insert coil with a free bore of 68 mm within the HOMER II magnet system.

Initially, the five HTS individual sections constructed in the previous year were assembled and connected. At the same time, particular consideration was given to the quench detection system, i.e. the detection of the start of a spontaneous and undesired transition of the magnet current from super conducting to normal conducting, and an appropriate monitoring system was constructed (see figure 17).

Fig. 17: Newly upgraded control system for magnet monitoring with quench detection for the independent current circuits of the NbTi-, NbSn- and HTS-magnet subsystems.

If a quench is detected in a coil section, the safe discharge of the complete magnet system will occur with the help of three switching circuits and external dump resistors. Figure 18 shows the fully-equipped HTS insert coil being lowered into the HOMER II cryostat in which the base magnet configuration is already situated.

After preliminary tests confirming the functionality of the construction, the operation of the upgraded HOMER II experimental facility was introduced incrementally over several days:

- Initially the targeted field of 25 T in a helium bath at 1.8 K was achieved. For this, the current supplies of the three individual magnet circuits were gradually increased to their respective desired values then held at a maximum field value of 25.1 T and the system was then discharged. The base magnet system and the HTS insert coil contributed 20 T and 5.1 T respectively to the total field.
- In the second experimental cycle, 26.1 T (20 T + 6.1 T) was achieved at 1.8 K.
- The tests at 1.8 K were carried out in a superfluid helium bath that is complicated to prepare. Therefore in the third test run, the magnet system was operated in normal liquid helium at 4.4 K. At this higher bath temperature the critical currents of the metallic NbTi and NbSn system sections are significantly reduced, so that a field of 24 T (17.6 T + 6.4 T) was reached.

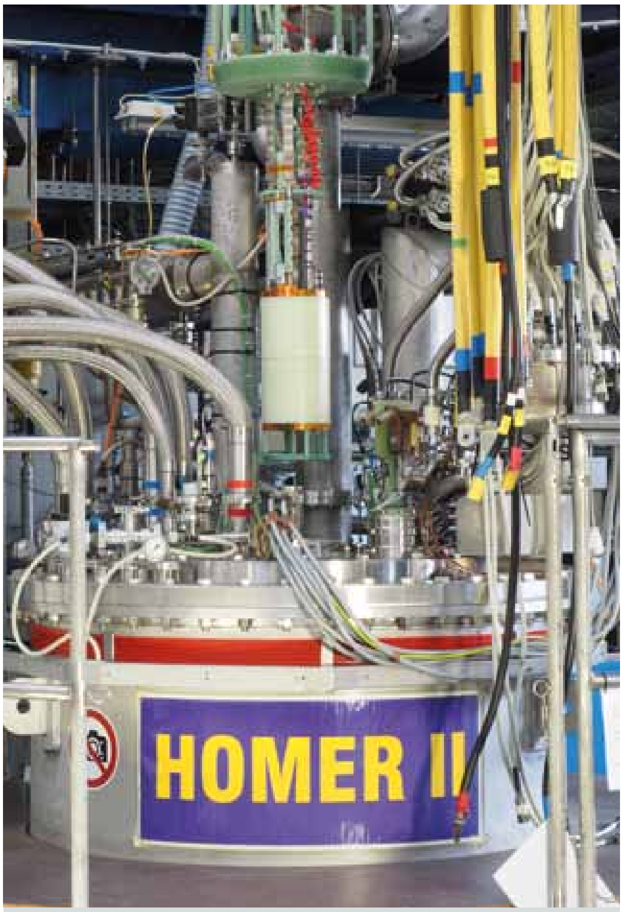


Fig. 18: Insertion of the HTS insert coil into the HOMER II cryostat in which the base NbTi and NbSn magnet system is already situated.

- The last test run was repeated at 1.8 K bath temperature and the maximum field increased to 26.5 T (20 T + 6.5 T) once more. Figure 19 shows the corresponding incremental increase of individual currents in the three magnet circuits along with the resultant total field.

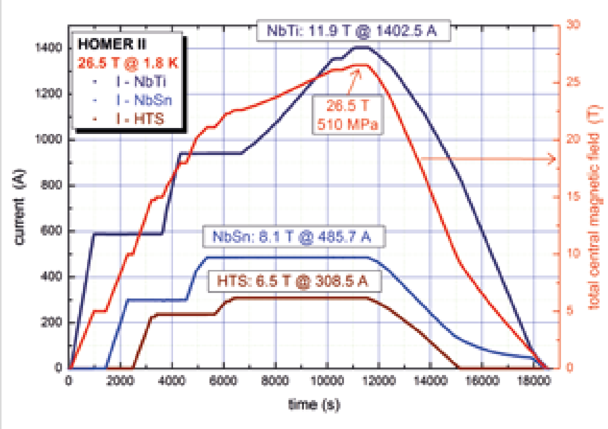


Fig. 19: Individual currents in the three magnet circuits and resultant total magnetic field during incremental approach to the maximum field of 26.5 T

Contact: Frank.Hornung@kit.edu

Assembly of the largest getter pump worldwide for fusion.

Results from the Research Areas

Technologies for the Fusion Fuel Cycle

Coordination: Dr.-Ing. Christian Day

The Research area ´Technologies for the Fusion Fuel Cycle' is developing innovative technologies to make the fuel cycle and related neighbouring systems of a future fusion power plant more efficient, thus ensuring that the in-situ generated fuel tritium is optimally utilised. The research area covers all three key technologies of the fuel cycle, namely matter injection, vacuum technology and tritium technology. The new architecture of the fuel cycle developed at the Institute comprises three loops: The first one returns unburnt fuel directly from the vacuum pumps to the pellet injectors, the second one is a quasi-continuously operated bypass of the remaining gas with isotope separation within the tritium plant, and the third one is finally the full circulation loop equipped with cryodistillation and water detritiation, which converts the remaining hydrogen isotopologues into pure hydrogen isotopes, which are then stored or released into the other loops. This work is firmly anchored in the European Fusion Programme EUROfusion. The immediate goal for 2020, the end of the current European research framework, is the delivery of a consistent preconceptual fuel cycle design for the demonstration fusion power plant DEMO. With this background, the following research topics have been established in the research area fuel cycle:

- Vacuum technology and process integration;
- Tritium extraction and recovery;
- Rarefied gas dynamics;
- Vacuum hydraulics.

A series of European reviews are scheduled for 2020, which will critically evaluate our research results. Work will then continue in the next European research framework programme 2021-2027.

Vacuum Technology and Process Integration

This research topic addresses all vacuum technology issues of a fusion plant. The activity goes beyond the relevant technological development of the corresponding subsystems of the fuel cycle and also includes vacuum systems outside the classical fuel cycle, such as the plasma chamber with the topics outgassing and gas inventory build-up. Vacuum technologies of other large-scale fusion facilities, such as the European neutron source IFMIF-DONES or the JT-60SA machine currently under construction in Japan, are also covered.

In contrast to the cryovacuum pumps at ITER, the new vacuum concept developed for DEMO operates continuously wherever possible and without cryogen. It consists of three pump stages.

For the separation of the unburnt fuel DT, super-permeable metal foils are to be used in a first stage. This will enable the separation of high-purity hydrogen from the fusion exhaust gas and does also compress the gas. For the development of a functional pump based on the metal foils, the Institute has started a systematic technology development over several years. A comprehensive R&D program has been set up for this purpose.

In order to be pumped, the hydrogen must be converted into an energetic state. For this purpose, a microwave plasma source is being developed which is aimed to reach a high degree of energization and, in combination with a further magnetic field, to fulfill the resonance condition. This development work is carried out on the basis of an industrial plasma source (Duo-Plasmaline, Muegge) in cooperation with industry, see Figure 1. To scale the yield of energetic hydrogen particles to the application size in DEMO, parametric electrodynamic calculations are performed with the software package COMSOL-Multiphysics.

Fig. 1: 3m long Duo-Plasmaline in operation.

The effect of the metal foil is only guaranteed if there is a passivating top layer on the surface. To understand the interaction of the incoming energetic particles with the barrier layer, complex molecular dynamic simulations are being performed with the VASP code. Finally, it must be ensured that the top layer remains stable over the long term or can be recovered in-situ by doping methods if necessary.

One of the special requirements of DEMO is the operation of the metal foil pump in a magnetic field of high field strength (around 1 T). This aspect is also being investigated in a specially constructed test rig, see Figure 2, which has just been commissioned in December 2019. This activity is carried out in collaboration with the Institute of Interfacial Process Engineering and Plasma Technology at the University of Stuttgart.

Fig. 2: Commissioning of a test set-up to investigate the plasma source under external magnetic fields (left to right: Stefan Hanke, Yannick Kathage, Stefan Merli).

In order to characterize the integrated (source + foil) structure, extensive measurement campaigns were carried out in our labs at the HERMESplus facility. Figure 3 shows how the performance data of the foil in terms of permeated flux could be increased by more than 1 order of magnitude compared to last year.

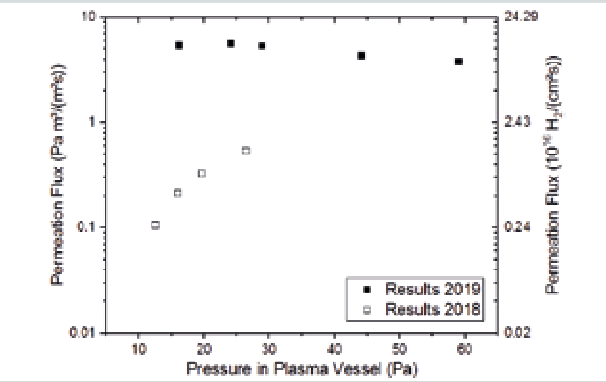


Fig. 3: Performance data of a niobium foil for protium (at 800 °C and 2 kW microwave power).

Another vacuum technology, which is used at various points in the fuel cycle, is based on getter materials (NEG). Here, the leading company in this field, SAES Getters, has in recent years developed a new material (trade name ZaO), which is manufactured as discs (25 mm diameter). For a better understanding of how different disc arrangements scale, a multi-stage R&D program was organized in cooperation with SAES and Consorzio-RFX to experimentally investigate disc arrangements on different scales (see highlight at the end of this article) (raw metal alloy; single disc; 12 / 31 discs in stacked arrangement with a central axial heater; 270 discs (6 stacks of 45 discs each) in a hexagon module with central heater). Based on this, a test pump with more than 9000 single discs was built in 2019, installed, commissioned and measured in the TIMO test facility. This is this year's highlight in the research area and will be treated separately in the last part of this chapter.

The Vacuum Technology Section in the Institute has been working for many years for the Japanese tokamak JT-60SA, which will go into operation in 2020. After an initial experimental campaign, the machine will be reopened in 2021 and completed with further installations. These include a powerful cryopump system that will be integrated directly into the divertor. We have been charged to develop the complete pump design and to supervise the industrial production of the system. Figure 4 shows the current status of the design, which follows the proven cryosorption pump concept developed at the Institute in earlier times for ITER, which is based on modular hydroformed cryopanels (2 pieces per wing).

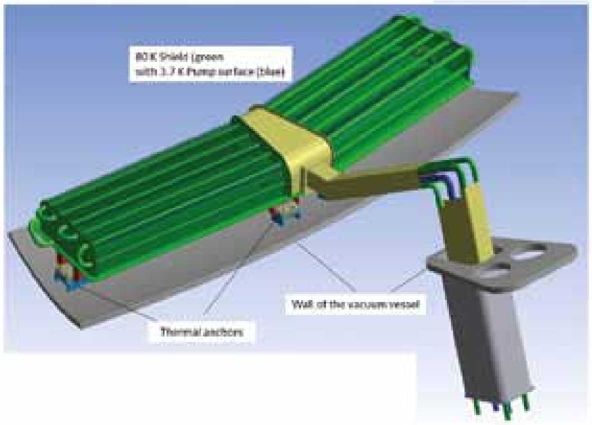


Fig. 4: Design of one of 10 cryopumps for the plasma vessel of JT-60SA.

Extensive vacuum modelling was carried out for the IFMIF-DONES material test facility, which is to be built from 2020. DONES is an accelerator that generates a fusion-typical neutron spectrum at a liquid lithium target, which can be used to test materials for fusion applications.

Also in this reporting period, the TRANSFLOW facility was used for further conductance measurements on microchannels with various surface functionalizations. These measurements are performed in collaboration with the University of Bremen (Centre for Environmental Research and Sustainable Technologies, UFT) within the framework of a DFG project.

Contact: Christian.Day@kit.edu

Tritium Extraction and Recovery

The main task of the fuel cycle in fusion is to separate the exhaust gas into its main constituents and feed the fusion plasma with new fuel. Deuterium consumed by the fusion reaction is supplied from the outside, while tritium is produced inside the plasma vessel in the so-called breeding blankets themselves and, after a further extraction step, is then processed in the fuel cycle. A major goal of the project to engineer a demonstration power plant is therefore to show the realization of this tritium self-sufficiency. The simpler this is possible, the lower the tritium inventory in the cycle is. The developed architecture of the fuel cycle is hence designed in such a way that only continuously operating technologies are used. The research topic tritium extraction and recovery deals primarily with this.

To provide the fuel in the desired composition it is necessary to adjust the D:T ratio exactly towards equimolar. This requires a technology that can adjust concentration shifts within the existing hydrogen isotopologues and extract H, which is unfavorable for the plasma reaction. For this purpose, a new concept has been developed in the department, in which different hydrogen-metal interactions are exploited. The gas mixture is cyclically moved back and forth between two columns - always in portions - in a semi-continuous process. After a certain number of cycles (depending on the desired concentration shift, this is several tens of cycles), the isotopes are enriched at the respective ends of the column, see Figure 5, and can be extracted continuously.

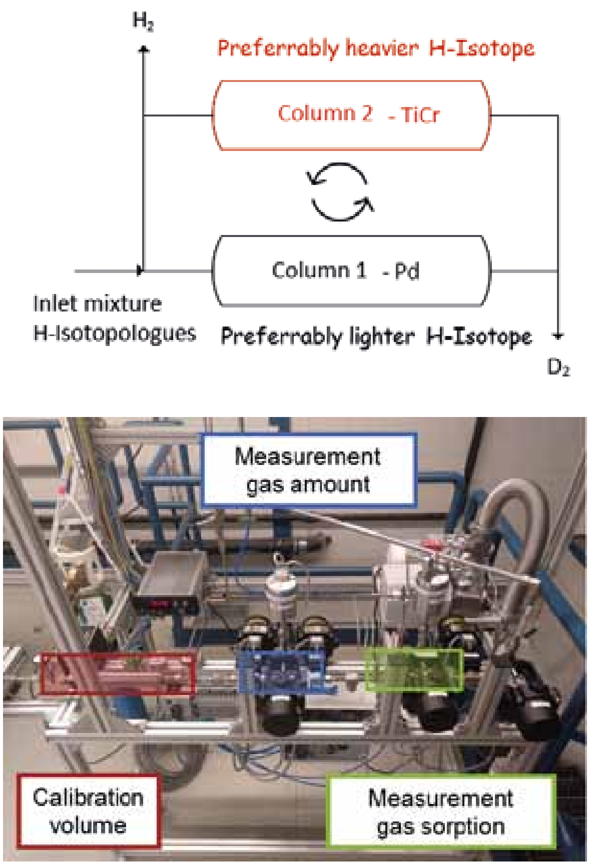


Fig. 5: The temperature swing absorption. Operating principle (top) and photo of the test facility (bottom).

For the thermodynamic characterization of the materials (hydrogen solubilities as a function of temperature and pressure) palladium is currently being investigated in an experimental setup; as a counterpart with inverse isotope effect TiCr is a candidate. As soon as a promising material pairing has been found via material characterization, the entire process will be demonstrated in the new HESTIA facility, which is currently under construction.

Contact: Christian.Day@kit.edu

Rarefied Gas Dynamics

For the design of complex vacuum systems, such as in the fusion fuel cycle, it is essential to be able to calculate rarefied gas flows quantitatively. This is done – in a mathematically exact manner - by solving the Boltzmann equation, which describes the flow in the entire range of rarefaction. For this purpose, the DSMC algorithm has been further developed over many years in the Vacuum Technology Section of the Institute, which is a statistical procedure that has the advantage over deterministic methods of being able to describe even complex geometries in a reasonable way.

This research topic focuses mainly on the physics of particle transport in the divertor of a tokamak, and here in particular on the area below the divertor cassettes: There the plasma is converted back into neutral gas, and this is the interface area where the pumping systems connect. The plasma scenario for DEMO will be very different from that of ITER. For example, it is necessary to maintain a divertor plasma in the so-called 'detachment mode', only then can the resulting heat loads be managed by the divertor materials with simultaneous neutron radiation. This plasma state is not yet fully understood, so it is intended to incorporate as many control options as possible into the design of the machine. Again, pumping systems come into play, which have to remove the helium formed during the fusion reaction (together with the unburned fuel gas and other necessary auxiliary gases added to the plasma to increase stability). There are a number of magnetic configurations for divertor realization, see Figure 6, where we completed a systematic study in 2019 in which we compared the divertor's ability to extract sufficient gas uniformly, with the same tool, and under identical boundary conditions.

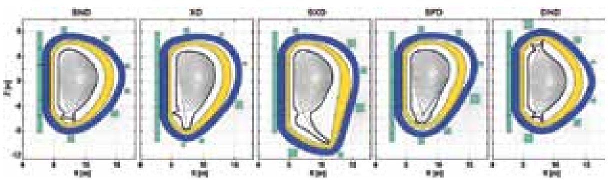


Fig. 6: Different magnet topologies for DEMO.

We always calculated the extraction efficiency (that is the ratio of the pumped particle flux to the particle flux entering the divertor (the rest is reflected back into the plasma via the divertor targets)) at varying pump capture coefficients (this is the measure of how good our pump has to be; at 1 we would have the ideal case of a black hole; in reality about 0.2-0.4 is achievable). Figure 7 shows that the pumped particle flux differs greatly between the different configurations. For the first time, it became apparent that the conventional divertor (SND) is much worse than previously thought. We have thus triggered important research directions in the coming fusion programme. The divertor we found to be the best is being investigated in MAST (and AUG is being converted so that this configuration can also be realized there).

In a further focus in this research topic we have been working on technical solutions for the liquid metal di-

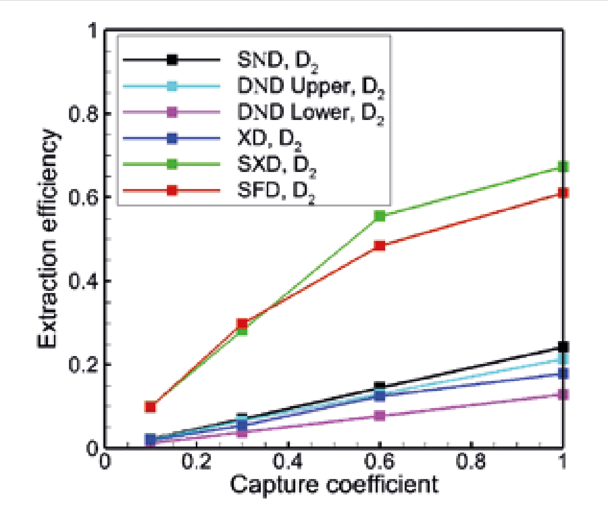


Fig. 7: Divertor simulations for DEMO.

vertor. The background is the idea of allowing higher heat flow densities by using liquid metals. Lithium (at 700 °C) and tin (at 1200 °C) are discussed as candidates. Figure 8 shows the results found for both cases. It can be seen that higher pumped fluxes can be realized with tin, but also – neither for helium nor for deuterium – they do not reach the required particle fluxes. Work on divertor geometry will therefore continue next year. In particular, attempts will be made to integrate a dome that will act as a support in order to be able to pump out more particles.

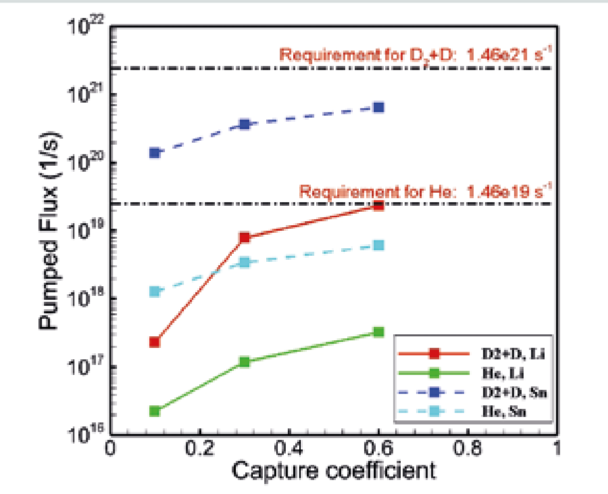


Fig. 8: Pump characteristics of the two liquid metal divertor variants (calculated for one cassette).

Finally, the research topic was extended to a completely new tokamak project in the course of 2019. In Italy, a new machine (DTT) will be set up by 2024, specifically to test divertor concepts. It will be designed in such a way that all magnetic configurations (Fig. 6) and liquid metal solutions can be realized, possibly with the aid of inner or outer coils. Furthermore, this machine will be the main facility for the development of the future DEMO plasma scenario, which will be characterized by the absence of major magnetic instabilities (so-called ELMs). The Institute was asked to take over the design of the vacuum systems for DTT. This will be done in a 2-step approach. First, the possible particle fluxes are modelled by means of divertor simulations, then compatible vacuum solutions are designed based on this, which fit the dimensions of the vacuum connections, see Figure 9. Currently we are investigating the use of cryogenic pumps or NEG-based pumps. In 2020 the topic will be supported by a guest scientist from the Italian DTT team at our institute. It is also planned to test a first prototype of the metal foil pump in DTT as soon as DTT is operational.

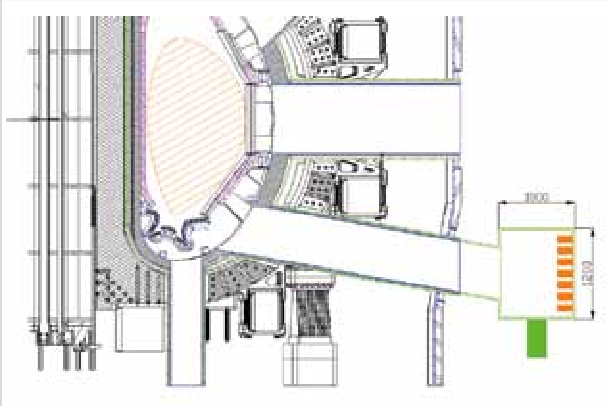


Fig. 9: Cross section of the plasma chamber of DTT with an indicated external solution for the vacuum pumps.

The gas flow research group was strengthened in 2019. This allows to perform simulations for the W7-X stellarator machine in the future. The description of the completely different magnetic configuration with island divertors will be a completely new challenge for the DIVGAS code used. In this context, DIVGAS is also to be extended to plasma-related areas.

Contact: Stylianos.Varoutis@kit.edu

Vacuum Hydraulics

The aim of the research topic vacuum hydraulics is to combine and further strengthen all activities dealing with the flow behaviour of liquids (especially liquid metals) in machines and processes under vacuum. To this end, the Institute's Vacuum Technology Department also develops processes for handling these working materials (e.g. purification and processing of mercury, development of associated analytical methods). This research topic exists only at KIT. All experimental activities in this activity are concentrated in a common hall (Building 602).

The reference concept for DEMO's torus vacuum system provides for a combination of mercury-based high or rough vacuum pumps downstream of the metal foil pumps (see above). Currently, a linear and fully tritium-compatible mercury diffusion pump is being developed for this purpose (in magnetic fields and with a minimum inventory of the working medium mercury). Mercury-driven ring pumps are to be used as backing pumps.

Originally for the use of the DT campaign in JET, a pumping station was developed and built, which consists of two fully tritium-compatible liquid ring pumps and a mercury diffusion pump as booster. Since the use in JET is no longer planned due to ongoing delays of the

DT campaign and Brexit complicality, the pumping station will remain at the Institute. It was successfully put into operation this year. Figure 10 shows the characteristic curves for the ring pump.

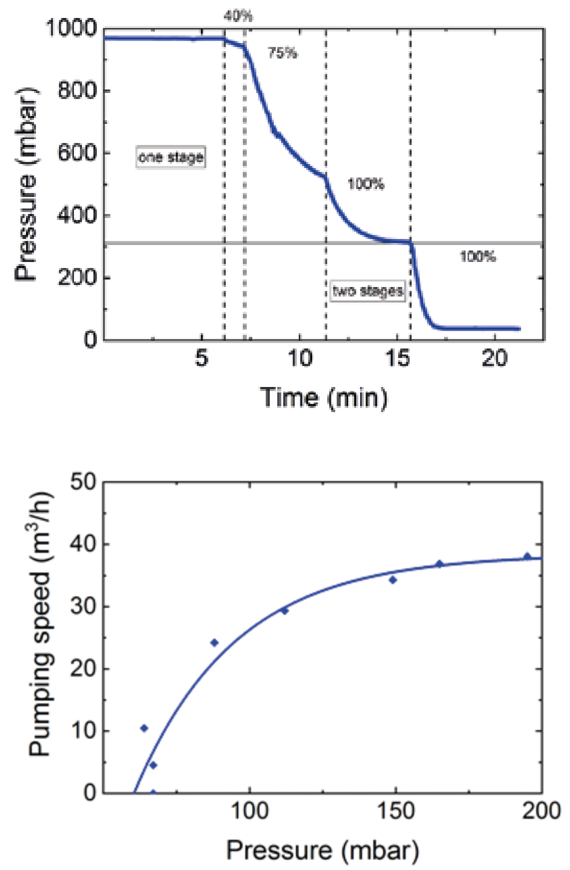


Fig. 10: Performance curves of the mercury ring pumps.

In the two-stage arrangement pressures of several mbar were achieved, the nominal pumping speed of one pump was 40 m³/h. Thus the ring pumps investigated are already of DEMO-relevant size. Based on the measurements, we are now planning a three-stage arrangement to generate the transfer vacuum to the diffusion pumps required in DEMO. The design of the booster built into the JET pumping station (Figure 11) is not DEMO-relevant, but it gives us the opportunity to gain relevant operational experience with the mercury diffusion pumping technology.

For testing mercury-driven pumps and the components required for them, a specially approved laboratory is required. This was put into initial operation in 2018 and was put into routine operation this year (Figure 12). The laboratory room is continuously monitored for the mercury content in the room air by means of atomic adsorption spectrometry. For the analysis of liquid metals, a mass spectroscopic analysis method (Agilent ICP-MS 7900) is available, which is also part of the laboratory and is to be used for the trace analysis of impurities in mercury and for the quantification of the lithium isotope content in aqueous solutions. The development of corresponding ICP-MS methods has already been started and will be essential for all isotope separation and mercury purification work in the coming years.

Fig. 11: The mercury booster in operation.

Fig. 12: View into the HgLab Karlsruhe.

In the HgLab, first investigations on the enrichment of the lithium-6 content in natural lithium (nominal Li-6 content of 7.6 %) were carried out in the context of a master thesis. Highly enriched lithium-6 (magnitude 60-80%) is the breeding material in the blankets of a fusion power plant. In a system analysis different processes were evaluated against each other and the most suitable process for the task in fusion (industrial production of some 10 t enriched lithium per power plant) was identified. This involves an isotope exchange between

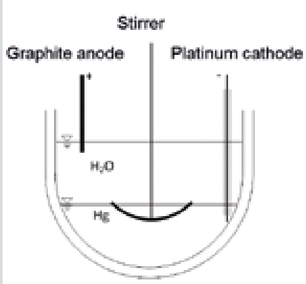


Fig. 13: Experimental setup for the enrichment of Li-6 with a mercury amalgam process in the HgLab.

Li amalgam and aqueous LiOH in an electrolytic process. In order to demonstrate the suitability of this concept, a small principle setup was realized in the HgLab, see Figure 13.

The degree of separation found is around 1.05, which makes a reasonable design in a multi-stage arrangement conceivable. Not least because of these promising results, the topic of lithium isotope enrichment is a central point in the area of 'future technologies' in the next fusion framework programme. The HgLab will thus become a central European infrastructure.

Contact: Thomas.Giegerich@kit.edu

Highlight: World-record pumping speed by a most compact getter pump with new materials

This year's highlight is a nice example of a long lasting cooperation with an industrial company (SAES Getters, Milan, Italy) under EUROfusion. Nearly 10 years ago we developed a very large cryopump system for the neutral beam heating in ITER, now we are developing the scientific basis to replace this cryopump system possibly in DEMO by a getter system. Based on our results, the decision will possibly be made as early as 2020.

This has been made possible because SAES has developed a new getter material (Zr-V-Ti-Al alloy) which has a 100 times higher hydrogen storage capacity. This will allow getter technology to be used for the first time in applications with only moderate vacuum and/or high particle fluxes. The new material is available in the form of discs (25 mm diameter). The first large scale application would be the density control in the gas neutralizer of DEMO's neutral beam heating system. This requires an extremely high pumping speed, which could be achieved with about 1.5 million NEG discs. To develop a robust design, however, the thermal effects (especially during regeneration, which requires temperatures around 600°C) and the difficult access to the discs due to shadowing effects must be well understood. To this end, a multi-stage R&D program has been organized in collaboration with SAES and Consorzio-RFX, which has experimentally investigated disc arrangements on different scales, see Figure 14.

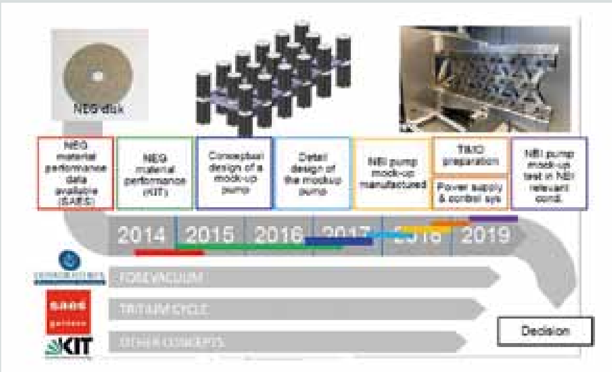


Fig. 14: Systematic technology development of a new getter pump.

Based on this, a detailed design of a first test pump was developed in 2018, which was built in 2019 and finally installed in the test facility TIMO, that was recommissioned for this purpose. This pump comprises 34 hexagon modules with a total of more than 9000 individual discs. Figure 15 shows the team during installation on site at the Institute and installation in the test tank. The test in September 2019 was extremely successful, the measured pumping speed curve is shown in Figure 16 (loading hydrogen H_2, 2.9 Torr·l/g; pressure $2 \cdot 10^{-4}$ mbar).

Based on this extremely successful result, we see a great future for the new technology. Due to the large number of planned parameter variations in TIMO, we will acquire key know-how. In November 2019 a joint workshop was organized by KIT and SAES to discuss potential new applications (see Figure 17). Thanks to the whole team for this great success.

Fig. 15: The test pump during installation.

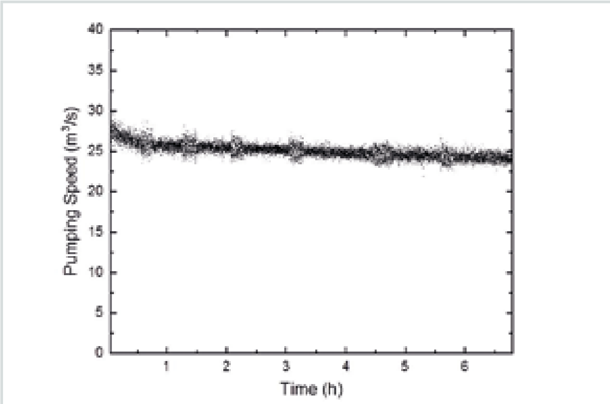


Fig. 16: Pumping speed of the test pump.

Fig. 17: Workshop on the new getter materials

Contakt: Stefan.Hanke@kit.edu

Prizes and awards

In 2019, ITEP employees were awarded the following distinctions and prizes.

Valentin Tschan, Jan Sas and Klaus-Peter Weiss receive the **Best Paper Award of the International Cryogenic Material Conference 2019** in the category Structural Materials for their paper "Temperature dependence on tensile properties of Cu-40 mass % Fe dual phase alloy". The conference program includes the latest developments in cryogenics and superconductivity from materials to applications. The paper was already presented in 2017.

Jörn Geisbüsch receives the **Best Presentation Award of the Ninth International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies** for his paper "Real-Time Simulation and System Integration". In his contribution, Mr. Geisbüsch shows, among other things, the manifold possibilities of the KIT Energy Lab 2.0 and links this very clearly with an overview of the state of development in this field.

Nicolò Riva is awarded the **IEEE Council on Superconductivity Graduate Study Fellowship in Applied Superconductivity** for his outstanding work on the quenching behaviour of high temperature superconductors for energy applications. Mr. Riva is a PhD student at the Ecole Polytechnique Federale de Lausanne (EPFL) and spent an exchange year with us at the institute from 2018 to 2019. We would like to take this opportunity to thank Bertrand Dutoit from EPFL for the very good cooperation and look forward to further collaboration.

Yingzhen Liu receives the **Chinese Government Award for Outstanding Self-financed Students Abroad.** Ms. Liu had already successfully recruited a DFG-funded project to develop basic technologies for superconducting wind power generators as a doctoral student.

Christian Day is appointed by the European Commission as a member of the **Broader Approach Project Committee.** There he is a member of the "Satellite Tokamak Project" and advises the further development of this development, which is important for fusion.

Michael Wolf and Walter Fietz receive the **3rd place of the KIT Neuland Innovation Award** in the **category Technology Transfer** for the project High Temperature Superconductor Cross Conductor – a basic element for energy-efficient DC high-current cables. This award honors the very successful development of the process patented at ITEP for the production of high-current conductors with superconducting tape conductors. With this process, which has already been licensed to an industrial partner, compact and powerful high-current conductors can be produced in a simple way.

Fig. 1: Walter Fietz (4th from left) at the award ceremony of the KIT Neuland Innovation Award

Klaus-Peter Weiss receives the **1906 Award of the International Electrotechnical Commission** for his valuable contributions to the IEC TC 90 working group, the International Electrotechnical Commission, or IEC for short, is an international standards organization for standards in the field of electrical engineering and electronics. The Technical Committee TC 90 develops standards and norms concerning superconductors. Among other things, this includes measurement methods for determining the critical current of superconductors.

Fig. 2: Klaus-Peter Weiss (right) at the presentation of the IEC 1906 Award

Bernhard Holzapfel receives the **Rudolf-Jaeckel Prize 2019 of the German Vacuum Society** (DVG) for his outstanding achievements and groundbreaking contributions to the establishment of laser deposition in thin-film technology, especially for the preparation of oxidic, thin films, especially superconducting, magnetic and ferroelectric films. outstanding achievements in

Fig. 3: Prof. Dr. Bernhard Holzapfel (3rd from left) at the award ceremony of the Rudolf-Jaeckel Prize of the DVG

the field of vacuum-assisted science. The prize honours long-standing and pioneering work on the fundamentals of the fields covered by DVG and on their applications and implementation in scientific and industrial practice.

The **building Energy Lab 2.0, Building 668** receives the **prize for exemplary building of the district of Karlsruhe.** The jury praised in particular the pleasant working atmosphere in the experimental hall and the offices and considers it an innovative, attractive and high-quality location for research. The building houses the data control and simulation centre, the microgrid and the 1 MVA power hardware-in-the-loop test stand. We would like to thank the architectural office Behnisch and the Facility Management of KIT for the very good cooperation during the construction of the building.

Fig. 4: KIT Energy Lab 2.0, Building 668.

We are very pleased about this recognition of the exceptionally good performance of our employees and thank you very much for your excellent achievements.

Completed PhD Theses

Dr. Simon Otten

Characteriazation of REBCO Roebel Cables

The Roebel cable made of HTS wires of the 2nd generation (REBCO coated conductor) is a concept that was first realized at the Institute of Technical Physics (ITEP) and is currently being further developed to meet the special requirements of various applications. Roebel cables are manufactured by stranding meandering REBCO conductors into a cable. Roebel cables have a high degree of filling, a full transposition of the individual conductors and a mechanical bending capability corres-ponding to the individual REBCO tape. Several HTS dipole magnets of the accelerator type are being built in the European project EuCARD-2 and its follow-up activi-ties. For two designs, the "Aligned-block-coil" (CERN) and the "Cosine-theta-coil" (CEA Saclay), the Roebel cable was chosen as conductor because of its high current density and the complete transposition of the tapes. The design of both coils was designed to provide a magnetic field of 5 T in the self field, or fields of 15.5 T ("Aligned-block-coil") and 16.9 T ("Cosine-theta-coil") in a 13 T background field. These fields would be abso-lute records for superconducting dipole magnets. The role of ITEP in this project was to develop and provide Roebel cables up to 32 m in length, the longest so far. The special requirements of accelerator magnets on the cable raised a number of questions about the mechani-cal, electromagnetic and thermal properties of the Roe-bel cables, which motivated the investigations of this thesis.

This dissertation consists of two parts. In the first part the mechanical properties of the REBCO Coated Conductor and Roebel cables are investigated. Torsion and bending occur during coil winding, whereas in high field applications the Lorentz forces lead to transverse stress loads. The influence of these deformations on the cable performance was investigated with short sample experiments. For this purpose a setup as shown in Fig. 1 was used.

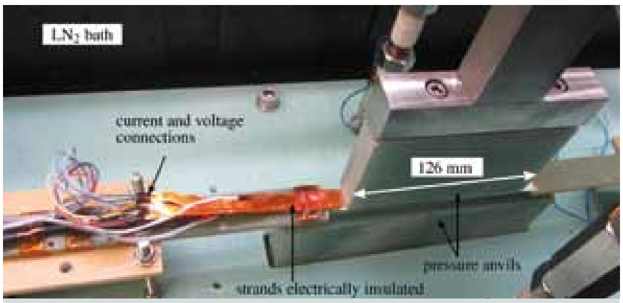


Fig. 1: Measurement setup for invetsigation of trans-veral mechanical stress on Roebel cables

It was found that the bare Roebel cable was irreversibly damaged without any impregnation even at transverse pressure loads of only 40 MPa. This is far below the calculated voltage values of 110 MPa for the "aligned block design" and 220 MPa for the "cosine theta design" of the dipole magnets that are being developed in the EuCARD-2 project. By impregnation with epoxy resin the resistance to transverse stress of two Roebel cables could be increased to values of 253 MPa and 169 MPa. This result was a very important step for the further development of Roebel cables for use in ac-celerator magnets. The bending properties of the Roe-bel cables perpendicular to the plane (out-of-plane) were investigated. The bending behaviour of Roebel cables is very similar to that of the individual conductors of which they are made. An explanation for this is the negligible influence of the cable geometry to the bending stress, since the individual tapes can slide freely in the cable. Therefore the bending behaviour of the cable can be derived from the results of the single tapes. The ben-ding properties of a large number of single and different conductors in both bending directions were measured, with special attention to the reversible behavior. All tested conductors could be bent in the compressive range up to a bending radius of 6 mm without perma-nent damage. Finally, a torsion experiment was carried out, in which cable samples were torsioned by twisting them into a 3D-printed form. The 3D moulds for this purpose were designed in such a way that the Roebel cable was deformed into the identical torsion as the inner winding of the EuCARD-2-cosine-theta magnet. As a result, no influence of the forced twist pitch of 389 mm was detected, thus validating the feasibility of the magnet design for the most critical inner winding. The second part of the dissertation deals with the effects of the electrical resistance between the individual conduc-tors (strands) on the cable properties. Low resistance Roebel cables allow current redistribution along the cable and thus improve thermal stabilization by offering alternative current paths at weak points in the conduc-tor. Low coupling resistances also allow for coupling currents caused by time-varying magnetic fields. These coupling currents flow through the resistive boundaries between the strands and cause electrical energy los-ses, which are called coupling losses. Coupling losses are undesirable because the resulting heating can cause stability problems and additional cooling power is requi-red. The influence of the resistance between the strands on both the electrical and thermal stabilization as well as on the AC losses must be understood before the resistance can be optimized for the best compromi-se. A new experimental setup has been set up to mea-sure the resistance between the strands as a function of an imposed transverse compression. The interstrand resistance was determined by applying a current between the two opposite strands and measuring the voltage profiles between all pairs of strands.

The voltage profiles can be described using a model and by defining two parameters: ρa is the length-normalized resistance between adjacent, directly tou-ching strands, and ρc is the length-normalized re-sistance between any pairs of strands. By means of a least-square-fit on the measured voltage profile ρa and ρc were determined in different cables. In pressed cables, resistances ρa were found in the range of 2.5 to 28 μΩm, depending on the pressure. The values for ρc were much higher in the pressed cables than ρa, an indication of good contact only between adjacent strands. A number of soldered cables were prepared in order to increase the resistance between the strands. These cables had a much lower resistance of ρa = 0.19-0.23 μΩm and ρc = 2.4-2.9 μΩm between the strands. The measured values obtained are not generally valid but depend on the cable geometry. With this method of measuring the resistance between the strands and modelling, the most reliable results for strand coupling are obtained. The influence of the resistance between the strands to the AC coupling losses was investigated in a sinusoidal magnetic field oriented perpendicular to the cable. A formula to describe the coupling losses was obtained by simplifying the cable geometry into two parallel strips with the definition of an effective re-sistance. Additionally, the AC losses including the contributions of both hysteresis and coupling losses were calculated numerically for the cable cross section. Both methods use the resistance value ρa of adjacent strips as input parameter. The calculated values were compared with AC current loss measurements using a calibration-free method. A series of Roebel cables with diffe-rent coupling resistance values were manufactured. The coupling resistance was determined by electrically isola-ting the strands, applying pressure or soldering mo-difiziert. An acceptable agreement with the numerical model was found for magnetic field amplitudes of 5 mT or higher. The applied formula for coupling losses esti-mates the coupling losses to be too high, presumably by not taking into account the shielding effects of the superconductor. However, it makes sense to estimate an upper limit for the coupling losses as a function of ρa. Finally, the influence of the coupling resistance of the strands was examined for the stabilization of the cable. The stabilization is described by the minimum quench energy (MQE), which is the smallest locally generated heat pulse in a strand that escalates to a quench of the entire cable. A simple method for calcula-ting the MQE taking into account the redistribution of electricity has been proposed. The current and tempera-ture distributions are described by a set of partial diffe-rential equations of the diffusion type, which have been solved numerically. This method uses the coupling resistance of the strands ρa and the transverse thermal conductivity as parameters. A large number of MQE calculations with different parameters have been per-formed. There was a general trend of improved stabi-lization when current redistribution is possible, but the heat remains on the strand. This happens when both the coupling resistance and the transverse heat conduc-tion are small. In addition to the calculations, an expe-riment was carried out on short Roebel cables. A gra-phite-epoxy resin heater was placed on a strand to generate heat pulses. The cable was placed in a GRP sample holder in a vacuum and cooled by thermal conduction. The MQE was determined by applying heat pulses of increasing intensity until a quench occurred. The measurements were performed with different cur-rents at temperatures between 73.5 and 84 K. MQE values between 0.08 and 2.2 J were measured, decrea-sing to zero as the imposed current approached the critical value. The experimental results were compared with the calculated MQE values, including the coupling resistances. The best agreement was found with a low thermal conductivity of 0.001 W/Km. This is an indicati-on of a very tight thermal contact between the strands in the cable.

Dr. Pattabhi Vishnuvardhan Gade

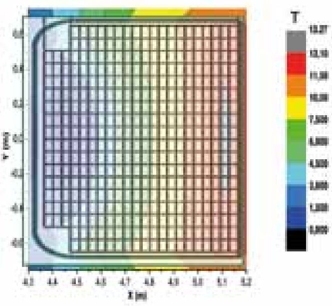
Conceptual design of high-temperature superconducting toroidal field coils for future Fusion power plants

Sustained research in magnetic confinement has given rise to Stellarators and Tokamaks, which utilise strong and non-uniform magnetic fields for trapping the plasma particles and enables them to move freely along spe-ci-fied paths. The Tokamaks have gained prominence due to simpler coil design, nested magnetic surfaces and ability to operate with positive magnetic shear. Currently, European Union (EU) is planning to extend its studies on Tokamak towards demonstration powerplant (EU-DEMO) that can generate electricity. The aim of this study is to develop a conceptual design for the toroidal field coil (TF coil) for future power plants using PROCESS system code. The PROCESS code gives certain output like, the ap-proximate shape of TF coil, area of winding pack, mag-netic field at plasma axis. From the input, winding pack of the TF coil is designed. For example, in case where pancake winding is preferred over the layer winding. The first layer facing plasma heat is accumulated since it is in high field region, as a result of which, the magnet operates at lower operating margin. However, the conductor of the pancake winding is wound in a circum-ferential direction rather than along the axis of a magnet and each module is wound separately and jointed electrically in series. The basic advantage in this me-thod is that the temperature is lowest in the high field region since the helium inlet is located in the high field region of the winding pack and the outlet at the low field region. The winding pack comprising the electrical cir-cuit is connected in series and hydraulic circuit is connected in parallel.

From the PROCESS code it is checked whether the magnetic field at plasma axis is equal to the required magnetic field. The peak magnetic field is also calcula-ted for defining the operating point of the conductor. 3D Electromagnetic simulation is carried out using the pre-processor TOKEF and the code EFFI. Codes for mag-netic field calculation of a general three-dimensional current distribution, that use formulations based on a filamentary approximation and the conductor finite size. These codes are approximated by set of distributed filaments using EFFI formula derived from Bio-Savart law for volume current distribution.

The structural analysis of the TFC determines the stresses in the coil casing and in the winding pack. The area with the highest stresses occurs in the midplane of the inboard leg that is confirmed by a similar analysis done with the JT-60SA TF coil magnet system. In EU DEMO, the TFC carries high currents (in MA) and pro-duces high fields. The TFC is hence subjected to high magnetic pressure and forces. To examine the stresses in the winding pack and at the casing, various methods are considered in COMSOL and ANSYS to analyse stress at casing, debonding of the coil winding pack and stresses in insulation components. One important failure that has to be taken care of in the superconducting magnet design is the transition from the superconducting to normal conducting phase known as quench. Since, in normal conducting mode, the electrical resistance of the superconductor material is high, introducing copper as an electrical diverter for the flow of current, generates joule heating. The magnet has to be discharged by connecting an external re-sistance parallel to the magnet to avoid excessive tem-perature rise. The maximum allowable adiabatic hotspot temperature as laid by International Thermonuclear Experimental Reactor (ITER) limits to 150 K, conside-ring all materials in the conductor, i.e., superconductor, copper, helium, stainless steel jacket, and insulation. To simulate quench propagation, an external heater is placed in the superconductor and checked how the propagation is and what is the maximum temperature that it attains during discharge time.

Magnetic field at winding pack



Parameters	Value
Total no of TFC	16
Current in one TFC (MA)	19.2
Total winding pack area (m^2)	1.10
Peak field on conductor (T)	13.27
Inductance (H)	7.28
Energy Stored (GJ)	9.09
Total number of conductors	384

PROCESS Code
Simulated Value

Figure. 2: Magnetic field and main parameters of the high-temperature superconducting winding pack

Dr. Alan Preuss

Development of high-temperature superconducting cables for high current applications

The focus of this work is on the development, manufacture and testing of the superconducting elements of a 35 kA HTS DC cable demonstrator. Three major HTS high current conductor concepts (Stack, Roebel, Cable on Round Core (CORC)) were analysed and the HTS Cross Conductor (HTS CroCo) stack concept was selected. For high current applications a design process for HTS DC cables was developed. Based on the de-sign process, a 100 kA cable design based on 36 CroCos was developed and then scaled down to a 35 kA cable demonstrator with 12 CroCos. The length of the cable demonstrator was set at 3.6 m and the opera-ting temperature at 77 K. Prior to CroCo production, a study was conducted on the degradation behaviour of the critical current density of second-generation HTS bands under thermal load. These studies are necessary because HTS tapes are often exposed to thermal stress during production, e.g. by soldering. An under-standing of the exact degradation behaviour can there-fore contribute to the optimisation of manufacturing processes. The investigation showed a predictable and repeatable degradation behaviour, which seems to be caused by the oxygen depletion of the crystal. It was shown that tin-silver solders could be a cost-effective alternative to lead-containing solders in CroCo produc-tion. For the production of CroCos, superconductors from two manufacturers were examined for their com-patibility with the CroCo production process. It was found that superconductors from one manufacturer are basically compatible, but have strong tendencies to have an uneven distribution of galvanized copper. Su-perconductors from the other manufacturer were not compatible at the time, but are promising candidates for future work. The CroCo manufacturing process has been further developed to integrate a round outer solder matrix. In addition, the manufacturing process has been adapted to allow superconductors with minimal galva-nized copper (about 5-10 µm), which helps to reduce the cost of the superconductors. A new CroCo produc-tion machine has been installed to enable these chan-ges. The 12 CroCos used in the demonstration cable were produced in 8 production runs. From each CroCo production run, one or two of the desired 3.6 m CroCos were cut. The critical current of each of the 12 CroCos was measured under self field conditions at 77 K and varied between 2890 A and about 3680 A. The relatively large variation is due to the optimization of numerous manufacturing steps and an increasing performance of the superconductors. It has been shown that the critical current of a CroCo can be reliably calculated based on the average critical current of the superconductors used to produce the CroCo. Solder joints were used to connect the CroCo to normal conducting copper cables. The average resistance of these connections was 200 nΩ and with a standard deviation of 43 nΩ at 77K. This would result in a heat load of approximately 0.7 mW per connection at an operating current of 3500 A. This should be sufficiently low for most applications. A 6 m long, 1 m wide and 0.8 m high cryostat was developed and built for testing the cable demonstrator. The demonstration cable itself consists of the 12 CroCos with 22 6 mm wide and 10 4 mm wide superconducting tapes. The CroCos are mounted on an aluminum core with a diameter of 110 mm and connected in parallel. During the series of measurements, the cable demonstrator (see Figure 3) reached a steady state current of 34 kA and 35 kA for a short time. An analysis of the current distribution during the cable test revealed a relatively large scattering of the current distribution across the CroCos, probably caused by water con-densing between the contacts, thus increasing the contact resistance. One CroCo was removed from the demonstrator after the test to ensure that no degradati-on, e.g. due to voltages during cooling, occurred. This work concludes with a case study of a superconducting cable in an aluminium electrolysis plant. It is shown that the energy savings for a 500 m long superconducting cable of class 100 kA compared to a conventional alu-minium busbar are in the range of 6 GWh to 6.5 GWh per year, which is about the annual energy consumption of 2000 2-person households in Germany. The invest-ment costs for the superconducting system mentioned above are currently three to six times higher than for a conventional aluminium busbar system. The big diffe-rence in the investment costs of the superconducting system is largely due to a large variance in the super-conductor costs. The break-even point between the superconducting system and the conventional system for the minimum investment costs of both systems is at an electricity price of about 30 ct/MWh, calculated over a period of 40 years.

Fig. 3: Setup of a 35 kA DC cable demonstrator with 12 Croco conductors

Dr. Roland Gyuráki

Fluorescent thermal imaging method for inve-stiga-ting transient effects in high temperature super-conductor tapes and coils

The focus of this work was the development and demonstration of a thermal imaging method based on fluorescent thermal images to be used for the investiga-tion of HTS tape conductors and coils in transient state. By upscaling the fluorescent thermal imaging technique, a new measuring method is demonstrated here, which can detect 2D temperatures of objects much better and larger than before. Furthermore, the recordings are possible thanks to a commercial high speed camera with a significantly higher temporal resolution and thus the method also allows the recording of transient ther-mal effects. The developed high speed fluorescent thermal imaging method uses europium tris (EuTFC) as fluorescent dye with precisely measured temperature dependent, fluorescent light emissions. The dye was applied by droplet coating on the surface of the samp-les, and then subjected to a heat treatment of 30 min at 175 °C to stabilize the coating. The coated samples were cooled to 77 K and the fluorescent surface coating was excited with UV LEDs. In the range from 77 K to 260 K, the fluorescent light intensity decreases almost linearly, while the color remains unchanged. To calcula-te temperatures from the thermal images, both the calibration of the dye and the high speed camera images were normalized at defined temperature (here 77K, boiling point of liquid nitrogen at atmospheric pres-sure). In post-processing, the surface temperature in the images can thus be determined using the calibration curve.

For demonstration purposes, the method was used for qualitative quench measurement on HTS tapes and for determining their propagation velocity of the normal conducting zone in liquid nitrogen. Short current pulses, close to the critical current, were applied to several tapes with different architectures and showed effects that were previously presented in the literature, but from a thermal perspective. The heating of the conductors in the form of tapes at several points at the same time was visible in several measurements, with pulses well above the critical current of the superconductor. This shows that the velocity of propagation of the normal conducting zone is more complex than a single normal conducting zone propagating at a constant velocity in one direction and that the amplitude of the current pulse not only affects the velocity of propagation but also the quenching behaviour significantly. It has also been shown that currents well above the critical current in strip conductors with copper stabilization are transferred to the stabilization almost immediately. However, cur-rent pulses around the critical current - both in conduc-tors without stabilization and in stabilized HTS striplines - cause a single quench point that propagates and quickly exceeds the measuring range of the thermal imaging images.

The propagation velocities calculated by the thermal imaging were compared with electrical measurements taken by the Ecole Polytechnique Montreal, Canada, to evaluate the method. The two methods for quench and propagation velocity from different physical approaches showed that at high current amplitudes the propagation velocities were similar. Since heating scales with the second power of the current, it is assumed that in tape conductors with high critical currents the electric field and the heating propagate almost simultaneously. In HTS tapes with lower critical currents, the fluorescent thermal imaging method provided consistently lower values for the propagation speed of the normal conduc-ting zone due to the significantly lower heating power.

The thermal imaging method was also used to test two pancake coils. One of the coils was wound as a con-ventional insulated coil, whereas the new non-insulated winding method was used for the second coil. In the measurements the surface of the coils was coated with the fluorescent dye and was measured by line cooling in the test setup at 77K. The self-protection mechanism of the non-insulated coil was observed in one of the measurements where the thermal images showed a fast redistribution of the currents (and heating) within the coil during operation in the critical current range. In another measurement a thermal runaway was also observed at 110% of the critical current. Over a period of 60 s, a slow but steady voltage rise caused a current in the radial direction. However, no local hot spots or pronounced heating were detected. A rapid temperature rise was observed during the transition to normal conductivity, with the inner windings of the coil heating up to 100 K, indicating the weakest point of the coil. The coil was discharged manually to prevent damage and the heating was concentrated in the middle of the coil and only included some of the innermost windings. The spread of the heat zone in the transverse direction was negligible. To artificially create a defect and to investigate the stability of the coil, an electrical resistor was glued to the coil surface and used as a radiator. After a 7s long heating pulse with a power of 3.2W, a thermal runaway was generated, where the coil could not stabilize after the end of the heating pulse (Fig. 4). The temperature rise was localized around the radiator, where it propagated along the windings in contact with the radiator, but not in the transverse direction. Tempe-ratures of up to 150 K were reached, whereupon the coil was quickly discharged.

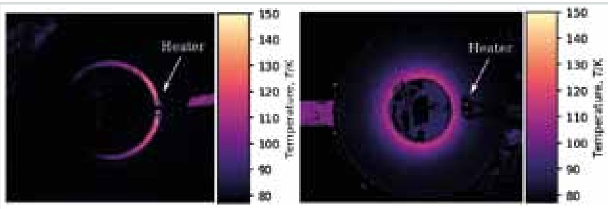


Fig. 4: Temperature evolution on an insulated coil (left) and non-insulated coil (right) after initiating a quench with a heater

Dr. Thomas Markus Kochenburger

Cryogenic mixed refrigerant circuits for high-temperature superconductor applications

High-temperature superconductors (HTS) have already demonstrated their performance in cables, busbars, electric motors, generators and transformers in several pilot projects. Due to the lack of availability of closed cooling processes in the relevant cooling capacity range of a few kW, these must usually be cooled by vacuum evaporation of liquid nitrogen at 65 K to 77 K in open processes.

Cryogenic mixed refrigeration cycles (CMRCs), which are used on a large scale for LNG production, allow efficient, cost-effective and reliable cooling in the temperature range of about 80 K to 150 K with almost unlimited scalability. In order to take advantage of closed CMRC cooling processes for HTS applications, their cooling temperatures must be lowered, which has so far been associated with a sharp drop in efficiency. For safety reasons, non-combustible refrigerant mixtures are also preferred to the nitrogen-hydrocarbon mixtures normally used. This work is intended to contribute to solving these challenges.

First, suitable components for high-boiling, non-combustible refrigerant mixtures with low freezing point are identified. In addition to the fluorinated aliphatic refrigerants used so far, the refrigerant R1234yf, which has only been available for a few years, is considered as a new possible mixture component. On the basis of an overview of previous work, a two-stage cooling process for HTS applications is designed. The first stage involves the use of a non-flammable refrigerant mixture, the second stage involves a significantly increased pressure level to increase efficiency and the use of oxygen to lower the freezing point.

For the calculations in the later process optimization of a modified Peng-Robinson equation of state is used, which is adapted to thermophysical pure substance data and binary phase equilibrium data from the literature to reproduce the phase behavior. Since no literature data at low temperatures exist for some binary sys-tems, own phase equilibrium measurements were car-ried out. For this purpose, an existing test facility was first modified to allow work with the selected refrigerants while complying with process and safety requirements. Subsequently, measurements were carried out in binary mixtures of R1234yf with R14, R23, R218, N_2 and Ar in the temperature range from 153 K to 273 K and at pressures up to 50 bar.

In the process simulation part of the work, the mixture compositions and the process parameters are defined and optimized in Aspen Plus for maximum process efficiency for each case. Based on a detailed consideration of the two sub-stages of the developed cooling process, results for two HTS cooling scenarios are presented and evaluated. The achieved efficiencies are significantly higher than in previous CMRC processes and comparable to those of other cooling processes for the temperature range under consideration. The use of R1234yf as a high-boiling mixture component proves to be advantageous over the alternative R218.

For validation of the process simulation, a CMRC test rig was set up and put into operation. First measurement results on three simple mixtures are in excellent agreement with the process calculations in Aspen Plus, which indicates a high prediction quality of the modeling. The experimental validation of the complete cooling process was no longer possible within the scope of this work, but will be continued in subsequent projects.

Teaching and Education

Lectures, Seminars, Workshops

Lectures

KIT-Fakultät Elektrotechnik und Informationstechnik
Supraleitende Systeme der Energietechnik (Holzapfel, Noe) WS 18/19, WS 19/20
Supraleitende Materialien (Holzapfel) WS 18/19, WS 19/20
Energy Storage and Network Integration (Noe, Grilli) WS 18/19, WS 19/20
Übungen zu Energy Storage and Network Integration (Noe, Kottonau) WS 18/19, WS 19/20
Projekt Management für Ingenieure (Noe, Day) SS 19
Grundlagen und Technologie supraleitender Magnete (Holzapfel) SS 19
Superconducting Materials for Energy Applications (Grilli) SS 19

KIT-Fakultät für Chemieingenieurwesen und Verfahrenstechnik
Vakuumtechnik (Day) WS 18/19, WS 19/20
Übung zu Vakuumtechnik (Day, Varoutis) WS 18/19, WS 19/20
Kältetechnik A (Grohmann) WS 18/19, WS 19/20
Übungen zu Kältetechnik A (Grohmann, Mitarbeiter) WS 18/19, WS 19/20
Cryogenic Engineering (Grohmann) WS 18/19, WS 19/20
Cryogenic Engineering – Exercises (Grohmann, Mitarbeiter) WS 18/19; WS 19/20
Projektarbeit zum Profilfach Termodynamik und Kältetechnik (Grohmann) WS 19/20
Physical Foundations of Cryogenics (Grohmann) SS 19
Physical Foundations of Cryogenics – Exercises (Grohmann) SS 19
Kältetechnik B (Grohmann) SS 19
Übungen zu Kältetechnik B (Grohmann, Mitarbeiter) SS 19

KIT-Fakultät Maschinenbau
Fusionstechnologie A (Bornschein, Day, Demange, Fietz, Frances, Weiss) WS 18/19
Magnet-Technologie für Fusionsreaktoren (Fietz, Weiss) SS 19
Vakuumtechnik und Tritiumbrennstoffkreislauf (Day, Größle) SS 19

House of Competence
„Wissenschaftliches Schreiben und Präsentieren …" mit inhaltlich-konzeptioneller Beteiligung von Dr. B. Bornschein; SS 19

Vorlesung in China
Vorlesung „Cryogenics" in China (Neumann); 15.–26.März 2019

Kryo-Seminare
VDI-Seminar „Kryotechnik" (Neumann, Schneider, Giegerich); 27.–29. März 2019
Haus der Technik Seminar „Kryostatbau" (Neumann, Weiss, Lietzow); 25.–27. September 2019

Duale Hochschule BW – Fachbereich Maschinenbau
Arbeitssicherheit und Umweltschutz (Bauer) SS 19
Thermodynamik 1 für Maschinenbauer (Neumann) WS 18/19, WS 19/20
Thermodynamik 2 für Maschinenbauer (Neumann) SS 19

* with participation of ITEP

Teaching and Education

PhD Theses – Master Theses – Bachelor Theses

PhD Theses 2019
(* Academic supervisor; ** completed)

Kai Ackermann (SUPRA)
Präparation und Charakterisierung supraleitender Joints REBCO-basierter Bandleiter
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel (KIT, ETIT)*, Prof. Dr. Matthieu Le Tacon (IFP)

Rodrigo Antunes (TLK)
Experimental and numerical study on advanced inorganic membranes for tritium processes and qualification for tritium recovery in the breeding blanket
Betreuer: Dr. L. Frances, Prof. Dr. Margarida Cruz (Universität Lissabon)*

Stefan Biser (SUPRA)
Entwicklung eines Tools zur analytischen Auslegung und Optimierung hybrid-elektrischer Luftfahrtantriebe
Betreuer: Prof. Dr. V. Hagenmeyer (IAI), Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Alexander Buchholz (SUPRA)
Prospective Life Cycle Analysis of high temperature superconductor tapes for future grid applications
Betreuer: Dr. M. Weil (ITAS), Prof. Dr.-Ing. M. Noe*

Carl Bühler (SUPRA)
Neue RRP Leiterkonzepte für verbessertes Pinning durch interne Oxidation
Betreuer: Dr. S. Kauffmann-Weiss, Prof. M. Heilmaier (MACH)*

Matthias Corduan (SUPRA)
Design, Konstruktion und Test einer rotierenden elektrischen Maschine basierend auf supraleitenden Ständerwicklungen aus Magnesiumdiborid (MgB2)
Betreuer: Prof. Dr.-Ing. M. Doppelbauer (KIT-ETIT), Prof. Dr.-Ing. M. Noe*

Ester Diaz-Alvarez (TLK)
Tritium extraction from liquid breeding blanket based on the vacuum sieve tray technique
Betreuer: Dr. U. Besserer, Prof Dr. R. Stieglitz (KIT, MACH)*

Wolfram Freitag (SUPRA)
Optimierung eines kontinuierlichen Prozesses zur Herstellung REBa2Cu3O7x-basierter supraleitender Bandleiter aus chemischen Präkursorenlösungen
Betreuer: Prof. Dr. B. Holzapfel, Prof. Dr.-Ing. J. Sauer (IKFT)*

Cristian Gleason-González (VAKUUM)
Modelling of rarefied neutral gas flow
Betreuer: Dr. S. Varoutis, Prof. Dr. R. Stieglitz (KIT, MACH)*

David Gomse (KRYO)
Entwicklung eines Wärmeüberträgers für MRC-Cryocooler
Betreuer: Prof. Dr.-Ing. Th. Wetzel (TVT), Prof. Dr.-Ing. S. Grohmann (KIT, CIW/VT)*

Lukas Grünewald (SUPRA)
Elektronenmikroskopische Untersuchung von eisen- und kupferbasierten Hochtemperatursupraleitern
Betreuer: Prof. Dr. B. Holzapfel, Prof. Dr. D. Gerthsen (LEM)*

Theresa Hanemann (FUSION)
Deformation Mechanisms in FCC and BCC High Entropy Alloys under various Conditions
Betreuer: Dr. K. Weiss, Prof. Dr.-Ing. M. Heilmaier (KIT, Mach)*

Yannick Hörstensmeyer (VAKUUM)
Ein Prozess-Simulator zur Auslegung, Modellierung und Optimierung des inneren Brennstoffkreislaufs eines Fusionskraftwerks
Betreuer: Dr.-Ing. C. Day, Prof. Dr.-Ing. R. Stieglitz (INR)*

Harald Itschner (SUPRA)
Entwicklung von Modellen zur speichergestützten Versorgung von Inselnetzen mit erneuerbaren Energien
Betreuer: Prof. Dr.-Ing. K. Glöser (Hochschule Kaiserslautern), Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Shahab Karrari (SUPRA)
Integration von Energiespeichern in Elektroenergiesysteme
Betreuer: Prof. Dr.-Ing. M. Noe, Dr. J. Geisbüsch (KIT, ETIT)*

Yannick Kathage (VAKUUM)
Entwicklung einer Metallfolienpumpe auf dem Prinzip der Superpermeation
Betreuer: Dr. C. Day, Prof. Dr. R. Stieglitz (KIT, Mach)*

Bennet Krasch (TLK)
Spektroskopische Untersuchungen zu intermolekularen Effekten in der WGTS
Betreuer: Dr. R. Größle, Prof. Dr. G. Drexlin (KIT, Physik)*

Philip Kreideweis (SUPRA)
Entwicklung von Niederspannungsschaltanlagen
Betreuer: Dr. J. Geisbüsch, Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Marco Langer (SUPRA)
Dünne Schichten pniktid-basierter Supraleiter für Detektoranwendungen
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel (KIT, ETIT)*

Sven Meyer (SUPRA)
Elektrische Transporteigenschaften epitaktischer Fe-basierter Supraleiterdünnschichten
Betreuer: Prof. Dr. B. Holzapfel, Prof. Dr. Matthieu Le Tacon (IFP)*

Sebastian Mirz (TLK)
Untersuchung der Molekularen Effekte in allen sechs flüssigen Wasserstoffisotopologen mithilfe Infrarot- und Ramanspektroskopischer Methoden
Betreuer: Dr. B. Bornschein, Prof. Dr. G. Drexlin (KIT, Physik)*

Cyra Neugebauer (VAKUUM)
Validation of a process for semi-continuous separation of hydrogen isotopes
Betreuer: Dr. C. Day, Prof. Dr. R. Stieglitz (KIT, Mach)*

Daniel Nickel (SUPRA)
Untersuchungen zum Quench-Verhalten und zur Degradation von HTS Hochstrom-Leitern für zukünftige Fusionsmagnete
Betreuer: Dr. M. Wolf, Prof. Dr. R. Stieglitz (KIT, Mach)*

Simon Niemes (TLK)
The TRIHYDE-Experiment: calibration grade gas samples of all six hydrogen isotopes in thermal equilibrium
Betreuer: Prof. Dr. B. Holzapfel, Prof. Dr. G. Drexlin (KIT, Physik)*

Benedikt Peters (VAKUUM)
Entwicklung einer Metallfolienpumpe
Betreuer: Dr. C. Day, Prof. Dr. R. Stieglitz (KIT, Mach)*

Ruslan Popov (SUPRA)
Stromtragfähigkeit und Pinningeigenschaften RE BCO-basierter Dünnschichten und Bandleiter bei tiefen Temperaturen und in hohen Magnetfeldern
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel (KIT, ETIT)*

Nicolo Riva (SUPRA)
Quench behavior of high-temperature superconductor tapes for power applications: a strategy toward resilience
Betreuer: Dr. F. Grilli, Dr. B. Dutoit (EPFL, Lausanne)*

Eugen Shabagin (KRYO)
Entwicklung einer 10 kA HTS-Stromzuführung mit kryogenem Gemischkältekreislauf
Betreuer: Prof. Dr.-Ing. S. Grohmann, Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Fabian Schreiner (SUPRA)
Aufbau eines supraleitenden DC Windkraftgenerators und Untersuchung der Netzanbindung
Betreuer: Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Jonas Schwenzer (VAKUUM)
Ein Prozess-Simulator zur Vorhersage und Optimierung des Betriebs des Brennstoffkreislaufs eines Fusionskraftwerks
Betreuer: Dr. C. Day, Prof. Dr. R. Stieglitz (KIT, Mach)*

Tim Teichmann (VAKUUM)
Entwicklung eines Berechnungsnverfahrens für quecksilbergetriebene Vakuumpumpen in einem weiten Bereich der Knudsenzahl
Betreuer: Dr. C. Day, Prof. Dr. R. Stieglitz (KIT, Mach)*

Christina Weber (KRYO)
Experimentelle Untersuchung und Modellentwicklung zum Einfluss der Zweiphasenströmung auf die Funktionsweise von Sicherheitseinrichtungen von Flüssighelium-Kryostaten
Betreuer: Prof. Dr.-Ing. J. Schmidt (CIW), Prof. Dr.-Ing. S. Grohmann (CIW)*

Friedrich Wiegel (SUPRA)
Realisierung und Untersuchung der Bitübertragungsschicht unabhängiger Meshnetzwerke für Smart Grid Anwendungen
Betreuer: Prof. Dr. V. Hagenmeyer (IAI), Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Simon Otten (SUPRA)**
HTS Roebel cables with thermal and mechanical stabilizations
Betreuer: Prof. Dr.-Ing. H. ten Kate (Uni Twente), Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Alan Preuß (FUSION)**
Development of high temperature superconductor (HTS) REBCO cables for large current applications
Betreuer: Prof. Dr. A. Morando (University of Bologna), Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Roland Gyuráki (SUPRA)**
Fluorescent thermal imaging method for investigating transient effects in high temperature superconductor tapes and coilsBetreuer: Prof. Dr.-Ing. Frédéric Sirois (École Polytechnique, Montréal, Canada), Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Master Theses 2019
(* Academic supervisor; ** completed)

Arnaud Kraskowski
Cryogenic High Strength MaterialsBetreuer: Dr. K.-P. Weiss, Prof. Dr. R. Stieglitz (KIT, MACH)*

Lana Liebl
Performance Investigation of a new cryogenic flow meter in the operating area of a helium refrigerator
Betreuer: Prof. Dr. S. Grohmann*

Daniel Nickel **
Mechanische und elektromechanische Untersuchungen an HTS CroCo-Triplett-Leiterverbünden
Betreuer: Dr. M. Wolf, Prof. Dr. R. Stieglitz (KIT, MACH)*

Mauro Naffarate **
Investigation of Power Grid Technologies for Offshore Wind farm Systems
Betreuer: F. Schreiner, Prof. Dr.-Ing. M. Noe*

Szymon Palasz
Modelling and experimental investigation of thermal stability of 2nd generation high temperature superconductors (2G HTS) for the application in DC fault current limiter (DC FCL)
Betreuer: Dipl.-Ing. A. Kudymow / Dr. F. Grillli*

Simone Pezzolato
Modeling and Real-time Simulation EV charging stations with Energy Storage Systems
Betreuer: Prof. Dr.-Ing. M. Noe, Prof. Dr. A. Morandi (University of Bologna)*

Pham Hung Quoc
Analytical modeling of electric machines with HTS stator windings for hybrid electric aircraft
Betreuer: M. Corduan (Siemens), Prof. Dr. B. Holzapfel*

Sabrina Schirle **
Experimentelle Untersuchung des Vakuumzusammenbruchs in Helium-Kryostaten mit Superisolation
Betreuer: C. Weber, Prof. Dr.-Ing. S. Grohmann (ITTK)*

Sonja Schneidewind
Investigation of tritium loading of thin metal layers
Betreuer: Dr. M. Schlösser, Prof. Dr. G. Drexlin (KIT, Physik)*

Jonas Schwenzer **
Basic characterization of a mercury based mass transfer process for lithium isotope separation
Betreuer: Dr. C. Day, Prof. Dr. R. Stieglitz (KIT, MACH)*

José Manuel Trueba Cutillas **
Design consoderations of an extruder for pellet injection at DEMO
Betreuer: Dr. C. Day, Prof. Dr. R. Stieglitz (KIT, MACH)*

Bachelor Theses 2019
(* Academic supervisor; ** completed)

Nico Beisig
Herstellung und Charakterisierung eisenbasierter supraleitender Schichten mit Dotierung
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel*

Leonhard Döring
Modellierung, Simulation und Messung des Verhaltens supraleitender Permanentmagnete in Form geschichteter Bandleiter
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel*

Michael Enns
Strukturelle und elektrische Eigenschaften von $Ba(Fe,Co)_2As_2$-Target- und Dünnschichtproben
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel*

Christopher Faschina
Untersuchung des Einflusses wiederholter Biegebelastung auf den kritischen Strom von HTS CroCo Supraleiterkabeln
Betreuer: Dr. M. Wolf, Prof. Dr. J. Aghassi Hagmann (INT)*

Lucian Fasselt
H2D2 Kalibrierung des Laser Raman Systems mit Trihyde
Betreuer: S. Niemes, Prof. Dr. G. Drexlin (KIT, Physik)*

Leonhard Hasselmann
Beladungstest von Metalloberflächen mit Tritium
Betreuer: M. Schlösser, Prof. Dr. G. Drexlin (KIT, Physik)*

Edward Hermann **
Entwicklung eines didaktischen Konzepts für die Station „Kernfusion" im KIT-Schülerlabor Energie
Betreuer: Prof. Dr. C. Rockstuhl (Physik), Prof. Dr. B. Holzapfel*

Sebastian Hetzler **
Evolution of mechanical properties at cryogenic temperatures of 316L processed by powder bed fusion
Betreuer: J. Sas, Prof. M. Heilmaier (IAM)*

Vadim Mai **
Elektrische Transporteigenschaften von YBa2Cu3O7-x-Schichten mit nanoskaligen Pinningzentren
Betreuer: K. Ackermann, Prof. Dr. B. Holzapfel*

Svenja Müller **
Erster Aufbau und Charakterisierung des optischen Systems des TApIR2-Experiments zur parallelen Analyse mittels Raman- und IR-Spektroskopie-Aufbaus
Betreuer: B. Krasch, Prof. Dr. B. Holzapfel*

Sebastian Sakmann **
Thermische Analyse zur Optimierung des TFA-MOD Prozesses bei der Herstellung supraleitender $REBa_2Cu_3O_{7-d}$ Dünnschichten
Betreuer: W. Freitag, Prof. Dr.-Ing. Jörg Sauer (IKFT)*

Sebastian Schorstädt **
In-situ-Ausscheidung von Nanopartikeln in REBCO-Dünnschichten zur Verbesserung der kritischen Stromdichte
Betreuer: W. Freitag, Prof. Dr.-Ing. Jörg Sauer (IKFT)*

Sebastian Vetter
Simulationen bei BIXS
Betreuer: Dr. M. Schlösser, Prof. Dr. G. Drexlin (KIT, Physik)

Teaching and Education

Colloquies

08.02.2019 Investigation of collection grid topologies for offshore windfarm systems
Mauro Nafarrate
Fachvortrag Masterarbeit, IB SUPRA

28.02.2019 Thermische Analyse zur Optimierung des TFA-MOD, Prozesses bei der Herstellung supraleitender REBa_2 Cu_3 O_(7-δ) Dünnschichten
Sebastian Sakmann
Fachvortrag Bachelorarbeit, IB Supra

16.04.2019 In-situ-Ausscheidung von Nanopartikeln in RE[Ba]_2 [Cu]_3 O_(7-δ) Dünnschichten zur Verbesserung der kritischen Stromdichte
Sebastian Masato Schorstädt
Fachvortrag Bachelorarbeit, IB Supra

15.05.2019 Entwicklung eines Didaktischen Konzepts für die Station „Kernfusion" im KIT-Schülerlabor Energie
Edward Hermann
Fachvortrag Bachelorarbeit, IB Supra

18.06.2019 Basic Characterization of a Mercury Based Mass Transfer Process for Lithium Isotope Separation
Jonas Schwenzer
Fachvortrag Masterarbeit, IB Vakuum

28.06.2019 Mechanische und elektromechanische Untersuchungen an HTS CroCo-Triplett-Leiterverbünden
Daniel Nickel
Fachvortrag Masterarbeit, IB Fusion

19.07.2019 Design considerations of an extruder for pellet injection at DEMO
José Manuel Trueba Cutillas
Fachvortrag Masterarbeit, IB Vakuum

23.07.2019 Modelling and experimental investigation of thermal stability of 2nd generation high tem-perature superconductors (2G HTS) for the application in DC fault current limiter (DC FCL)
Szymon Palasz
Fachvortrag Masterarbeit, IB Supra

06.08.2019 Elektrische Transporteigenschaften von YBa2Cu3O7-x-Schichten mit nanoskaligen Pinningzentren
Vladim Mai
Fachvortrag Bachelorarbeit, IB Supra

28.08.2019 Discovery of new superconductors under high pressure using materials informatics
Yoshihiko Takano
Gastvortrag, IB Supra

17.10.2019 Progress and status of 2G HTS wire development in China
Yue Zhao
Fachvortrag, Kolloquium, IB Fusion

22.10.2019 Untersuchung des Einflusses wiederholter Biegebelastung auf den kritischen Strom von Hochtemperatur-Supraleiter-Stromkabeln
Christopher Faschina
Fachvortrag, Bachelorarbeit, IB Fusion

Figures and Data

Chart of Organization

Superconducting and Cryo-Materials	Energy Applications	Superconducting Magnet- Technology	Fusion Fuel Cycle Technologies
Superconducting Materials	Superconducting power system components	Winding and coil technology	Vacuum Technology and Integration
Cryo- Structural Materials	New Application of Superconductivity	HTS-Fusions-magnets and current leads	Tritium Extraction and Recovery
Cryogenic Properties of Substances	Modelling of Superconductors and Components	Rotaoting Machines	Rarefied Gas Dynamics
Conductor and Wire Concepts	Real- Time System Integration	Industry Applications	Vacuum Hydraulics

Personnel Status (December 31, 2019)

Total	**158**
Academic staff	48
Engineers and technicians	45
Others	16
Doctoral students	28
Master's students	11
Students of the Baden-Württemberg Cooperative State University	7
Apprentices	3

Additional staff in 2019:	
Guests	8
Trainees	10
Student assistants	29
Term papers, bachelor's theses	13

Figures and Data

Personnel Changes

Newly Recruited (Excluding Trainees, Guests, and Student Assistants)

Tabea Arndt

Denis Bobrov

Lennard Busch

Giovanni de Carne

Yannick Kathage

Stefan Kern

Daniel Nickel

Jonas Schwenzer

Christos Tantos

Tim Teichmann

Alejandro Vazquez-Cortes

Leaving (Excluding Trainees, Guests, and Student Assistants)

Carina Galante

Wilfried Goldacker

David Gomse

Reinhard Heller

Marco Langer

Mayraluna Lao

Simon Otten

Benedikt Peters

Nico Pitzschel

Alan Preuß

Vincent Przikling

Rajini-Kumar Ramalingam

Nicolo Riva

Alexander Reiner

Jan Sas

Matthieu Scannapiego

Severin Strauß

Elisabeth Urbach

Figures and Data

Student assistants

Aker Max

Barbosa Estefane

Barthlott Dominic

Beisig Nico

Blaschtschak Julian

Bobien Johanna

Böhmländer Alexander

Diel Felix

Enns Manuel

Faschina Christopher

Fasselt Lucian

Frank Marius

Hermann Edward

Hetzler Sebastian

Jansen Rica

Kathage Yannick

Klenk Rafael

Mai Vadim

Masuch Paul

Müller Nikolas

Poornasrkhakbaz Soheil

Pham Quoc

Raczka Kevin

Reinking Johannes

Ribic Niklas

Saad Daniel

Schulz Pia

Tertulliani Nicola

Wolter Michael

Figures and Data

Guest Researcher

Dr. J. Ogawa
28.08.18–03.04.19 Niigata University, Japan

S. Kunze
10.09.18–28.02.19 Universität Bremen, BRD

Y. Zhang
22.01.19–21.04.19 School of Electrical and Electronic Enigineering, HUST, Wuhan, China

Dr. O. Roberto
10.03.19-10.04.19 New University of Lisbon, Caparica, Portugal

Dr. A. Busnyuk
01.09.19-31.10.19 Bonch-Bruevich Saint Petersburg State University of Telecommunications, Russia

P. Zhou
09.09.19-09.12.19 Applied Superconductivity Laboratory, Chengdu, China

Ch. Li
14.10.19-31.10.19 University of Cambridge, U.K.

Q. Meng
05.11.19-31.10.20 Hefei Institute of Physical Science, Hefei, China

Figures and Data

Memberships of relevant technical and scientific organisations

Tabea Arndt
- Member/guest of the DKE standardization committee K 184 (German Electrical Engineering Commission)

Wescley Batista de Sousa
- Member of the “HTS Modelling Workgroup“

Kai Bauer
- Member of the Helmholtz-working group of the HSE “Health, Safety and Environment“
- Member of the examination boards of the Baden-Württemberg Cooperative State university, Karlsruhe, in the programmes of “Mechanical Engineering” and “Business Engineering”

Christian Day
- Member of the Executive Board of the German Vacuum Society (DVG).
- Vice-president of the „Fachverbandes Vakuumphysik und -technik der Dt. Physikalischen Gesellschaft (DPG)“.
- Project leader “Tritium-fuelling-vacuum“ of the EUROFUSION
- Member of Fusion For Energy – Technical Advisory Panel
- Spokesperson of the Topic 'Vakuum and Tritium' of the German DEMO Initiative
- Member of the International Advisory Committee RGD (Rarefied Gas Dynamics Conference)
- Member of the Program Committee of the ISFNT (international Symposium of Fusion Nuclear Technology).
- Chartered Engineer der American Vacuum Society (AVS).
- Member of the Steering Committee JT-60S

Giovanni de Carne
- Member of the “Institute of Electrical and Electronics Engineers”
- Member of the „Verband der Elektrotechnik, Elektronik und Informationstechnik“

Walter H. Fietz
- Member of the “Technical Advisory Panels (TAP) of F4E”
- Member of the “International Organizing Committee of Symposium of Fusion Technology (SOFT) conference“
- Program Comittee Member of HTS4Fusion Conductor Workshop
- Leader of the “Task Force Magnets“ of the “KIT Fusion programme”
- IEEE Senior Member
- Member of the “IEEE Council of Superconductivity“
- Member of the KIT Senate

Jörn Geisbüsch
- Member and expert of the EERA “Integrated Energy System – A Pathway for Europe” programmes
- Member of the Editor-Board of the “Applied Superconductivity Conference”
- KIT membership, representative and participant of the “DERlab General Assembly” and of the “DERlab Workshops”
- Member of the „User Selection Panels“ of the ERI-Grid project
- Member of the „Deutschen Physikalischen Gesellschaft“
- Chapter Chair and member of the “working group P2004” of the „Institute of Electrical and Electronics Engineers”
- Member of the “ENERGY 2019 Technical Program Committee” of the “International Academy, Research, and Industry Association”
- External member of the organization panel of the workshop “Applications and Challenges in Power-to-X Systems” in Lappeenranta, Finnland

Thomas Giegerich
- Chairman of the „Fachverbandes Vakuumphysik und -technik der Dt. Physikalischen Gesellschaft (DPG)“.

Jens Hänisch
- Superconductor Science and Technology, Advisory board member
- European Magnetic Field Laboratory EMFL, User Proposal Selection Committee member
- Applied Superconductivity Conference, Materials programme committee member
- Materials Research Meeting MRM 2020, Japan, Symposium co-organizer
- Condensed Matter Division meeting CMD2020GEFES 2020, Spain, Symposium co-organizer
- KIT-Convent

Reinhard Heller
- Computation of Thermo-Hydraulic Transients in Superconductors (CHATS-AS), Board member
- DKE/DIN K 184 – Supraleiter
- International Electrotechnical Commission (IEC TC90) – Superconductivity – Member WG 12 – “Superconducting Power Devices – General Requirements for Characteristic Tests of Current Leads designed for Powering Superconducting Devices”

Bernhard Holzapfel

- President of the European Society for Applied Superconductivity (ESAS)
- Applied Superconductivity Conference, Board member
- European Conference on Applied Superconductivity, Member of International Programme Committee
- International Symposium on Superconductivity (ISS), Member of International Programme Committee
- Member of the „KIT-Lenkungskreis KATRIN"

Shahab Karrari

- Member of the "Institute of Electrical and Electronics Engineers"
- Member of the "Power & Energy Society" of the "Institute of Electrical and Electronics Engineers"

Holger Neumann

- Member of the ICE Commitee
- Board member of the Cryogenic Engineering Conference CEC since 2019
- Chairman of the DKV
- Guest professor in China at Zhejiang University in Hangzhou

Mathias Noe

- Trustee of the High-temperature Superconductivity Research Network of the BMWi
- International Expert of the CIGRE D1 69 working group "Assessing Emerging Test Guidelines for HTS Applications in Power Systems"
- International Expert of the CIGRE D1 64 "Cryogenic Dielectric Insulation"
- Spokesperson of the Helmholtz Program "Storage Systems and Cross-linked Infrastructures"
- Member of the Management Board of the research field Energy of the Helmholtz Association
- Member of the Board of the European Society for Applied Superconductivity (ESAS)
- German representative of the International Energy Agency, Technology Cooperation Program high-temperature superconductivity
- Member of the International Organizing and Scientific Program Committee of the International Conference on Magnet Technology
- Member of the Board of the Applied Superconductivity Conference
- Member of the industrial association for superconductivity (ivsupra)

Sonja Schlachter

- Member of the "International Cryogenic Material Conference (ICMC) Board of Directors"

Stylianos Varoutis

- Member of the Scientific Committee of the NEGF (European Conference on Non-equilibrium Gas Flows).
- Member of the Selection Committee of the EU High Performance Computers MARCONI
- Member of the „Deutschen Vakuumgesellschaft (DVG)"

Klaus-Peter Weiss

- DKE German Commission for Electrical Engineering, Electronics, and Information Technology of DIN and VDE Committee K 184 "Superconductors", Deputy Chairman
- IEC International Electrotechnical Commission/Technical Comittee 90 "Superconductivity", member of WG 2 "Critical current measurement of Nb-Ti composite superconductors", WG 5 "Tensile test and electro-mechanical properties of composite superconductors", WG 7 "Critical current measurement method of Nb_3Sn composite superconductors", WG 11 „Critical temperature measurement – Critical temperature of composite superconductors", WG 13 "General characteristics for practical superconducting wires"
- Spokesperson of the working group "Magnet Design" of the German coordination body for fusion research for DEMO
- Member of the International Technical Program Committee – MEM18 9th Workshop on Mechanical and Electromagnetic Properties of Composite Superconductors
- Board Member ICMC (International Cryogenic Materials Conference) Subcommittee International Cryogenic Material Library

Publications

Fusion

(* Wo Sand/or Scopus referenced)

Proceedings

* Luo, X.; Day, Chr.
Monte Carlo simulation of a dynamic sieve system, 31st International Symposium on Rarefied Gas Dynamics, Glasgow, UK, July 23–27, 2018, 978-0-7354-1874-5, 0094-243X

Luo, Xueli, Day, Christian
Monte Carlo simulation of a dynamic sieve system, Proceedings 31st International Symposium on Rarefied Gas Dynamics, AIP Conference Proceedings 2132, 090004 (2019)

C. Sozzi, L. Figini, D. Farina, D. Micheletti, A.Moro, P. Platania, D.Ricci, T.Kobayashi, K.Takahashi, A. Isayama, M. Wanner, M. Scannapiego, C. Day,
An analysis of the ECRF stray radiation in JT-60SA, European Physics Conference, Milano, Italien, 8–12 Jul 2019, online veröffentlicht http://ocs.ciemat.es/EPS2019PAP/pdf/P4.1089.pdf

Lecture

Aker, Max; Röllig, Marco
Material studies to reduce the tritium memory effect in BIXS analytic systems

Day, Christian
The metal foil pump – How cold plasma helps to meet hot plasma

Giegerich, Thomas; Butler, Barry; Day, Christian; Hanke, Stefan; Härtl, Thomas; Hörstensmeyer, Yannick; Neugebauer, Cyra; Ploeckl, Bernhard
Innovative fuel cycle concepts for the EU-DEMO

Giegerich, T.; Battes, K.; Day, C.
Lithium enrichment needs for fusion and fission applications

Giegerich, T.; Day, C.; Gliss, C.; Hanke, S.; Härtl, T.; Hörstenmeyer, Y.; Ionescu-Bujor, M.; Müller, R.; Peters, B.; Scannapiego, M.; Strobel, H.
Design status of the torus vacuum pumping system for tritium processing in the EU-DEMO

Varoutis, Stylianos; Igitkhanov, Yuri; Day, Christian; Innocente, Paolo; Subba, Fabbio; Ambrosino, Roberto; Reimerdes, Holger
Assessment of the pumping efficiency in DEMO alternative divertor configurations

Cismondi, F.; Boccaccini, L. V.; Chiovaro, P.; Ciattaglia, S.; Day, C.; Del Nevo, A.; Di Maio, P. A.; Federici, G.; Hernandez, F.; Moreno, C.; Moscato, I.; Rapisarda, D.; Santucci, A.; Spagnuolo, G.A.; Utili, M.
Progress of the conceptual design of the European DEMO Breeding Blanket, Tritium Extraction and Coolant Purification Systems

Aker, Max; Röllig, Marco
Material studies to reduce the tritium memory effect in BIXS analytic systems, 12th International Conference on Tritium Science and Technology (Tritium 2019), Busan, Südkorea, 22-26 Apr 2019.

U. Fischer, L.V. Boccaccini, F. Cismondi, M. Coleman, C. Day, Y. Hörstensmeyer, F. Moro, P. Pereslavtsev
Required, achievable and target TBR for the European DEMO, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019

K. Battes, Th. Giegerich, Christian Day
Lithium enrichment needs for fusion and fission applications, 1st Tritium School (2019), Ljubljana, Slowenien, 25 – 28 Mar 2019

B. Butler, R. Lawless, T. Jackson, R. George, J. Lopes, S. Davies, A. Santucci, C. Day, T. Giegerich, B. Ploeckl, R. Shaw, Y. Hörstensmeyer, C. Neugebauer
Latest Design Developments for the Fuel Cycle and Tritium Plant for the European DEMO Fusion Reactor, 12th International Conference on Tritium Science and Technology (Tritium 2019), Busan, Südkorea, 22-26 April 2019

Xueli Luo, Benedikt Peters, Christian Day
Monte Carlo study of a metal foil pump with normal and energetic deuterium gas molecules, Int. Vacuum Congress (IVC), Malmö, Schweden, 1-5 Jul 2019

Th. Giegerich, Chr. Dahlke, Chr. Day, S. Ochoa
Test and modelling of a mercury ring pump train for nuclear fusion applications, 4th Int. Rotating Equipment Conference, Wiesbaden, 24-25 Sept 2019

Cismondi, F.; Boccaccini, L.V.; Chiovaro, P.; Ciattaglia, S.; Day, C.; Del Nevo, A.; Di Maio, P.A.; Federici, G.; Hernandez, F.; Moreno, C.; Moscato, I.; Rapisarda, D.; Santucci, A.; Spagnuolo, G. A.; Utili, M.
Progress of the conceptual design of the European DEMO Breeding Blanket, Tritium Extraction and Coolant Purification Systems, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

A. Santucci, M. Incelli, L. Noschese, C. Moreno, F. Di Fonzo, M.Utili, S. Tosti, C. Day
The issue of tritium in DEMO coolant and mitigation strategies, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

G. Federici, Chr. Day et al.
DEMO Programme in Europe Beyond 2020, 28th IEEE/NPSS Symposium on Fusion Engineering (SOFE), Jacksonville, FL, USA, 2-6 June 2019

P.T. Lang, F. Cismondi, Ch. Day, E. Fable, A. Frattolillo, C. Gliss, F. Janky, B. Pégourié, B. Ploeckl
Optimizing the EU-DEMO pellet fuelling scheme, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

Silvano Tosti, Christian Day, Ion Cristescu, Marco Utili, Alessia Santucci, Carlos Moreno, David Rapisarda
Tritium control and handling: Selected major design issues, European Fusion Programme Workshop, Marseille, Frankreich, 3-5 Dez. 2019

G. Giruzzi, Chr. Day et al.
Advances in the physics studies for the JT-60SA tokamak exploitation and research plan European, Physics Conference, Milano, Italien, 8-12 Jul 2019

Journal article

* Federici, G.; Bachmann, C.; Barucca, L.; Baylard, C.; Biel, W.; Boccaccini, Lorenzo V.; Bustreo, C.; Ciattaglia, S.; Cismondi, F.; Corato, V.; Day, Christian; Diegele, E.; Franke, T.; Gaio, E.; Gliss, C.; Haertl, T.; Ibarra, A.; Holden, J.; Keech, G.; Kembleton, R.; Loving, A.; Maviglia, F.; Morris, J.; Meszaros, B.; Moscato, I.; Pintsuk, G.; Siccinio, M.; Taylor, N.; Tran, M. Q.; Vorpahl, C.; Walden, H.; You, J. H.
Overview of the DEMO staged design approach in Europe Nuclear fusion, 0029-5515, 1741-4326

Federici, G.; Bachmann, C.; Barucca, L.; Baylard, C.; Biel, W.; Boccaccini, Lorenzo V.; Bustreo, C.; Ciattaglia, S.; Cismondi, F.; Corato, V.; Day, Christian; Diegele, E.; Franke, T.; Gaio, E.; Gliss, C.; Haertl, T.; Ibarra, A.; Holden, J.; Keech, G.; Kembleton, R.; Loving, A.; Maviglia, F.; Morris, J.; Meszaros, B.; Moscato, I.; Pintsuk, G.; Siccinio, M.; Taylor, N.; Tran, M. Q.; Vorpahl, C.; Walden, H.; You, J. H.
Overview of the DEMO staged design approach in Europe, Nuclear Fusion 59, 066013 (2019)

Christian Day, Barry Butler, Thomas Giegerich, Bernhard Ploeckl, Stylianos Varoutis
A smart three-loop fuel cycle architecture for DEMO, Fusion Engineering and Design 146 (2019) 2462-2468

A. Frattolillo, L.R. Baylor, F. Bombarda, F. Cismondi, A. Colangeli, S.K. Combs, Chr. Day, G. D'Elia, T.E. Gebhart, F. Iannone, P.T. Lang, S.J. Meitner, S. Migliori, F. Moro, R. Mozzillo, B. Pégourié, B. Ploeckl, S. Podda, F. Poggia
Addressing the feasibility of inboard direct-line injection of high-speed pellets for core fueling of DEMO, Fusion Engineering and Design 146 (2019) 2426-2429

Thomas Giegerich, Christian Day, Curt Gliss, Xueli Luo, Holger Strobel, Andrew Wilde
Preliminary configuration of the torus vacuum pumping system installed in the DEMO lower port, Fusion Engineering and Design 146 (2019) 2180-2183

F. Siviero, L. Caruso, T. Porcelli, M. Mura, E. Maccallini, P. Manini, E. Sartori, M. Siragusa, C. Day, P. Sonato
Characterization of ZAO® sintered getter material for use in fusion applications, Fusion Engineering and Design 146 (2019) 1729-1732

S. Varoutis, Yu. Igitkhanov, Chr. Day
Effect of neutral screening on pumping efficiency in the DEMO divertor, Fusion Engineering and Design 146 (2019) 1741-1746

M. Siragusa, P. Sonato, M. Visentin, M. Mura, F.Siviero, L. Viale, E. Maccallini, C. Day, S. Hanke, E. Sartori
Conceptual design of scalable vacuum pump to validate sintered getter technology for future NBI application, Fusion Engineering and Design 146 (2019) 87-90

Gliss Curt, Ambrosino Roberto, Bachmann Christian, Ciattaglia Sergio, Flammini Davide, Giegerich Thomas, Jimenez Samuel, Wilde Andrew
Initial integration concept of the DEMO lower horizontal port, Fusion Engineering and Design 146 (2019) 2667-2670

A. Murari, N. Bekris, J. Figueiredo, H.-T. Kim, C. Perez Von Thun, I. Balboa, P. Batistoni, T. Giegerich, T. Huddleston, M. Rubel, R. Vila, R. Villari, A. Widdowson
Implementation and exploitation of JET enhancements at different fuel mixtures in preparation for DT operation and next step device, Fusion Engineering and Design 146 (2019) 741-744

T. Giegerich, K. Battes, J.C. Schwenzer, C. Day
Development of a viable route for lithium-6 supply of DEMO and future fusion power plants, Fusion Engineering and Design 146, 111339 (2019).

M. Coleman, Y. Hörstensmeyer, F. Cismondi
DEMO tritium fuel cycle: performance, parameter explorations, and design space constraints, Fusion Engineering and Design 141, (2019) 79-90.

S. Varoutis, Yu. Igitkhanov, Chr. Day
Assessment of the 3D geometrical effects on the DEMO divertor pumping efficiency, Nuclear Materials and Energy 19 (2019) 120-123.

V. Toigo, S. Hanke et al.
Progress in the ITER neutral beam test facility, Nuclear Fusion 59, 086058 (2019)

Poster

Stylianos Varoutis, Yuri Igitkhanov, Christian Day, Paolo Innocente, Fabio Subba, Roberto Ambrosino, Holger Reimerdes, Fulvio Militello
Assessment of the pumping efficiency in demo alternative divertor configurations, 28th IEEE/NPSS Symposium on Fusion Engineering (SOFE), Jacksonville, FL, USA, 2-6 June 2019.

Yuri Igitkhanov, Stylianos Varoutis, Christian Day, Volker Hauer
Assessment of the pumping efficiency in DEMO conventional and alternative divertor configurations, Third technical IAEA Meeting on divertor concepts, Vienna, Austria, 4-7 Nov 2019.

Yuri Igitkhanov, Boris Bazylev, Sergey Pestchany
The Runaway Electron Evolution in the DEMO Reactor Plasmas, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

Vasilii Alimov, Andrei Busniuk, Christian Day, Stefan Hanke, Evgenii Peredistov, Alexander Livshits
D/T separation from He with superpermeable membranes: FCC V-alloys as new membrane materials, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

Stefan Hanke, Christian Day, Thomas Giegerich, Juri Igitkhanov, Yannick Kathage, Xueli Luo, Stylianos Varoutis, Alejandro Vazquez Cortes, Thomas Härtl, Andrei Busniuk, Alexander Livshits, Stefan Merli, Andreas Schulz, Matthias Walker, Klaus Baumgärtner, Jens Hofmann
Progress of the R&D programme to develop a Metal Foil Pump for DEMO, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

Katharina Battes, Thomas Giegerich, Christian Day
HgLab Karlsruhe – An Infrastructure Facility to support the Development of DEMO Vacuum Pumps with Mercury as Working Fluid, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

Cyra Neugeabuer, Y. Hörstensmeyer, Christian Day
Technology Development for Isotope Rebalancing and Protium Removal in the EU DEMO, 12th International Conference on Tritium Science and Technology (Tritium 2019), Busan, Südkorea, 22-26 Apr 2019

Y. Hörstensmeyer, Silvano Tosti, Alessia Santucci, G. Bruno
Permeator Simulations for the EU-DEMO Fuel Cycle, 12th International Conference on Tritium Science and Technology (Tritium 2019), Busan, Südkorea, 22-26 Apr 2019

Oriol Nomen, Daniel Sanchez-Herranz, Concepción Oliver, Ivan Podadera, Rodrigo Varela, Francisco Ogando, Volker Hauer, Fernando Arranz, Sofía Coloma, Roland Heidinger and Hervé Dzitko
Preliminary design of the HEBT of IFMIF DONES, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22-27 Sept 2019.

S. Ochoa, T. Giegerich, Chr. Day
Mercury Ring Pump Modelling: Concept, Progress and Challenges, 17th Multiphase Flow Conference 2019, Dresden, 11-15 Nov 2019.

Publications

Energy efficiency, materials and resources (EMR)
(* Wo Sand/or Scopus referenced)

Journal article

* Chen, H.; Kauffmann, A.; Seils, S.; Boll, T.; Liebscher, C.H.; Harding, I.; Kumar, K.S.; Szabó, D.V.; Schlabach, S.; Kauffmann-Weiss, S.; Müller, F.; Gorr, B.; Christ, H.-J.; Heilmaier, M.
Crystallographic ordering in a series of Al-containing refractory high entropy alloys Ta-Nb-Mo-Cr-Ti-Al, Acta materialia, 1359-6454

Publications

Storage and Cross-linked Infrastructures (SCI)
(* Wo Sand/or Scopus referenced)

Proceedings

* Karrari, Shahab; Ludwig, Nicole; Hagenmeyer, Veit; Noe, Mathias
A method for sizing centralised energy storage systems using standard patterns; 2019 IEEE Milan PowerTech, 23-27 June 2019, Milan, Italy; 978-1-5386-4722-6

Geisbuesch, Joern
DERlab (European Distributed Energy Resources Laboratories) activities

Geisbuesch, Joern
Status of Energy Lab 2.0 and projects from the power grid side

Geisbuesch, Joern; Etinge, Ewane
IEEE WG P2004 First Consolidated Draft and Progress of Chapter 4

Geisbuesch, Joern; Etinge, Ewane
IEEE WG P2004 Status of Chapter 4

Geisbuesch, Joern; Karrari, Shahab; Kottonau, Dustin; Batista de Sousa, Wescley Tiago; Kreideweis, Philip; Lange, Christian; Groener, Frank; Noe, Mathias
Real-Time Simulation and System Integration

Weber, Christina; Henriques, Andre; Schirle, Sabrina; Grohmann, Steffen
Measurement of heat flux in multi-layer insulated helium cryostats after loss of insulating vacuum

Book essay

Hänisch, Jens; Iida, Kazumasa
Grain Boundaries in Fe-Based Superconductors
Superconductivity – From Materials Science to Practical Applications. Ed.: P. Mele; 978-3-030-23302-0

Kottonau, Dustin; Shabagin, Eugen; Batista de Sousa, Wescley Tiago; Geisbüsch, Jörn; Noe, Mathias; Stagge, Hanno; Fechner, Simon; Woiton, Hannes; Küsters, Thomas
Bewertung des Einsatzes supraleitender 380-kV-Kabel
1000093864

Journal article

* Cayado, Pablo; Rijckaert, Hannes; Erbe, Manuela; Langer, Marco; Jung, Alexandra; Hänisch, Jens; Holzapfel, Bernhard
CSD-Grown $Y_{1-x}Gd_xBa_2Cu_3O_{7-\delta}$-$BaHfO_3$ Nanocomposite Films on Ni5W and IBAD Technical Substrates; Nanomaterials; 2079-4991

* Rijckaert, Hannes; Cayado, Pablo; Nast, Rainer; Diez Sierra, Javier; Erbe, Manuela; López Dominguez, Pedro; Hänisch, Jens; De Buysser, Klaartje; Holzapfel, Bernhard; Van Driessche, Isabel
Superconducting HfO_2-$YBa_2Cu_3O_{7-\delta}$ Nanocomposite Films Deposited Using Ink-Jet Printing of Colloidal Solutions; Coatings; 2079-6412

* Bagrets, N.; Anvar, V. A.; Chiesa, L.; Delgado, M. A.; McRae, D. M.; Nijhuis, A.; Nishijima, G.; Osamura, K.; Shin, H. S.; Walsh, R. P.; Weiss, K.-P.; Zhang, Y.; Zhao, Y.; Zhao, Z.
International round robin test for tensile testing HTS wires at cryogenic temperatures; Superconductor science and technology; 0953-2048, 1361-6668

Berrospe-Juarez, E.; Zermeño, V. M. R.; Trillaud, F.; Grilli, Francesco
Real-time simulation of large-scale HTS systems: Multiscale and homogeneous models using the T-A formulation; Superconductor science and technology; 0953-2048, 1361-6668 Ja

* De Sousa, Wescley T. B.; Kottonau, Dustin; Noe, Mathias
Transient Simulation and Recovery Time of a Three-Phase Concentric HTS Cable; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515

* De Sousa, Wescley T. B.; Matt, C. F. T.
An unconditionally stable laguerre based finite difference method for transient diffusion and convection-diffusion problems; Numerical mathematics; 1004-8979, 2079-7338

* Dong, Qihuan; de Sousa, Wescley T. B.; Geng, Jianzhao Zhang, Xiuchang; Zhang, Heng; Shen, Boyang; Coombs, Tim
Influences of the Resistive SFCL on the Incremental Power Frequency Relay of Transmission Lines; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515, 2378-7074

* Gao, P.; Dhallé, M.; van Nugteren, B.; Norder, H.; Kario, A.; Otten, S.; Goldacker, W.; van Nugteren, J.; Kirby, G.; de Rijk, G.; Bottura, L.; Rossi, L.; ten Kate, H.H.J.
Inter-strand resistance and AC loss in resin-filler impregnated ReBCO Roebel cables; Superconductor science and technology; 0953-2048, 1361-6668

* Gao, P.; Wessel, W. A. J.; Dhallé, M.; Otten, Simon; Kario, Anna U.; Van Nugteren, J.; Kirby, G.; Bottura, L.; Ten Kate, H. H. J.
Effect of resin impregnation on the transverse pressure dependence of the critical current in ReBCO Roebel cables; Superconductor science and technology; 0953-2048, 1361-6668

* Gomse, D.; Grohmann, S.
Heat transfer and pressure drop in the main heat exchanger of a cryogenic mixed refrigerant cycle; IOP conference series / Materials science and engineering; 1757-899X

* Grohmann, S.; Barthélémy, H.; Down, R.; Ercolani, E.; Fournel, J.-L.; Henriques, A.; Krichler, M.; Otte, W.; Parma, V.; Pengo, R.; Poncet, J.-M.; Reinhardt, M.; Soika, R.; Vallcorba-Carbonell, R.; Weber, C.; Zick, G.; Zoller, C.
Status of a European Standard for the protection of helium cryostats against excessive pressure; IOP conference series / Materials science and engineering; 1757-899X

* Gyuráki, R; Benkel, T; Schreiner, F; Sirois, F; Grilli, F
Fluorescent thermal imaging of a non-insulated pancake coil wound from high temperature superconductor tape; Superconductor science and technology; 0953-2048, 1361-6668

* Hänisch, J.; Iida, K.; Hühne, R.; Tarantini, C.
Fe-based superconducting thin films – preparation and tuning of superconducting properties; Superconductor science and technology; 0953-2048, 1361-6668

* Hellmann, S.; Abplanalp, M.; Elschner, S.; Kudymow, A.; Noe, M.
Current Limitation Experiments on a 1 MVA-Class Superconducting Current Limiting Transformer IEEE transactions on applied superconductivity; 1051-8223, 1558-2515

* Iida, Kazumasa; Sugimoto, Yuwa; Hatano, Takafumi; Urata, Takahiro; Langer, Marco; Holzapfel, Bernhard; Hänisch, Jens; Ikuta, Hiroshi
Novel method to study strain effect of thin films using a piezoelectric-based device and a flexible metallic substrate Applied physics express; 1882-0778, 1882-0786

* Kauffmann-Weiss, Sandra; Iida, Kazumasa; Tarantini, Chiara; Boll, Torben; Schneider, Reinhard; Ohmura, Taito; Matsumoto, Takuya; Hatano, Takafumi; Langer, Marco; Meyer, Sven; Jaroszynski, Jan; Gerthsen, Dagmar; Ikuta, Hiroshi; Holzapfel, Bernhard; Hänisch, Jens
Microscopic origin of highly enhanced current carrying capabilities of thin NdFeAs(O,F) films; Nanoscale Advances; 2516-0230

* Kottonau, Dustin; de Sousa, Wescley T. B.; Bock, Joachim; Noe, Mathias
Design Comparisons of Concentric Three-Phase HTS Cables; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515, 2378-7074

* Kubiczek, Krzysztof; Grilli, Francesco; Kario, Anna; Godfrin, Aurelien; Zermeno, Victor Manuel Rodriguez; Stepien, Mariusz; Kampik, Marian
Length Uniformity of the Angular Dependences of Ic and n of Commercial REBCO Tapes with Artificial Pinning at 77 K; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515, 2378-7074

* Kudymow, Andrej; Bauer, A.; Elschner, Steffen; Goldacker, Wilfried; Kraemer, H.-P.; Noe, Mathias; Strauss, Severin; Schacherer, C.
Smartcoil - Design, assembly and test of a 10 MVA superconducting air coil fault current limiter; Superconductor science and technology; 0953-2048, 1361-6668

Kunniyoor, Keerthi Raj; Richter, Thomas; Ghosh, Parthasarathi; Lietzow, Ralph; Schlachter, Sonja; Neumann, Holger
Performance analysis of a NbTi level sensor while filling LHe into a cryostat; Indian Journal of Cryogenics; 0379-0479, 2349-2120

* Langer, Marco; Meyer, Sven; Ackermann, Kai; Grünewald, Lukas; Kauffmann-Weiss, Sandra; Aswartham, Saicharan; Wurmehl, Sabine; Hänisch, Jens; Holzapfel, Bernhard
On the growth of Co-doped $BaFe_2As_2$ thin films on CaF_2; Journal of physics / Conference Series; 1742-6588, 1742-6596

* Lao, Mayraluna; Pahlke, P.; Sieger, M.; Falter, M.; Bäcker, M.; Hänisch, Jens; Hühne, R.; Eisterer, M.
Manifestation of granularity in the transport current of coated conductors; Superconductor science and technology; 0953-2048, 1361-6668

* Lao, M.; Hänisch, J.; Kauffmann-Weiss, S.; Gehring, R.; Fillinger, H.; Drechsler, A.; Holzapfel, B.
High current variable temperature electrical characterization system for superconducting wires and tapes with continuous sample rotation in a split coil magnet; Review of scientific instruments; 0034-6748, 1089-7623, 1527-2400

* Lao, M.; Willa, R.; Meledin, A.; Rijckaert, H.; Chepikov, V.; Lee, S.; Petrykin, V.; Van Driessche, I.; Molodyk, A.; Holzapfel, B.; Hänisch, J.
In-field performance and flux pinning mechanism of pulsed laser deposition grown $BaSnO_3/GdBa_2Cu_3O_{7-\delta}$ nanocomposite coated conductors by SuperOx; Superconductor science and technology; 0953-2048, 1361-6668

* Otten, S.; Grilli, F.
Simple and fast method for computing induced currents in superconductors using freely available solvers for ordinary differential equations; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515

* Ou, J.; Liu, Y.; Liang, D.; Doppelbauer, M.
Investigation of PM eddy current losses in surface-mounted PM motors caused by PWM; IEEE transactions on power electronics; 0885-8993, 1941-0107

* Pardo, E.; Grilli, Francesco; Liu, Yingzhen; Wolftadler, S.; Reis, T.
AC Loss Modeling in Superconducting Coils and Motors with Parallel Tapes as Conductor; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515

* Popov, Ruslan; Erbe, Manuela; Hänisch, Jens; Holzapfel, Bernhard
Superconducting $BaHfO_3$-$GdBa_2Cu_3O_7$ Nanocomposite Thin Films: Influence of Growth Temperature and Deposition Rate on Transport Properties; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515

* Preuss, Alan; Wolf, Michael Johannes; Heiduk, Mathias; Lange, Christian; Fietz, Walter H.
Production and Characterization of Strands for a 35 kA HTS DC Cable Demonstrator; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515, 2378-7074

* Riva, N.; Richard, S.; Sirois, F.; Lacroix, C.; Dutoit, B.; Grilli, Francesco
Overcritical Current Resistivity of YBCO-Coated Conductors Through Combination of PCM and Finite-Element Analysis; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515

* Shabagin, Eugen; Grohmann, Steffen
Development of 10 kA Current Leads Cooled by a Cryogenic Mixed-Refrigerant Cycle; IOP conference series / Materials science and engineering; 1757-899X

* Simmendinger, J.; Hänisch, J.; Bihler, M.; Ionescu, A. M.; Weigand, M.; Sieger, M.; Hühne, R.; Rijckaert, H.; van Driessche, I.; Schütz, G.; Albrecht, J.
Magnetically induced anisotropy of flux penetration into strong-pinning superconductor/ferromagnet bilayers; New journal of physics; 1367-2630

* Tamson, J.; Stamm, M.; Grohmann, S.
Set-up of the cryogenic phase equilibria test stand CryoPHAEQTS; IOP conference series / Materials science and engineering; 1757-899X

* Tixador, Pascal; Bauer, Markus; Bruzek, Christian-Eric; Calleja, Albert; Deutscher, Guy; Dutoit, Bertrand; Gomory, Fedor; Martini, Luciano; Noe, Mathias; Obradors, Xavier; Pekarcikova, Marcela; Sirois, Frederic
Status of the European Union Project FASTGRID; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515, 2378-7074

* Weber, C.; Henriques, A.; Grohmann, S.
Study on the heat transfer of helium cryostats following loss of insulating vacuum; IOP conference series / Materials science and engineering; 1757-899X

Proceedings

Meyer, Sven; Langer, Marco; Grünewald, Lukas; Hänisch, Jens; Gerthsen, Dagmar; Holzapfel, Bernhard
Pulsed Laser Deposition of quasi-multilayer superconducting $Ba(Fe_{0.92}Co_{0.08})_2As_2$-$BaHfO_3$ nanocomposite films; 14th European Conference on Applied Superconductivity (EUCAS 2019)

Lecture

Arndt, Tabea
Cooling Methods for HTS Applications – Challenges and Approaches

Arndt, Tabea
HTS for Accelerators – Connections to Industry and Applications

Arndt, Tabea
HTS Systems and Value Propositions

Benkel, Tara; Lao, Mayraluna; Liu, Yingzhen; Pardo, Enric; Wolfstädter, Simon; Reis, Thomas; Grilli, Francesco
AC loss calculation in electrical machines with HTS coils using T-A formulation

Boll, Martin; Corduan, Matthias; Biser, Stefan; Weber, Phillip; Kuehn, Lars; Filipenko, Mykhaylo; Schlachter, Sonja; Holzapfel, Bernhard; Berg, Frederick Timothy Neil; Rostek, Peter
Holistic system approach for electric aircraft using superconducting components

Cayado, Pablo; Hauck, Daniel; Erbe, Manuela; Hänisch, Jens; Holzapfel, Bernhard
Optimization of the oxygenation process in CSD-grown $REBa_2Cu_3O_{7-x}$ films

Erbe, Manuela; Cayado, Pablo; Freitag, Wolfram; Meledin, Alexander; Falter, Martina; Hänisch, Jens; Holzapfel, Bernhard; Bäcker, Michael
Pinning enhancement in CSD-grown REBCO nanocomposites towards high-field applications

Erbe, Manuela; Cayado, Pablo; Freitag, Wolfram; Meledin, Alexander; Hänisch, Jens; Holzapfel, Bernhard
Advanced CSD-grown REBCO nano-composites for high-field applications

Goldacker, Wilfried; Fluekiger, René
Role of strains in superconducting Nb_3Sn

Goldacker, Wilfried; Noe, Mathias
Overwiew on HTS projects and applications worldwide

Goldacker, W.; Kario, A.; Otten, S.
HTS Roebel cables, status and potential

Grilli, Francesco; Benkel, Tara; Hänisch, Jens; Lao, Mayraluna; Reis, Thomas; Berberich, Eva; Wolfstädter, Simon Schneider, Christian; Miller, Pail; Palmer, Chloe; Glowacki, Bartek; Climente-Alarcon, Vicente; Smara, Anis; Tomkow, Lukasz; Teigelkötter, Johannes; Stock, Alexander; Büdel, Johannes; Jeunesse, Loïc; Staempflin, Martin; Delautre, Guillaume; Zimmermann, Baptiste; Woude, Ruud van der; Perez, Ana; Samoilenkov, Sergey; Molodyk, Alexander; Pardo, Enric; Kapolka, Milan; Li, Huo; Dadhich, Anang
Superconducting motors for aircraft propulsion: the Advanced Superconducting Motor Experimental Demonstrator project

Grilli, F.; Zermeño, V.; Brambilla, R.; Benkel, T.; Morandi, A.; Pardo, E.
Magnetic vector potential-based formulations for modeling superconducting applications: a valid alternative to the H-formulation

Grohmann, Steffen
A new European Standard for the protection of helium cryostats against excessive pressure

Grohmann, Steffen
A new European Standard for the protection of helium cryostats against excessive pressure

Grohmann, Steffen
Development potential of mid-scale cooling systems for HTS applications

Grohmann, Steffen
Standardization and material databases: a successful example

Gyuráki, Roland; Schreiner, Fabian; Benkel, Tara; Sirois, Frédéric; Grilli, Francesco
Electrical and thermal behaviours of insulated and non insulated HTS wound pancake coils at 77 K

Hänisch, Jens
Jc in Fe-based superconducting films – dimensionality, anisotropy, microstructure

Lida, K.; Tarantini, C.; Matsumoto, T.; Kondo, K.; Hatano, T.; Meyer, S.; Hänisch, J.; Jaroszynski, J.; Wang, C.; Saito, H.; Hata, S.; Ikuta, H.
Electrical transport properties of NdFeAs(O,F) thin films on vicinal substrates

Neumann, H.
Kryotechnik – Einführung

Neumann, H.
Sicherheitstechnik - Gefahren im Umgang mit Kryogenen

Neumann, H.
Thermische Isolation

Neumann, H.
Thermodynamische Grundlagen

Neumann, H.
Tieftemperaturmess- und Regeltechnik

Neumann, H.
Wärmeübertragung an Kryogene – Kühltechniken

Neumann, Holger
MSR – kryogene Temperaturmessung

Neumann, Holger
MSR – Kryoventile

Vortrag Neumann, Holger
MSR – Prozessmesstechnik

Neumann, Holger
MSR – Sicherheitstechnik

Neumann, Holger
Vakuumtechnik und Gefahren im Umgang mit Kryogenen

Schlachter, Sonja I.; Brand, Jörg; Elschner, Steffen; Fink, Stefan; Holzapfel, Bernhard; Lietzow, Ralph; Kudymow, Andrej; Neumann, Holger; Müller, Ralf; Strauß, Severin
HTS Cable for Power Distribution in Hybrid-Electric Propulsion System for Aircraft

Shabagin, Eugen; Grohmann, Steffen
Einsatz eines kompakten, mikrostrukturierten Wärmeübertragers im kryogenen Gemischkältekreislauf

Shabagin, Eugen; Grohmann, Steffen
Influence of mixture composition on the performance of cryogenic mixed refrigerant cooled current leads

Shabagin, Eugen; Raczka, Kevin; Grohmann, Steffen
Investigation of cryogenic mixed-refrigerant cooled current leads in combination with Peltier elements

Tamson, Jens; Grohmann, Steffen; Blanck, P.
Inbetriebnahme des Cryogenic Phase Equilibria Test Stand CryoPHAEQTS

Tamson, Jens; Stamm, Michael; Grohmann, Steffen
Aufbau des Cryogenic Phase Equilibria Test Stand CryoPHAEQTS

Weber, Christina
Status of a european standard for the protection of helium cryostats against excessive pressure

Journal article

* Antunes, Rodrigo; Frances, Laëtitia; Incelli, Marco; Santucci, Alessia
Numerical study and experimental verification of protium permeation through Pd/Ag membranes for fusion applications; Fusion engineering and design; 0920-3796

* Blanken, T. C.; et.al.
Real-time plasma state monitoring and supervisory control on TCV; Nuclear fusion; 0029-5515, 1741-4326

* Coad, J. P.; Rubel, M.; Likonen, J.; Bekris, N.; Brezinsek, S.; Matthews, G. F.; Mayer, M.; Widdowson, A. M.
Material migration and fuel retention studies during the JET carbon divertor campaigns; Fusion engineering and design; 0920-3796, 1873-7196

* Coleman, M.; Hörstensmeyer, Y.; Cismondi, F.
DEMO tritium fuel cycle: performance, parameter explorations, and design space constraints; Fusion engineering and design; 0920-3796, 1873-7196

* Day, Christian; Butler, B.; Giegerich, Thomas; Ploeckl, B.; Varoutis, Stylianos
A smart three-loop fuel cycle architecture for DEMO; Fusion engineering and design; 0920-3796, 1873-7196

* Drenik, A.; et.al.
Analysis of the outer divertor hot spot activity in the protection video camera recordings at JET; Fusion engineering and design; 0920-3796, 1873-7196

* Frattolillo, A.; Baylor, L.R.; Bombarda, F.; Cismondi, F.; Colangeli, A.; Combs, S.K.; Day, Chr.; D'Elia, G.; Gebhart, T.E.; Iannone, F.; Lang, P.T.; Meitner, S.J.; Migliori, S.; Moro, F.; Mozzillo, R.; Pégourié, B.; Ploeckl, B.; Podda, S.; Poggi, F.
Addressing the feasibility of inboard direct-line injection of high-speed pellets, for core fueling of DEMO; Fusion engineering and design; 0920-3796

* Giegerich, T.; Battes, K.; Schwenzer, J. C.; Day, C. Development of a viable route for lithium-6 supply of DEMO and future fusion power plants; Fusion engineering and design; 0920-3796, 1873-7196

* Gliss, Curt; Ambrosino, Roberto; Bachmann, Christian; Ciattaglia, Sergio; Flammini, Davide; Giegerich, Thomas Jimenez, Samuel; Wilde, Andrew
Initial integration concept of the DEMO lower horizontal port Fusion engineering and design; 0920-3796

* Hatano, Y.; et.al.
Tritium distributions on W-coated divertor tiles used in the third JET ITER-like wall campaign; Nuclear materials and energy; 2352-1791

* Heller, Reinhard; Blanchier, Paul; Fietz, Walter H.; Wolf, Michael J.
Quench Analysis of the HTS CrossConductor for a Toroidal Field Coil; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515, 2378-7074

* Heller, R.; Bau, H.; Nagel, M.; Rummel, T.
Operation Experience of the Wendelstein 7-X High-Temperature Superconductor Current Leads; IEEE transactions on applied superconductivity; 1051-8223, 1558-2515

* Ho, A.; Citrin, J.; Auriemma, F.; Bourdelle, C.; Casson, F.J.; Kim, Hyun-Tae; Manas, P.; Szepesi, G.; Weisen, H.
Application of Gaussian process regression to plasma turbulent transport model validation via integrated modelling; Nuclear fusion; 0029-5515, 1741-4326

* Kiptily, V.G.; Belli, F.; Eriksson, J.; Hellesen, C.; Goloborodko, V.; Schoepf, K.
On a fusion born triton effect in JET deuterium discharges with H-minority ion cyclotron range of frequencies heating Nuclear fusion; 0029-5515, 1741-4326

* Kirov, K.K.; Baranov, Yu.; Carvalho, I.S.; Challis, C.D.; Eriksson, J.; Frigione, D.; Garzotti, L.; Graves, J.; Jacquet, P.; Keeling, D.L.; Lerche, E.; Lomas, P.J.; Lowry, C.; Mantsinen, M.; Rimini, F.
Fast ion synergistic effects in JET high performance pulses; Nuclear fusion; 0029-5515, 1741-4326

* Labit, B.; et.al.
Dependence on plasma shape and plasma fueling for small edge-localized mode regimes in TCV and ASDEX Upgrade; Nuclear fusion; 0029-5515, 1741-4326

* Lawson, K. D.; et.al.
Population modelling of the He II energy levels in tokamak plasmas: I. Collisional excitation model; Journal of physics / B; 0022-3700, 0368-3508, 0953-4075, 1361-6455, 1747-3713, 1747-3721

* Meyer, H.; et.al.
Overview of physics studies on ASDEX Upgrade; Nuclear fusion; 0029-5515, 1741-4326

* Neverov, V. S.; et.al.
Determination of isotope ratio in the divertor of JET-ILW by high-resolution H alpha spectroscopy: H-D experiment and implications for D-T experiment; Nuclear fusion; 0029-5515, 1741-4326

* Orsitto, F P; Segre, S E
Approximate analytic expressions using Stokes model for tokamak polarimetry and their range of validity; Plasma physics and controlled fusion; 0741-3335, 1361-6587

* Perez von Thun, C.; Frassinetti, L.; Horvath, L.; Saarelma, S.; Meneses, L.; de la Luna, E.; Beurskens, M.; Boom, J.; Flanagan, J.; Hillesheim, J.C.; Maggi, C.F.; Pamela, S.J.P.; Solano, E.R.
Long-lived coupled peeling ballooning modes preceding ELMs on JET; Nuclear fusion; 0029-5515, 1741-4326

* Plouin, J.; Baudouy, B.; Four, A.; Charrier, J. P.; Maurice, L.; Novo, J.; Peters, B. J.; Liao, K.
Experimental study of second sound quench detection for superconducting cavities; Physical review accelerators and beams; 2469-9888

* Reinking, Johannes; Schlösser, Magnus; Hase, Frank; Orphal, Johannes
First high-resolution spectrum and line-by-line analysis of the 2ν$_{2}$$ band of HTO around 3.8 microns; Journal of quantitative spectroscopy & radiative transfer; 0022-4073, 1879-1352

* Röllig, Marco; Aso, T.; Hara, M.; Priester, F.
Galet – Benchmark of a Geant4 based application for the simulation and design of Beta Induced X-ray Spectrometry systems; Fusion engineering and design; 0920-3796, 1873-7196

* Santucci, Alessia; Antunes, Rodrigo; Bruni, Giacomo; Mallozzi, Federica; Incelli, Marco; Sansovini, Mirko
Recent achievements of the Pd-Ag membrane technologies in tritium extraction system applications [in press]; Fusion engineering and design; 0920-3796

* Sias, G.; et.al.
A locked mode indicator for disruption prediction on JET and ASDEX upgrade; Fusion engineering and design; 0920-3796, 1873-7196

* Sirunyan, A. M.; et.al.
Measurement of exclusive $\rho(770)^{0}$ photoproduction in ultraperipheral pPb collisions at √sNN=5.02Te; The European physical journal / C; 1434-6044, 1434-6052

* Ström, P.; et.al.
Analysis of deposited layers with deuterium and impurity elements on samples from the divertor of JET with ITER-like wall; Journal of nuclear materials; 0022-3115

* Tierens, W.; et.al.
Validation of the ICRF antenna coupling code RAPLICASOL against TOPICA and experiments; Nuclear fusion; 0029-5515, 1741-4326

* Trier, E.; et.al.
ELM-induced cold pulse propagation in ASDEX Upgrade; Plasma physics and controlled fusion; 0032-1028, 0368-3281, 0741-3335, 1361-6587, 1879-2979, 2057-7648

* Varoutis, S.; Igitkhanov, Yu.; Day, Chr.
Assessment of the 3D geometrical effects on the DEMO divertor pumping efficiency; Nuclear materials and energy; 2352-1791

* Vasilopoulou, T.; et.al.
Improved neutron activation dosimetry for fusion; Fusion engineering and design; 0920-3796, 1873-7196

* Wolf, Michael J.; Heller, Reinhard; Fietz, Walter H.; Weiss, Klaus-Peter
Design and analysis of HTS subsize-conductors for quench investigations towards future HTS fusion magnets [in press]; Cryogenics; 0011-2275

* Zappatore, A.; Fietz, W. H.; Heller, R.; Savoldi, L.; Wolf, M. J.; Zanino, R.
A critical assessment of thermal-hydraulic modeling of HTS twisted-stacked-tape cable conductors for fusion applications; Superconductor science and technology; 0953-2048, 1361-6668

Proceedings

* Fink, Stefan; Zwecker, Volker
15 Min Dc breakdown tests with liquid nitrogen; 2019 IEEE 20th International Conference on Dielectric Liquids (ICDL), Roma, Italy, June 23-27, 2019; 978-1-72811-718-8; 2153-3725

* Vollmer, Michael; Englhardt, Adrian; Trittenbach, Holger; Bielski, Pawel; Karrari, Shahab; Böhm, Klemens
Energy Time-Series Features for Emerging Applications on the Basis of Human-Readable Machine Descriptions; Tenth ACM International Conference on Future Energy Systems (ACM e-Energy) and its co-located workshops, Phoenix, AZ, United States, 25th - 28th of June 2019; 978-1-4503-6671-7

Publications

Invited Papers

Tabea Arndt

- T. Arndt, "Cooling Methods for HTS Applications – Challenges and Approaches", 3. International Workshop on Cooling Systems for High-Temperature Superconductor Applications (2019), GE Global Research, Niskayuna, NY, USA, 15.10.2019–17.10.2019
- T. Arndt, "HTS for Accelerators – Connections to Industry and Applications", 105. Plenary ECFA Meeting (2019), CERN, Genf, Schweiz, 14.11.2019–15.11.2019
- T. Arndt, "HTS Systems and Value Propositions", 32. International Symposium on Superconductivity (ISS 2019)
- Kyoto, Japan, 03.12.2019–05.12.2019

Christian Day

- Day, Christian, The metal foil pump – How cold plasma helps to meet hot plasma, 7th International Conference on Advanced Plasma Technologies (ICAPT-7), Hue, Vietnam, 24 Feb – 1 Mar 2019.
- Katharina Battes, Christian Day, Volker Hauer, Systematic study of the outgassing behavior of different ceramic materials, Int. Vacuum Congress (IVC), Malmö, Schweden, 1–5 Jul 2019
- Christian Day, Vacuum Technology in Nuclear Fusion Int. Vacuum Congress (IVC), Malmö, Schweden, 1–5 Jul 2019.
- Giegerich, Thomas; Butler, Barry; Day, Christian; Hanke, Stefan; Härtl, Thomas; Hörstensmeyer, Yannick; Neugebauer, Cyra; Ploeckl, Bernhard, Innovative fuel cycle concepts for the EU-DEMO, 28th IEEE/NPSS Symposium on Fusion Engineering (SOFE), Jacksonville, FL, USA, 2–6 June 2019.
- Thomas Giegerich, Katharina Battes, Christian Day, Jonas Schwenzer, Tim Teichmann, The HgLab Karlsruhe – A key facility for mercury related work in the development of the EU-DEMO fuel cycle, 6th Int. Symposium on liquid metal applications in fusion (ISLA), Urbana, IL, USA, 30 Sep–3 Oct 2019.
- Giegerich, T.; Day, C.; Gliss, C.; Hanke, S.; Härtl, T.; Hörstenmeyer, Y.; Ionescu-Bujor, M.; Müller, R.; Peters, B.; Scannapiego, M.; Strobel, H., Design status of the torus vacuum pumping system for tritium processing in the EU-DEMO, 12th International Conference on Tritium Science and Technology (Tritium 2019), Busan, Südkorea, 22–26 April 2019
- Y. Hörstensmeyer, Optimization of the DEMO Fuel Cycle using Dynamic Modelling, 14th Int. Symp. On Fusion Nuclear Technology (ISFNT), Budapest, Ungarn, 22–27 Sept 2019.

Mathias Noe

- M. Noe, „Superconducting Materials and Applications R&D at Institute for Technical Physics at KIT" PSI Colloquium, Paul Scherrer Institute, Villigen, Switzerland 28 January, 2019
- E. Marzahn, M. Noe, „Hochtemperatur-Supraleiter Kabel und Strombegrenzer", 91. Kabelseminar, 19–20 February 2019, Leibniz Universität Hannover
- M. Noe, „Review of Power Applications for HTS", 5th Workshop on Accelerator Magnets in HTS, Budapest 8–12 April, 2019
- M. Noe, M. Wolf, W. Fietz „Entwicklung von HTS Leiterkonzepten für Hochstromanwendungen", 10. Braunschweiger Supraleiterseminar, 25–26 June, 2019
- M. Noe, "High-field conductor for future high-field applications", 26th Magnet Technology Conference, Vancouver, Canada, September 22–27, 2019.

Sonja Schlachter

- Sonja I. Schlachter, Jörg Brand, Steffen Elschner, Stefan Fink, Bernhard Holzapfel, Ralph Lietzow, Andrej Kudymow, Holger Neumann, Ralf Müller, Severin Strauß, HTS Cable for Power Distribution in Hybrid-Electric Propulsion System for Aircraft, CEC-ICMC 2019, Hartford, July 21–25, 2019
- M. Erbe, P. Cayado, W. Freitag, J. Hänisch, B. Holzapfel, Advanced CSD-grown REBCO nanocomposites for high-field applications, CEC-ICMC 2019, Hartford, July 21–25, 2019
- Jens Hänisch et al., Jc in Fe-based superconducting films – dimensionality, anisotropy, microstructure, EUCAS 2019, Glasgow, 1.–5.9.2019
- M. Lao, J. Hänisch, D. Fuchs, B. Holzapfel, Examining vortex creep via electrical transport measurements of coated conductors, EUCAS 2019, Glasgow, 1.–5.9.2019
- F. Grilli et al., Superconducting motors for aircraft propulsion: the Advanced Superconducting Motor Experimental Demonstrator project, ISS 2019, Kyoto, Japan, Dec 3-5
- Boll, Martin; Corduan, Matthias; Biser, Stefan; Weber, Phillip; Kuehn, Lars; Filipenko, Mykhaylo; Schlachter, Sonja; Holzapfel, Bernhard; Berg, Frederick Timothy Neil; Rostek, Peter, Holistic system approach for electric aircraft using superconducting components, 14th European Conference on Applied Superconductivity (EUCAS 2019), Glasgow, Vereinigtes Königreich, 01.09.2019–05.09.2019

Michael Wolf

- M. J. Wolf: "High Temperature Superconductor Cable in Conduit Conductors for Future Fusion Magnets", 28th International Toki Conference (ITC-28) Toki, Japan, Nov. 2019
- M. J. Wolf: "HTS CroCo – a Strand for High Direct Current Applications", International Symposium on Superconductivity, Kyoto, Japan, Dec. 2019

Publications

Patents Held

(* Neue Schutzrechtsanmeldungen in 2019
** Schutzrechtserteilungen mit Wirkung für Deutschland in 2019

Strombegrenzer mit elektrischen Ventilen zum Begrenzen des Kurzschlußstromes in einem elektrischen Leistungsstromkreises
Jüngst, Klaus-Peter; Kuperman, Grigory
DE 1149452
US 6654222

Kryostat mit einem Magnetspulensystem, das eine LTS- und eine gekapselte HTS-Sektion umfasst
Kläser, Marion
DE 102006012508
US 8255023

Kryostat mit einem Magnetspulensystem, das eine unterkühlte LTS- u. eine in einem separaten Heliumtank angeordnete HTS-Sektion umfasst
Schneider, Theo
CH 1999764
DE 102006012511
FR 1999764
GB 1999764
US 8255022

Anlage zur supraleitenden magnetischen Energiespeicherung, elektrolytischen Wasserzerlegung und wassersynthetisierenden Strombegrenzer
Gehring, Rainer; Sander, Michael (verstorben)
DE 102007042711

Vorrichtung zur Strombegrenzung mit einer veränderbaren Spulenimpedanz
Noe, Mathias; Schacherer, Christian
DE 2532016
FR 2532016
GB 2532016
JP 5907894
US 9583258

Vorrichtung zur Speicherung von Wasserstoff und von magnetischer Energie sowie ein Verfahren zu ihrem Betrieb
Neumann, Holger; Sander, Michael (verstorben)
DE 2684198
FR 2684198
GB 2684198

Isolierter Hochtemperatur-Bandsupraleiter und Verfahren zu seiner Herstellung
Brand, Jörg; Elschner, Steffen; Fink, Stefan; Goldacker, Wilfried; Kudymow, Andrej
AT 2729969
CH 2729969
DE 2729969
FR 2729969
GB 2729969
IT 2729969
KR 10192955
US 939840

Vorrichtung und Verfahren zur Bestimmung des Massenstroms eines Fluids
Grohmann, Steffen
CA 2857065
CH 2791629
DE 2791629
FR 2791629
GB 2791629
IT 2791629
JP 6042449
KR 10-2014-7017781
US 9964423
AU 2016200479

Verfahren und Vorrichtung zur kontinuierlichen Wiederaufbereitung von Abgas eines Fusionsreaktors
Day, Christian; Giegerich, Thomas
CN 105706175
DE 3061098
FR 3061098
GB 3061098
KR 1020167007345

Design of Superconducting Devices By Optimization Of The Superconductor's Local Criticial Current
Holzapfel, Bernhard; Rodriguez Zermeno, Victor
EP 14002754.1
US 10153071

Advanced method for the treatment and the tritium recovery from tritiated water
Cristescu, Ion
EP 15154339.4

Schienengebundene Magnetschwebebahn
Holzapfel, Bernhard; Noe, Mathias
CN 201680010135.3
DE 102015001746.2
EP 16705424.6-1754
US 15/549,188

Transformator, Wickelkörper dafür und Verfahren zur Herstellung eines Wickelkörpers
Hellmann, Sebastian
DE 102015114208.2
EP 16758091.9-1212
US 15/754,298

Supraleitfähiger Leiter und Verwendung des supraleitfähigen Leiters
Fietz, Walter; Heller, Reinhard; Weiss, Klaus-Peter; Wolf, Michael J.
CN 201680059630.3
DE 102015010636.8
EP 16757151.2
US 15/752.235

Verbinder für supraleitfähige Leiter und Verwendung des Verbinders
Fietz, Walter; Heller, Reinhard; Weiss, Klaus-Peter; Wolf, Michael J.
CN 201680059651.5
DE 102015010634.1
EP 16756585.2
US 15/752.221

Verfahren und Vorrichtung zur Herstellung eines supraleitfähigen Leiters
Fietz, Walter; Heller, Reinhard; Weiss, Klaus-Peter; Wolf, Michael J.
CN PCT/EP2016/001369
DE 102015010676.7
EP 16756943.3-1212
US 15/752.224

Design of contacts for superconducting busbars and cables
Rodriguez Zermeno, Victor
EP 17000099.6

Heat exchanger element and method for manufacturing same
Gomse, David; Grohmann, Steffen
EP 17401041.3 *
WO PCT/EP2018/000057*

Verfahren und Vorrichtung zur Anreicherung oder Abreicherung mindestens eines Wasserstoffisotops in einem Gasstrom
Day, Christian; Giegerich, Thomas; Hörstensmeyer, Yannik; Müller, Ralf; Peters, Benedikt
DE 102017213886.6
EP 18185454.8*

Stromschienensystemelement mit einem Supraleiterstrand und einem Verbindungsstück sowie Stromschiene mit einer Vielzahl von solchen Elementen
Kudymow, Andrej; Rodriguez Zermeno, Victor; Strauß, Severin
DE 202017102659

Stromschienensystemelement mit einem Supraleiterstrand und einem Verbindungsstück sowie Stromschiene mit einer Vielzahl von solchen Elementen
Kudymow, Andrej; Rodriguez Zermeno, Victor; Strauß, Severin
EP 18720292.4

Automatic liquid cool-down of mixed-refrigerant cycles (ALC-MRC)
Gomse, Dvis, Grohmann, Steffen; Shabagin, Eugen
DE

Microstructured current leads for application of superconductivity (Micro-CL)
Gietzelt, Thomas; Grohmann, Steffen; Lambach, Heinz; Rabsch, Georg; Schorle, Cornelia; Shabagin, Eugen; Stamm, Michael
DE

Contact

Karlsruher Institute of Technology (KIT)
Institute for Technical Physics
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen

Phone: +49 721/608-direct access
E-Mail: First Name.Family Name@kit.edu

www.itep.kit.edu

Head
Prof. Dr.-Ing. Mathias Noe (-23500)
Prof. Dr. Bernhard Holzapfel (-26000)
Prof. Dr. Tabea Arndt (-23515)

Deputy Head
Dr. Walter Fietz (-24197)

Secretariat
Dagmar Klimmek (-23501)

Cryo-Engineering
Dr. Holger Neumann (-22625)

Superconducting material development and energy applications
Prof. Dr.-Ing. Mathias Noe (-23500)
Prof. Dr. Bernhard Holzapfel (-26000)

Administration
Kai Bauer (-23705)

Fusion Magnets
Dr. Walter Fietz (-24197)
Dr. Klaus-Peter Weiss (-23919)

Vacuum Technology
Dr. Christian Day (-22609)

Contact

Karlsruhe Institute of Technology (KIT)
Campus Nord
Institute for Technical Physics

Hermann-von-Helmholtz-Platz 1
D-76344 Eggenstein-Leopoldshafen, Germany

www.itep.kit.edu

Published by

Karlsruhe Institute of Technology (KIT)
Hermann-von-Helmholtz-Platz 1
D-76344 Eggenstein-Leopoldshafen, Germany

State as of July 2020

www.kit.edu