ITEP – Institute for Technical Physics

Results of Research and Development
2023 Annual Report

IMPRINT

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COVER PHOTO:
Direct access 'Preparation of an HTSL strip
conductor coating on highly textured
IBAD metal strip substrates as part of
the KIT-CERN collaboration KC[4]'

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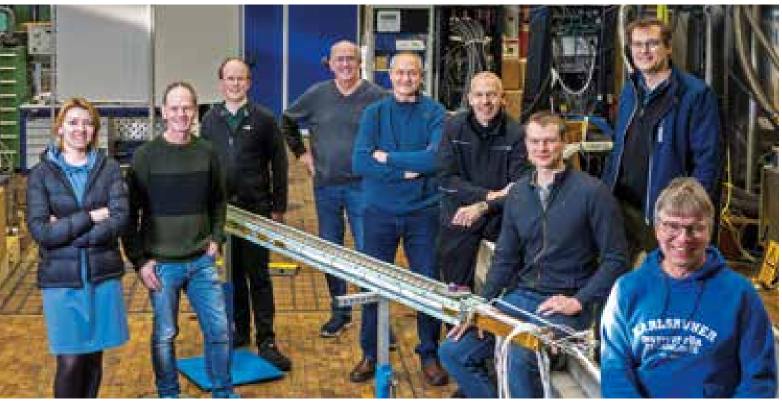

Foreword

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

- **Superconducting and cryogenic materials**
- **Energy applications of superconductivity**
- **Superconducting magnet technology and**
- **Technologies of the fusion fuel cycle**

The work of the ITEP is anchored in the long term in the programmes "Fusion", "Materials and Technologies for the Energy Transition", "Energy System Design" 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 work on the complex and mostly multidisciplinary tasks, which are constantly adapted to the changing requirements and questions.

These include, for example,

- a laboratory for the development of superconducting components for energy technology,
- a technical centre for the development of superconducting materials,
- the magnet laboratory for the development of specific superconducting windings and magnets,
- the cryogenic high-voltage laboratory for investigating the high-voltage strength of cryogenic insulating materials and the
- cryogenic material laboratories for investigating electrical and mechanical properties at very low temperatures.

2023, W1 TT Prof. Dr. Giovanni de Carne was appointed to a W3 professorship for real-time systems in energy technology at KIT. This will ensure the long-term integration of our work in this field and recognize the scientific quality of Prof. de Carne. We congratulate Prof. Dr. Giovanni de Carne on this appointment and look forward to continuing our collegial collaboration.

2023, our institute also achieved very pleasing scientific results, a large number of successful development projects and some special challenges and events, which we will briefly discuss below.

The investigation of new superconductors is an important research focus in the **research field of superconductor and cryogenic materials.** In 2023, a comprehensive study on the chemical composition of $BaHfO_3$ nanoparticles in various mixed $REBa_2Cu_3O_7$ phases was completed. Here it was shown that mixing the rare earth (RE) provides an additional increase in pinning force as well as an improvement in irradiation resistance. As part of a long-term cooperation with CERN, the pilot production of high-temperature superconductor tapes based on Bruker technology was set up at KIT and successfully put into operation for the first time in 2023. The further aim is to improve the material parameters and produce special Coated Conductor architectures. The joint project AdHyBau (additive hybrid construction methods) was successfully completed in 2023. At ITEP, the material parameters of 4K-400K were essentially determined and, in combination with microstructure investigations, the manufacturing parameters were understood (grain size, defects, prorosity). The data is available in a database that can be read directly into design software.

In the **research field of energy technology applications,** a bridge rectifier was realized for the first time using the dynamic resistance of superconductors. The next step is to further increase the voltage of the circuit and to develop superconducting converters for high-current applications in the future. Work at the ITEP on two joint projects to develop a superconducting industrial busbar with a current of 200,000 amperes and a superconducting magnetic heater was successfully continued in 2023 so that the final commissioning can be carried out by the industrial partners. In the simulation of high-temperature superconductors, the current path of the frequently used helical arrangement was better understood. This serves to calculate the alternating current losses more accurately. A Horizon Europe project "Research Facility 2.0" worth € 5 million was successfully applied for in the research topic "Real-time system integration", which will start in 2024. In collaboration with five of the largest accelerators in Europe (ALBA, CERN, DESY, HZB, MAX IV), energy efficiency topics from the component to the system level will be investigated for both physics and energy technology and concrete solutions proposed that will be experimentally validated in demonstration facilities at the accelerator facilities.

An important task in the **research field of superconducting magnet technology** is the development of high-temperature superconducting magnets. The institute operates a laboratory for the robotic winding of non-planar high-temperature superconducting magnets. A new and improved winding hand was realized for this robotic winding in 2023, with which further windings will be produced in the coming year. An initial conceptual design was created for a hybrid energy pipeline for electricity and liquid hydrogen, which will form the basis for further technical and economic evaluation. A rotating machine was designed for the "disk-up-down assembly" (DUDA) of high-temperature superconductors patented at KIT and further improved tape stacks were produced. Furthermore, it was shown how the alternating current losses in this arrangement can be significantly reduced.

Prof. Dr. Tabea Arndt was awarded the IEEE prize for continuous and significant contributions to applied superconductivity. This is in recognition of her many years of outstanding technical and scientific achievements.

In the **research field of fusion fuel cycle technologies,** we are developing fundamentally new vacuum technologies and processes for tritium extraction and recovery. The simulator developed at ITEP for the fuel cycle of a fusion power plant was used to simulate plasma start-up ramps and show, among other things, that helium peaks at the inlet lead to tritium peaks at the outlet. In October, the cryopumps developed at ITEP and manufactured by an industrial partner for the Japanese fusion experiment JT60-SA were delivered. The vacuum systems for the divertor test tokamak in Italy were modeled and some design changes were made based on the results. Furthermore, the best configuration was found for the metal foil pumps for DEMO. The "Direct Internal Recycling" method developed at the Institute for the DEMO fuel cycle is now also being set up on a large scale. To this end, the plans for the "Direct Internal Recycling Development Platform Karlsruhe" (DIPAK) have been revised and initial construction planning has begun. This plant replicates two of the three cycles of the fuel cycle and includes all new technologies such as pellet injection, metal foil pumps, mercury pumps and temperature swing absorption for isotope separation.

In 2023, 30 doctoral theses, 18 master's theses and 10 bachelor's theses were supervised by the ITEP.

The results mentioned and summarized in the report would not have been possible without the dedication and commitment of our employees and without the diverse and fruitful collaborations with our cooperation partners from universities, research institutions and industry. Our very special thanks for this. We look forward to continuing our collaboration in 2024 and wish you all the best.

Sincerely, Your Directors of the Institute

Mathias Noe

Bernhard Holzapfel

Tabea Arndt

Results from the Research Areas

The ITEP-KC⁴ team in the newly commissioned newly laboratory area for the synthesis of HTS ribbon conductor structures of medium length

Superconducting- and Cryo-materials

Coordination: Prof. Dr. Bernhard Holzapfel

The understanding of superconducting materials and the characterization of material properties at cryogenic cryogenic temperatures as well as the realization of conductor structures form the basis of any superconducting power or magnetic applications. In the research field of superconducting and cryogenic materials ITEP is currently working on the following research topics:

- Superconducting Materials
- Conductor Concepts and Technologies
- Materials for Cryogenic Applications

SUPERCONDUCTING MATERIALS

HIGH TEMPERATURE SUPERCONDUCTORS

In the field of high-temperature superconductors, we have continued our investigations into the precise determination of oxygen in thin films using X-ray diffraction (XRD) and TOF-SIMS, published studies on the mixture of rare earth RE in $REBa_2Cu_3O_7$-$BaHfO_3$ nanocomposites and deposited films on various tape samples using pulsed laser deposition and chemical solution deposition, and optimized their oxygen loading.

The combination of several rare earth elements (*RE*s) on the *RE* lattice site in *RE*BCO layers can have a positive effect on their superconducting properties. The main difficulty in producing such layers is optimizing the production parameters, as these differ for each rare earth element. In addition, nanoparticles are often incorporated as pinning centers, for example $BaHfO_3$ (BHO), to increase the current carrying capacity. Ideally, these nanoparticles should not react chemically with the surrounding *RE*BCO layer. In reality, however, diffusion processes take place between BHO and *RE*BCO, which was investigated in detail for the first time in a publication this year [1]. At ITEP, *RE*BCO layers with different *RE*s were produced by means of chemical solution deposition and then examined at the Laboratory for Electron Microscopy (LEM).

Figure 1a shows a scanning transmission electron microscopy (STEM) cross-sectional image of a (Gd,Dy,Y,Ho,Er) BCO layer with embedded BHO nanoparticles.The particles appear with lower image brightness and roundish shape. Dark horizontal lines are stacking faults, which are mainly generated by the BHO particles and may also act as pinning centers. The different colored element distribution maps (Figure 1b), which were created by electron energy loss spectroscopy (EELS) analysis, show that the rare earth elements (bottom row) are incorporated into the BHO particles (see Hf map) in different concentrations. This effect can lead to a lack of *RE*2s in the formation of

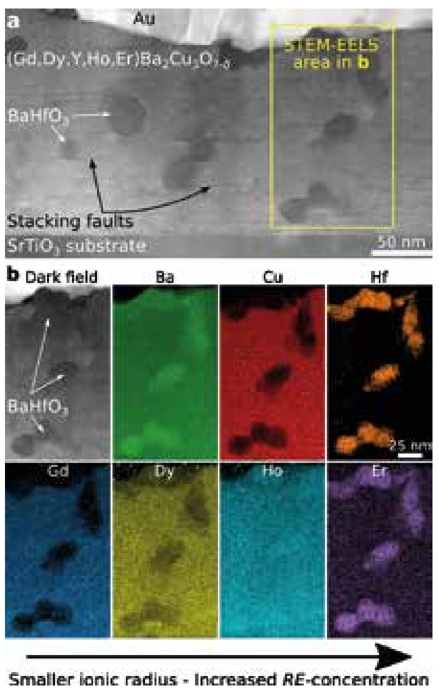

Fig. 1: (a) STEM dark-field image of a cross-sectional sample of a *RE*BCO layer with mixed *RE*s. The BHO particles and stacking faults are visible with lower image intensity.(b) The STEM-EELS elemental distribution maps show the incorporation of *RE*s into the BHO particles as a function of *RE* ion radii.

the *RE*BCO crystal structure or to a change in the lattice constant and thus the effective volume of the BHO particles. A trend in signal intensity with decreasing ionic radius from Gd to Er in BHO shows that *RE*s with smaller ionic radius are more strongly incorporated into the BHO particles. The knowledge gained will be used to improve the fabrication of *RE*BCO-BHO nanocomposite films in order to produce higher performance superconducting films.

As recently shown for $GdBa_2Cu_3O_7$ (GdBCO) films deposited on MgO single crystals by pulsed laser deposition (PLD), the critical current density Jc can be increased and even tailored at low temperatures and high fields by ex-situ oxygen loading [2]. Therefore, to further improve the properties of *RE*BCO tape conductors, oxygen loading was also investigated on GdBCO thin films deposited on metallic tapes by PLD. Similar to single crystals, the optimum growth conditions were determined as T_{sub} = 800 °C, f = 10 Hz and p_{O2} = 0.4 mbar. Three oxygen annealing processes were then investigated: (1) in situ: cooling in 0.4 mbar O_2 to 450 °C, 30 min in 0.4 bar O_2, (2) ex situ long: cooling in 0.4 mbar O_2 to room temperature, transfer to a tube furnace, heating in 1 bar Ar to 800 °C, then cooling to 450 °C, annealing at 1 bar and 2000 ml/min oxygen,(3) ex situ short: as ex situ long, without heating to 800 °C. Differences in the transport properties of the differently annealed layers are illustrated in Figure 2 for T = 77 K, in which the anisotropies of the critical current density with respect to the magnetic field direction (angle θ relative to the c-axis) are shown. While the long ex-situ oxygen-loaded sample generally shows

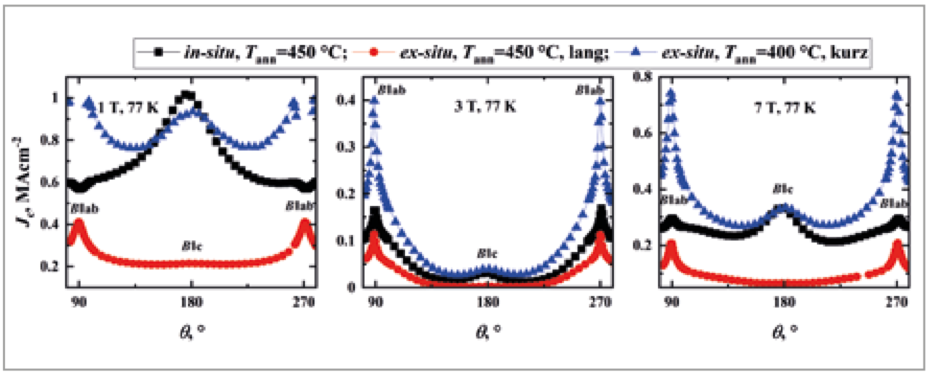

Fig. 2: Anisotropy of the critical current density for GdBCO layers on metallic tapes as a function of the oxygen loading route.

smaller J_c values, the short ex-situ loaded sample shows in particular an improvement for B‖ab, i.e. magnetic fields parallel to the tape surface.

This can be explained by the relaxation of defects at elevated temperatures and/or longer times or by the formation of stacking faults at low temperatures. However, more detailed microscopic investigations are still pending. As $LaMnO_3$ instead of CeO_2 appears to be become the standard as the final buffer layer in coated conductor production, ErBCO and YBCO layers on $LaMnO_3$-buffered tapes were successfully optimized in terms of critical temperature and current density by chemical solution deposition using Definite Screening Design (DSD) as part of a master's thesis. Furthermore, Data Diver, a program for merging and analyzing large measurement data sets, was also developed as part of a master's thesis. DataDiver can now be used to investigate correlations that were previously difficult to access. Automated identification, allocation and analysis of measurement data together with the integration of meteorological and material science databases have already provided new insights into our measurement data sets, which have been collected over many years. For example, the mean critical current density of CSD-grown layers appears to depend periodically on the time of year (Figure 3), which could be explained by variations in air humidity.

FE-BASED SUPERCONDUCTORS

In the field of Fe-based superconductors, we continued to work on the production of Fe(Se,Te) thin films using pulsed laser deposition as part of a DFG project, with a particular focus on improvements in equipment for more accurate and reproducible substrate temperature measurement. Collaborations with the Institute of Physics, Chinese Academy of Science, and Nihon University, Japan, were continued with transport measurements on single-crystal and thin-film samples from the partners. For a collaboration with the University of Rome III, Co-doped $BaFe_2As_2$ layers were deposited on various single-crystal and tape substrates as part of a master's thesis and the deposition parameters were optimized with the long-term goal of enabling cost-effective Fe-based tape superconductors. The current state of the art in the deposition of Fe-based superconductor thin films was presented and published in a review article [3].

STACKED TAPE MAGNETS

Within an AiF/ZIM-funded project "Novel superconducting magnetic bearings with YBCO tape stacks" with the company evico GmbH, Dresden, we have developed novel, improved superconductor permanent magnets based on tape conductor stacks. Especially at high temperatures around 77 K, the levitation forces could be doubled. In this project, which was successfully completed in summer 2023, the ITEP's tasks included extensive literature and patent research as well as the validation and evaluation of experimental force measurement results using finite element

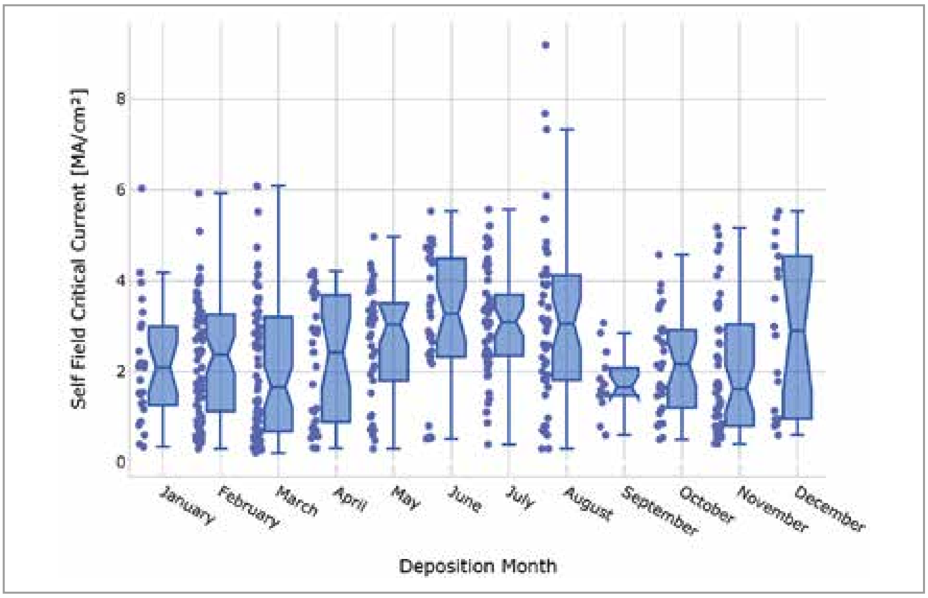

Fig. 3: Variation of the mean critical current density of REBCO coatings with the month of CSD sample production.

simulations and the thinning of the commercial coated conductors. An electrolyte consisting of phosphoric, sulphuric and citric acid in a mixing ratio of 5.5:3.5:1 was used to thin the tapes. The thinning procedure was carried out at room temperature with a working current density of 50 A/dm2. This resulted in a material removal rate of 2 µm/min. The top side of the tape was protected with a self-adhesive Kapton film so that no etching took place here. To measure the levitation force of the tape stacks at the project partner evico, 240 tape pieces with a length of 24 mm and 40 tape pieces with a length of 70 mm were thinned by 10 µm (Figure 4).

[1] L. Grünewald et al. (2023) Analytical electron microscopy study of the composition of BaHfO$_3$ nanoparticles in REBCO films: the influence of rare-earth ionic radii and REBCO composition, Mater. Adv., https://doi.org/10.1039/D3MA00447C.
[2] R. Popov et al., Oxygen Annealing of GdBa$_2$Cu$_3$O$_7$-δ Superconducting Thin FIlms: Influence of Annealing Time, IEEE-TAS (2024), accepted.
[3] K. Iida et al., Recent progress on epitaxial growth of Fe-based superconducting thin films, Supercond. Sci. Technol. 36, 063001 (2023) https://doi.org/10.1088/1361-6668/acccb2

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STRUCTURAL AND FUNCTIONAL MATERIALS FOR CRYOGENIC APPLICATIONS

"HIGH STRENGTH MATERIALS" PROJECT

In order to realize compact superconducting high-field magnets for fusion, it is necessary to find high-strength and at the same time cost-effective structural materials and to qualify them for cryogenic use. The austenitic stainless steel Nitronic 50 (XM-19) in forged condition was selected

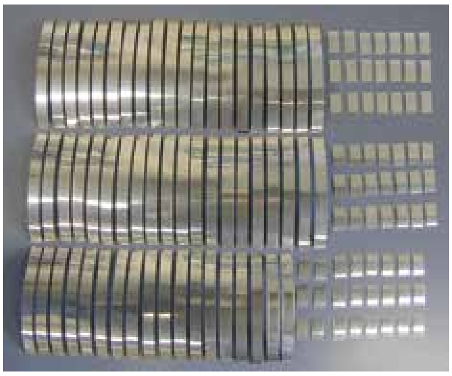

Fig. 4: Electropolished THEVA coated conductors

as a potential material for a required component in a project involving the stainless steel plant KIND (Germany) and the fusion organization CFS (USA). The properties were investigated both at room temperature and at cryogenic temperatures. To evaluate the mechanical and microstructural parameters, samples were selected from different parts of a forged block, taking into account the criterion of the optimum combination of yield strength and fracture toughness (>1230 MPa and >160 MPa√m respectively) required in Figure 5.

The results of the samples showed a significant spread of values. To clarify this, a microstructural examination was carried out in three directions as a first step. All samples showed rod-shaped Nb-Cr-rich phases, which were, however, distributed differently. In the samples within the mechanical specification, the alignment of this second phase in the defined X and Y directions is remarkable, in addition to a significant formation of twins in all directions. This alignment leads to specific phase-free sections in all directions (Figure 6). The rod-shaped phases in the microstructure can be seen as white spots. Samples outside the specification show little or no evidence of these characteristics. The extent to which these phases influence and scatter the mechanical properties is subject of current investigations.

HTS CHARACTERIZATION PROJECT

High-temperature superconductors (HTS) are used in various high-current conductors, for example for large high-field magnets or so-called cable-in-conduit-conduc-

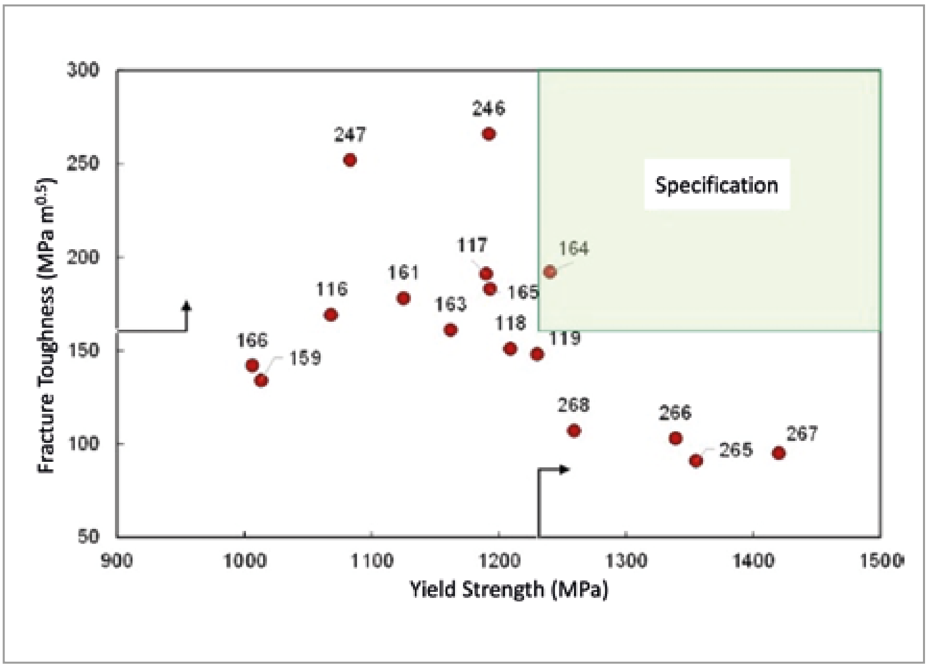

Fig. 5: Fracture toughness and tensile strength of different sample positions (numbers). The green area corresponds to the required specification (>1230 MPa or >160 MPa√m).

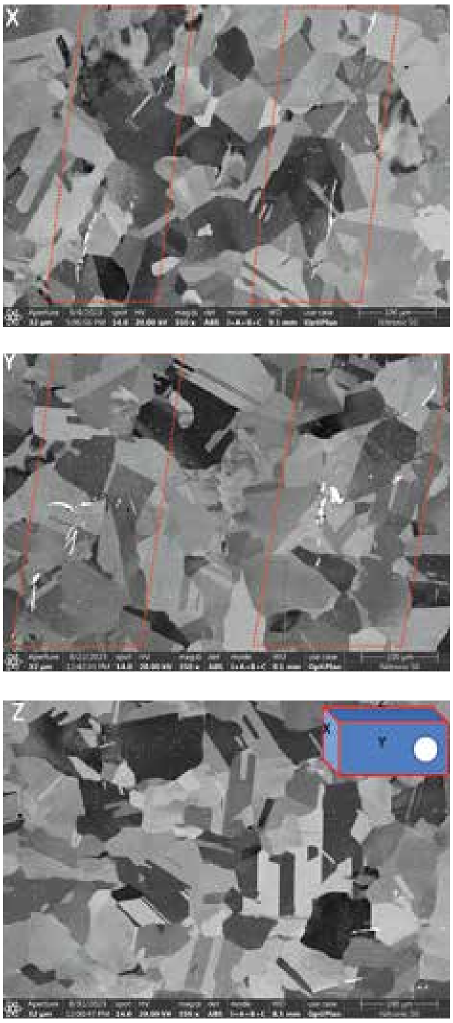

Fig. 6: Microstructure of the Nitronic50 sample within the mechanical specification in different directions x, y, and z (see viewing direction of the surfaces in the schematic drawing). The measurement bar corresponds to 100 µm.

tors (CICCs). CICCs are often made up of several HTS strands, which in turn consist of individual HTS tapes that are pressed together under mechanical pressure by the compaction of the cable. Even in small HTS coils, HTS wires are often wound on top of each other, forming a stacked structure in the direction perpendicular to the HTS tape plane. To simulate a quench in such a cable, for example, the knowledge of the thermal and electrical resistance of tape stacks in both directions - radial and axial - is required (Figure 7). Such measurements in the radial direction are possible with the newly developed extension of the so-called standard thermal transport option within the physical property measurement system (Quantum Design). The device (Figure 8) enables the measurement of thermal and electrical resistances across the stack of HTS tapes in a wide temperature range from 4 to 300 K, which are pressed together under controlled pressure. The results at different contact pressure values can be used to simulate quench propagation in CICC or HTS coils.

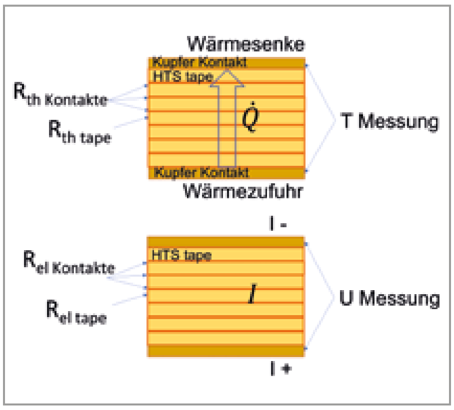

Fig. 7: Measurement configuration perpendicular to the HTS tape plane for electrical and thermal characterization.

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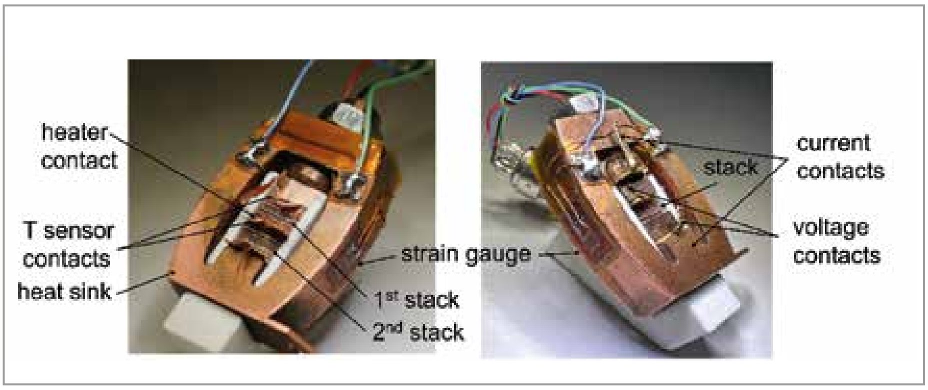

Fig. 8: Realization of the thermal and electrical measurement with a configuration suitable for the PPMS platform from Quantum Design.

Highlight

Successful commissioning of pilot production of HTS coated conductors

As part of the KC[4] collaboration project (KIT-CERN Collaboration on Coated Conductor), HTS pilot production was successfully put into operation at ITEP in 2023 and corresponding research work was started.

As part of the KC[4] project, HTS coated conductor coating systems, which have been developed with great success by an industrial superconductor manufacturer in recent years, have been transferred to the KIT. This will make it possible in future to develop complete HTS coated conductor architectures for special application scenarios at ITEP and produce them in conductor lengths of up to several hundred meters so that new coil concepts, for example, can be tested. From 2024, this expansion will make it possible for the first time at a research institute in Europe to directly combine current short sample material developments with the HTS tape length requirements of application demonstrators. As part of KC[4], special HTS tape architectures that are not available industrially will be developed in the coming years for the development of HTS-based accelerator magnets and their special requirements profile.

KC[4] will also produce wide HTS coated conductors that are currently not produced industrially and can be used for the development of new coil topologies. KC[4] is based on the established combination of ion beam textured metal substrates and their coating using pulsed laser deposition (PLD) and vapor deposition processes for HTS coated conductor synthesis. KC[4] is an industry-independent project, so that in the medium term it will also be possible to provide interested research institutions and companies with an openly accessible development platform for special HTS coated conductor developments. The HTS coating process of a coated conductor consists of several individual steps in which, in addition to the actual HTS layer, other buffer and metallic cover layers are applied to a heavily textured metal tape substrate of low thickness (<80 µm) (Figure 9). All relevant coating steps for tape lengths of up to 30 m were successfully put into operation and qualified last year. A special feature of the coating process used in KC[4] is that the tape length to be coated is wound onto a cylinder and coated in rotation in an almost always closed oven chamber using PLD.

Figure 10 shows an example of the critical current-carrying capacity of the KC[4] conductors based on measurements obtained as part of process parameter optimization.

Since March 2023, HTS coated conductors have now been routinely synthesized and characterized for further research work as part of the KC[4] work. One current focus of the research work is to understand the electromechanical properties of the coated conductors and their relationship with the underlying coating processes.

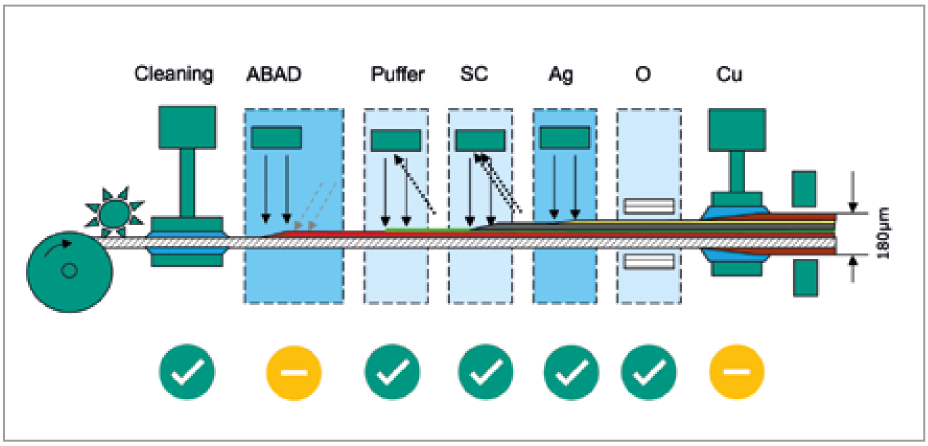

Fig. 9: The process steps required for HTS coated conductor synthesis and their implementation status within the KC[4] project. After a cleaning step, a textured buffer layer (ABAD) is deposited before diffusion barrier layers (buffers), the actual superconductor layer (SC) and finally Ag and Cu layers are deposited. Within KC[4], commercially available textured tape substrates are currently used as the coating base.

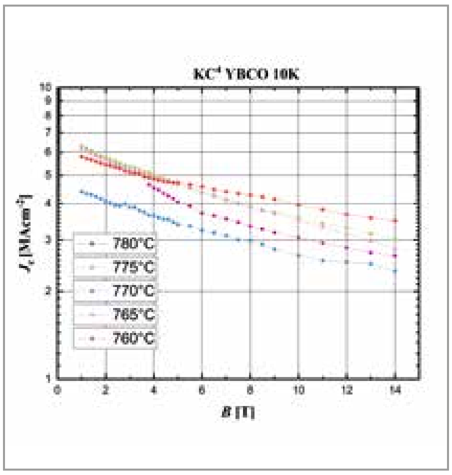

Fig. 10: Exemplary Jc measurements at 10 K and magnetic fields up to 14 T, which were obtained in the course of synthesis optimization (here variation of the coating temperature).

Results from the Research Areas

Organizers of the 8.th IEEE Workshops on the Electronic Grid (eGrid 2023) 16.–18.10.2023 at KIT

Superconducting Power Applications

Coordination: Prof. Dr.-Ing. Mathias Noe

In the research field Superconducting Power Applications, ITEP scientists work on the following topics:

- Superconducting network and energy components
- Modeling of superconductors and components
- Real-time system integration

The focus in the topic of Superconducting Grid and Energy Components is on the development of novel operating materials for electric power systems and the development of resource- and energy-efficient applications for energy technology. To this end, researchers achieved the following results in 2023.

SUPERCONDUCTING NETWORK AND ENERGY COMPONENTS

RESISTIVE SUPERCONDUCTING FAULT CURRENT LIMITERS

High-temperature superconducting current limiters (HTSL SSB) have already been used successfully in the medium-voltage grid in Germany. In collaboration with the TH Cologne, ITEP was asked by TenneT to investigate the technical and economic feasibility of a resistive HTSL SSB for 380 kV, 5 kA.

The feasibility study was completed in 2023 and is available at the link https://www.ksp.kit.edu/site/books/m/10.5445/KSP/1000161057/. In summary, it can be said that a 380 kV, 5 kA resistive superconducting current limiter is technically feasible and that a special research and development program is initially recommended for the further development of the critical key components. Overall, it appears possible to develop such a limiter within the next five years.

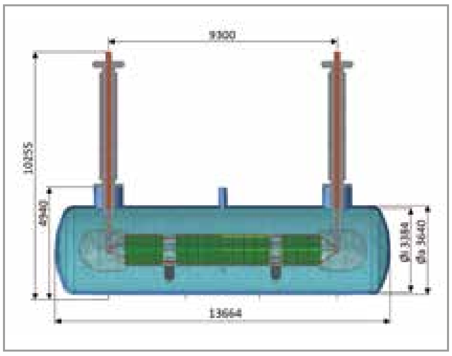

Fig. 1: Main dimensions and sketch of a phase of a superconducting 380 kV current limiter

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HTS SWITCHING

One promising application for REBCO tape conductors is superconducting switching. We utilize the dynamic resistance of the superconductor, which occurs when the superconductor is in an alternating magnetic field. A superconducting bridge circuit has now been demonstrated for the first time as part of a doctoral thesis. By selectively controlling the switches S1-S4 (see Figure 2), a converter can be constructed in a similar way to semiconductors. The main aim of further work is to increase the voltages and thus reduce the time required for current commutation.

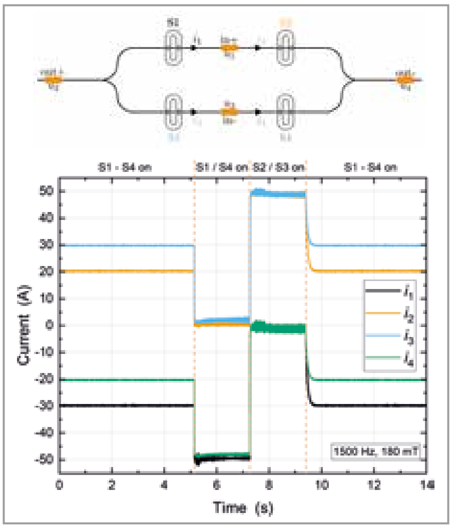

Fig. 2: Top: Basic structure of the bridge circuit with two parallel, superconducting paths. Bottom: Current flow in the individual current branches of the bridge circuit

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CRYOGENIC HIGH VOLTAGE

The Combutt test stand (Cryogenic One Meter Build-Up for Tube Testing) enables high-voltage testing of three-phase short samples of insulating arrangements for the medium-voltage range, which are cooled with liquid nitrogen. The concept was initially designed with regard to withstand voltage tests with single-phase AC voltage, three-phase current (Fig. 3) and standard lightning impulse voltage with the highest voltage of equipment (Um) at 12 kV.

Fig. 3: Three-phase current test with the Combutt system with a voltage of 86.6 kV (effective, phase against phase).

After successful tests with PE disks, the system was improved so that it can also be tested with test voltages for equipment with Um = 24 kV. A rigid pipe was initially used as the earthed outer conductor, which corresponds to the structure of a liquid-insulated cable. In this setup, either four PE disk insulators or four discrete printed PLA support insulators were tested (Fig. 4).

Fig. 4: PE disk insulator (left) and printed PLA support insulator (right)

Fig. 5: Individual segments of printed continuous cable insulators made of PLA (left) and PA (right).

As part of the HighAmp project, an earthed outer conductor based on a corrugated tube has been used and two different continuous insulation structures have been tested to date.

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BMWK PROJECT DEMO200

The DEMO200 joint project is developing the technology for a superconducting high-current system for a direct current of 200 kA. In 2023, a pressure-tight feedtrough and two 20 kA current leads for separating the conductor path from the terminations were completed and extensively tested with the project partners Vision Electric Superconductors and Messer (see Fig. 6). This combined test carried out at the ITEP was used to check the functionality of the individual components and to verify the temperature layer formation in the supercooled nitrogen. This concludes the work on this project at ITEP and the technology demonstrator is currently being set up in an aluminum plant for a final test.

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Fig. 6: Construction of the pressure-tight bushing including two 20 kA current feeds

BMWK PROJECT ROWAMAG

Superconducting magnetic heaters enable to save more than 30 percentage points of energy when heating metals for industry compared to previous methods and have already been built and operated in individual units. However, not all operational requirements have yet been met. The main objective of the ITEP in the BMWK joint project ROWAMAG (Robust and low-maintenance magnetic heater with HTS coils for hot forming processes) to build and test a robust and low-maintenance magnetic heater with superconductors is therefore to develop a long-lasting cryosystem including the cryostat and the refrigeration systems.

Together with partners THEVA, Bültmann and Beck Maschinenfabrik, the superconducting magnetic heater was successfully assembled and tested in 2023. In the final step, tests will be continued and the magnetic heater will be extensively tested in a trial operation at Bültmann.

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SIMULATION OF SUPERCONDUCTORS AND COMPONENTS

An integral method was developed and used to calculate AC losses in superconducting tapes in an air-filled electrical machine in a two-stage process: The magnetic field is calculated in a finite element method model without superconducting

Fig. 7: Superconducting magnet of the magnetic heater in current test at KIT with iron yoke

tapes and exported to the integral method model consisting only of the tapes. The advantage of this approach is that the magnetic field maps can be calculated using different finite element methods (FEM). The calculation of the AC loss is performed with programs written in widely used languages such as Matlab and Python codes (Fig. 8). The code provided the same results obtained with a full machine model in Comsol Multiphysics (based on the T-A formulation), but in a fraction of the time. In addition, the Matlab/Python codes are now publicly available on the hts.modelling.com website.

A numerical model combining an H-formulation FEM model with an electrical circuit was developed to investigate the overall performance of self-regulating HTS flux pumps that enable DC injection into a closed-loop superconducting coil without electrical contact. The results indicate that the proposed model can capture all critical characteristics of a self-regulating HTS flux pump, including superconducting properties and the influence of secondary resistance.

Three-dimensional numerical simulations based on the minimum electro-magnetic entropy production (MEMEP) method were used to predict the levitation force between a permanent magnet and a double stack of HTS tapes. The force was calculated at different temperatures from 57 to 77 K, both at zero field cooling and field cooling. It was found that the results were in good agreement (maximum error 9 %) matched the experimental values. In contrast to other approaches presented in the literature, the model uses the anisotropic field dependence of HTS tapes on the magnetic field as an input rather than a

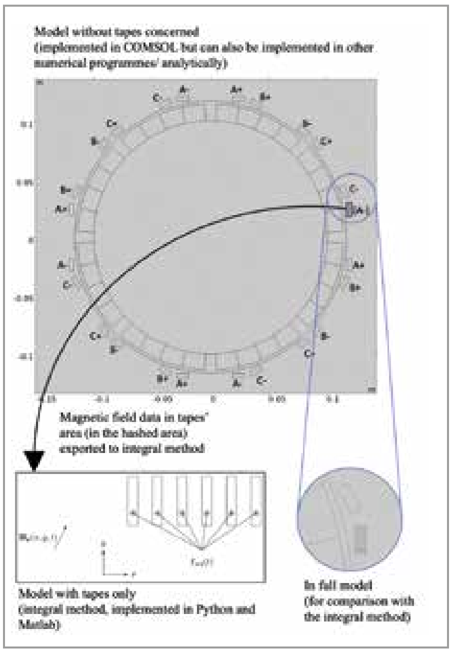

Fig. 8: Principle of using the integral method to calculate the alternating current losses of superconducting tapes in a machine

back-fitting parameter to match the experimental levitation force data.

Three-dimensional simulations based on the H-formulation were used to study the current distribution in a conductor-on-round-tube (CORT) cable carrying alternating current. It was found that even in the simple scenario of a cable consisting of only one layer of three HTS tapes, the current follows a non-trivial path that can be described as a spiral within a spiral and that was visually revealed by the simulations (Fig. 9).

In principle, this has important implications for the total current carrying capacity and AC losses of the lines. It also means that conventional simplifying assumptions used in simulations, such as neglecting or artificially extending the HTS thickness, are likely to lead to an incorrect estimate of AC losses.

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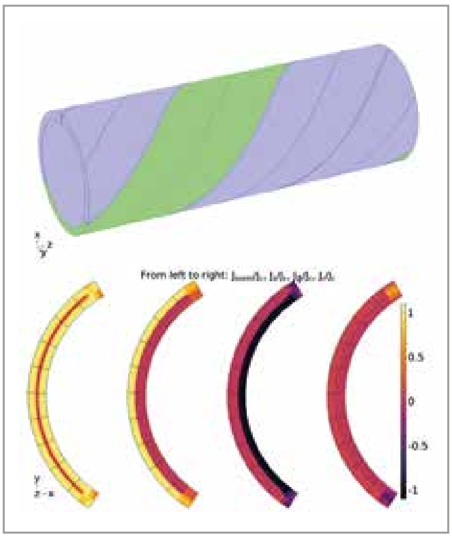

Fig. 9: Top: 3D model of a CORT cable (one layer, 3 ribbons, one ribbon highlighted in green). Bottom: Current density components at the peak of the transport current.

REAL-TIME SYSTEM INTEGRATION

FAST REAL TIME MODELS FOR ENERGY SYSTEMS

The Real Time Systems for Energy Integration (RTSET) group works extensively on devices modelling approaches for digital real time simulators, focusing on making these models lighter under the required computational power. Within the Helmholtz Young Investigator group "Hybrid Networks", we have proposed a novel 3-phase dynamic load model for real time simulators, that achieves the same accuracy performance of well-known and longer-validated Simulink models, but it requires 30% less computational time to be computed. This model is based on the instantaneous-power theory and it does not rely on rotating synchronous frame to control active and reactive power injection, and thus it avoids trigonometric calculation and use of large memory arrays. The model, presented in a recent journal publication, has been validated in two large distribution networks (SimBench network and IEEE 118-bus distribution system), showing improved computational performance.

REAL TIME LOAD SENSITIVITY IDENTIFICATION

Demand response plays an important role in achieving flexible power controllability in energy networks. In the RTSET group we focus on voltage- and frequency-led load control, that exploits the voltage and frequency dependency of the active and reactive power consumption of loads and gen-

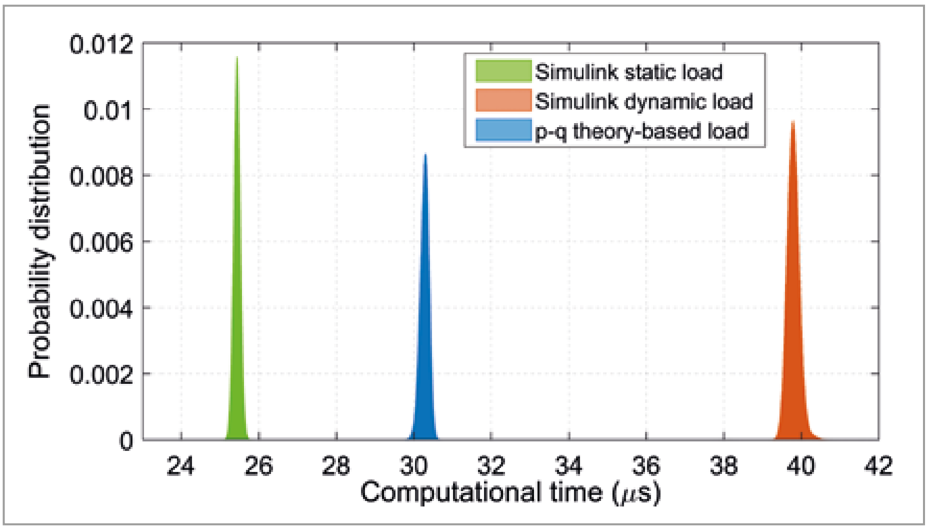

Fig. 10: Computational time for computing the IEEE 118-bus test feeder grid with the proposed and existing approaches.

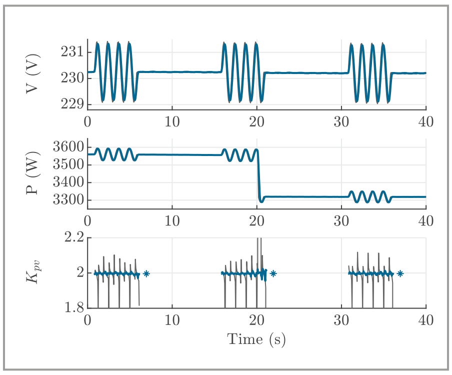

Fig. 11: Example of the load sensitivity approach proposed at Energy Lab 2.0.

erators. Our activities involve as first step the identification of these sensitivities. We have developed and submit as patent application a novel load sensitivity method, that fully independent from the grid conditions is able to estimate the load sensitivity during disturbance with little to no error. This approach has been validated in the KIT experimental facility "Energy Smart Home Lab" with commercially available loads and in realistic household conditions. The results show that the load power consumption is still largely dependent on the voltage, while it shows independency from the frequency value. On the distributed generators side, we have proven as commercial devices are typically slower than what the norms prescribe, slowing the service provision dynamics. Current studies are focusing on the load frequency dependency on large frequency variations (e.g., 44-56Hz range).

POWER HARDWARE IN THE LOOP STABILITY AND ACCURACY

Experimental testing of novel energy technology is a vital step before their introduction in the market. However, field testing requires time, manpower and money in order to allow extensive validation of the technology performance. Power Hardware In the Loop (PHIL) allows laboratory testing in realistic grid conditions, connecting a digital real time simulated network with the real technology hardware by means of power amplifiers. A lot of open questions remain unanswered regarding the stability and testing accuracy of PHIL testing. In the RTSET group, we are working on advanced mathematical approaches based on the well-known "impedance-based stability theory" for a more accurate estimation of PHIL stability and accuracy. Recent experimental testing and publications showed that our approach accurately predict the stability of PHIL within little error margin.

HYBRID ENERGY STORAGE SYSTEMS

Energy storage systems play an important role in supporting the grid stability and guarantee supply reliability. However, it is not realistic to rely on batteries for both bulk power support and fast dynamic services. Different energy storage technologies shall be integrated in the energy network and shall work cooperatively. At this regard, the RTSET group focuses on hybrid energy storage systems (HESS), where an energy-intensive storage technology (e.g., battery or hydrogen) is coupled a power-intensive one (e.g., flywheel or supercap). This allows to dispatch large but slow quantity of energy with the energy-intensive resource, leaving the fast power variations to the power intensive one. In the RTSET group, we have validated the performance of a battery-flywheel-based HESS, showing how the power transients of the battery can be minimized, and thus increasing the battery lifetime. This improves the economical prospects of the whole HESS. Currently, we are focusing in developing novel control strategies for HESS, where the state of charge is also controlled optimally, avoiding fast discharging of the power-intensive energy storage technology.

HYDROGEN TECHNOLOGY PLATFORM

One of the major focus in Germany, and in particular at KIT, is the production, transport and usage of hydrogen for energy processes purpose. At this regard, RTSET joined several other groups at KIT to develop the Hydrogen Integration Platform,

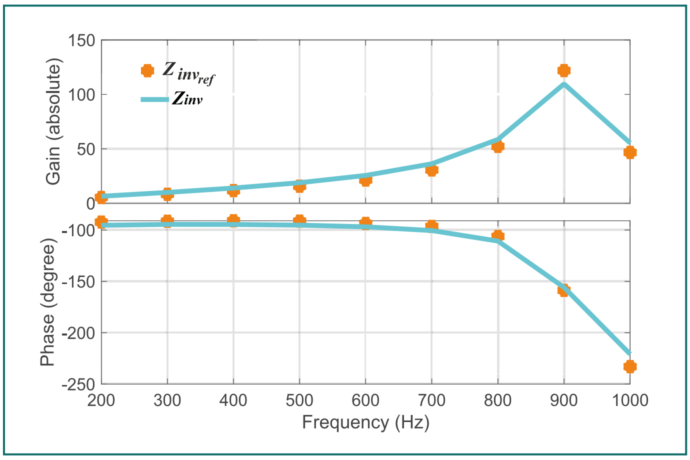

Fig. 12: Impedance Profile of the converter unter test in PHIL.

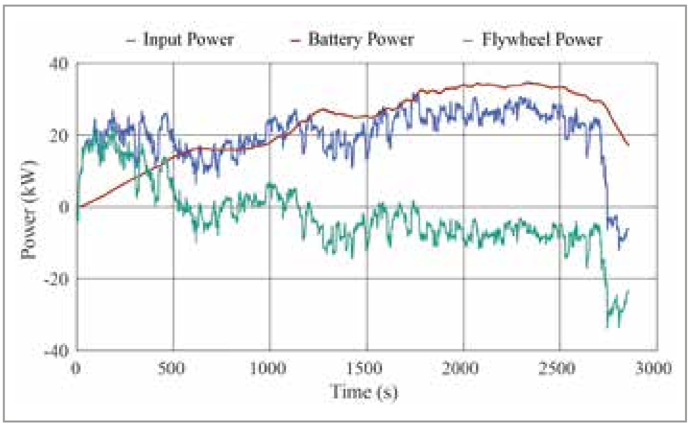

Fig. 13: Power profile of the hybrid flywheel / battery HESS during deliver of grid services.

ment, design and control of power electronics-based and energy storage technologies.

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Fig. 14: H_2-in-the-loop lab for experimental validation of hydrogen technologies.

where hydrogen-related energy technologies will be installed in Energy Lab 2.0 and connected to the PHIL lab facility. These technologies, including electrolyzers, compressors, liquefiers, fuel cells, will have their performance validated in realistic grid conditions by means of PHIL technique. The H2-in-the-loop lab is the first effort in this direction. A 50kW electrolyzer and a 10kW fuel cell system will provide next year first results on what services hydrogen technologies can provide to the main power system (e.g., frequency regulation.).

KIT TESTFIELD FOR ENERGY EFFICIENCY AND NETOWRK STABILITY IN LARGE RESEARCH INFRASTRUCTURES – KITTEN

Particle accelerators are energy-intensive facilities, that offer little demand flexibility and require high power quality standards. On the other side, they aim at better energy efficiency due to the high energy costs. The RTSET group, together with the particle accelerator KARA at KIT, developed jointly the research infrastructure KITTEN to address these energy efficiency and stability challenges in accelerators. As a result, a 5M€ Horizon Europe project "Research Facility 2.0" has been successfully proposed and it will begin in 2024. Together with 5 of the largest accelerators in Europe (ALBA, CERN, DESY, HZB, MAX IV), energy efficiency topics from component to system level, for both physics and energy engineering areas, will be studied and concrete solutions will be proposed and validated experimentally in demonstrators at the accelerators facilities. The RTSET group will focus on the digital twinning of accelerators, particularly for digital real time applications, and in the optimal place-

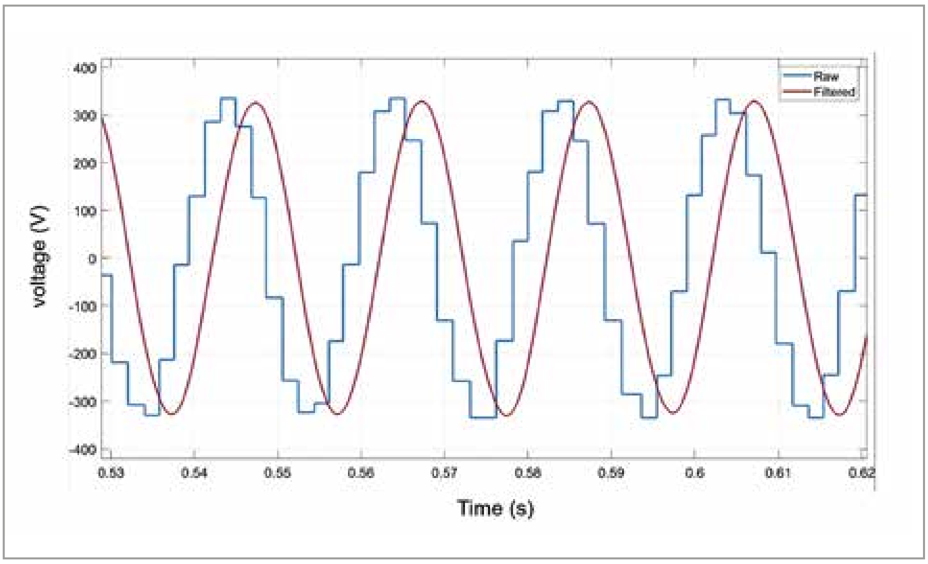

Fig. 15: KITTEN first voltage waveform transfer between KARA and Energy Lab 2.0.

Results from the Research Areas

The team and the result: completed 2G-HTS triplet cable sample for characterisation in the SULTAN facility at EPFL in 2023

Superconducting Magnet Technology

Coordination: Prof. Dr. Tabea Arndt

In this research field, the degree of maturity of the various technologies in the research topics was further increased in 2023. The good interlinking and collaboration across the various ITEP research topics was also particularly evident.

In the three research topics "Coil and magnet technology", "High-current components for hydrogen technologies and fusion" and "Rotating machines", the fundamental results of previous years were expanded in the reporting year.

For example, the robotic winding technology of HTS was further developed, superconductivity in combination with hydrogen technology was detailed and the HTS-DUDA approach was developed towards applications. Furthermore, several projects with superconducting motors in the field of drive technology were successfully completed and new projects in the field of electrical energy generation using wind were acquired.

In the Collaborative Research Centre SFB 1527 "Hyperion" (work package "Compact HTS magnets for the NMR background field"), the first magnet designs were carried out and procurements made.

The fusion activities resulted in the completion of a sample of an HTS cable for quench investigations.

COIL AND MAGNET TECHNOLOGY

ROBOTIC WINDING TECHNOLOGY

Coils and magnets are still by far the main area of application for technical superconductors. Increasingly, complex, truly three-dimensional winding geometries are required. These can no longer be easily produced by hand using conventional lathes. To provide such windings, a robotic winding system has therefore been designed and built since 2020 and the first coils have been produced with it. The first results published in 2023 led to a large number of enquiries from industry and science – also with a view to a possible transfer of expertise.

The globally unique robotic winding system, in which a workpiece positioner picks up the former and two non-collaborative robots (i.e. robots that do not interact with humans) guide the so-called winding hand, is not a finished tool, but is itself subject to continuous further development. The winding hand has currently been revised. This picks up the pay-off spool with the superconductor wire, winds it onto a former and keeps the wire tension at the set value via a servomotor and tension sensor. It turned out that the original winding tension control via a Siemens S7 controller in conjunction with the bus system used did not adequately fulfil the requirements in terms of reactivity and dynamics. This method was therefore replaced by an on-board solution in the form of a dedicated PID control module with a response time of 1 ms. The winding tension is thus controlled on the winding hand itself; only the setpoint is still specified via the S7. The dynamics of the winding tension control could thus be improved by more than an order of magnitude.

Fig. 1: Electronics side of the winding hand. Bottom left: PID tension controller. Further clockwise: Docking flange for robot, rotary encoder for length measurement, electronics for S7 connection, tensile force sensor, motor control. In the centre: servo motor.

Figure 1 shows the electronics side of the revised winding hand.

COOLING CONCEPT: THERMOSYPHON AND COLDHEAD

Many technical applications for high-temperature superconductors (HTS) are intended for a temperature range of around 30 K. Hydrogen, which will be an important energy vector in the future, boils at 21 K. Dry cooling with cryocoolers is the easiest way to access this temperature range for experiments and investigations. In contrast to the usual connection to the cold head via solid copper, i.e. heat conduction, in this system the connection of the object to be cooled via a thermosyphon is to be investigated. In principle, a thermosyphon (heat pipe) consists of an evaporator (on the object to be cooled), a condenser (on the cold head) and a connecting pipe. This closed system contains a small amount of a cryogen (in this case neon). The material flow and the phase transitions of the neon at the cold and warm ends ensure extremely effective heat transfer.

The construction of the test stand was completed in 2023. Specifically, the pipework was completed, the cryostat insert finalised and all pumps connected. This also applies to the specially designed control cabinet with components for controlling the pumps, heaters and so on and for re-

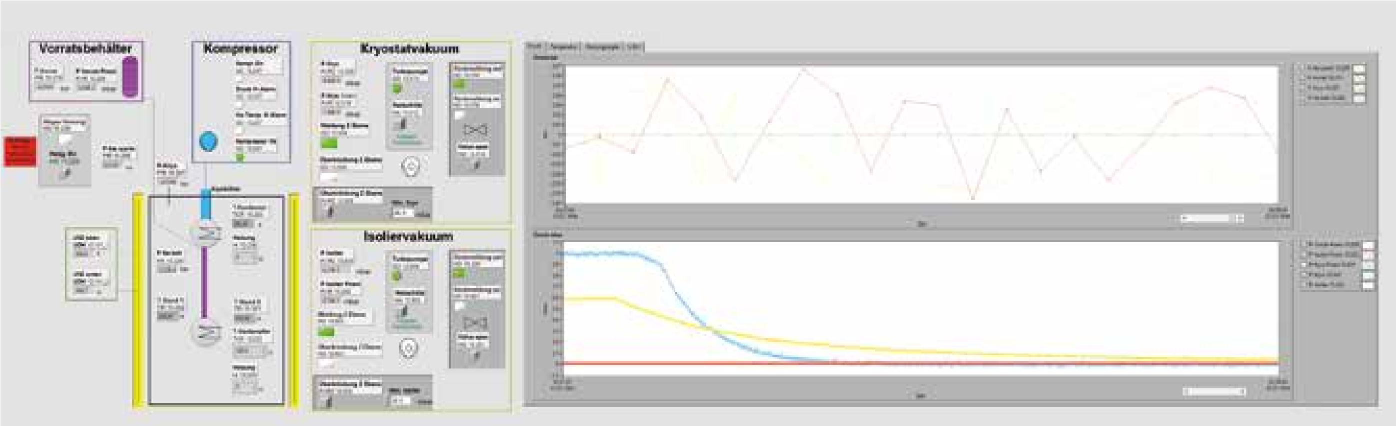

Fig. 2: LabView GUI for controlling the heat pipe test stand.

cording measured variables such as temperatures and pressures. The system is now ready for TÜV approval. For system control and process data recording, a graphical user interface in LabVIEW was programmed (see Screenshot Figure 2).

Inauguration of the setup and first experiments are scheduled for 2024.

WORK ON THE DUDA COIL CONCEPT

A "DUDA", or "disk-up-down-assembly", is a stack of alternating layers of superconductor tapes with a free hole in the centre. Alternating means that the tapes are arranged alternately with the substrate and the superconducting layer facing upwards, so that connections are always made between the superconducting sides of the tapes. A DUDA arrangement can be circular or, as shown in Figure 3, rectangular in shape. This shape is referred to as rDUDA. This type of arrangement makes it possible to generate compact, high magnetic fields in the free bore of the stack and thus to investigate new approaches, for example in motor development.

In 2023, techniques for forming low-resistance contact points between REBCO tapes were systematically analysed as part of a bachelor's thesis. For the experiments, 12 mm wide tapes from SuperPower were used. In a first step, series of tests were carried out on single contacts in which the parameters listed in Table 1 were varied. The best possible method resulted in a single contact resistance of approx. 12 nΩ and a surface resistance of approx. 33 nΩcm². Using this method, two DUDA stacks of four and six tapes were produced.

Figure 4 shows the DUDA stack, which consists of four individual tapes, clamped in the measuring apparatus. The total resistance for this stack with four tapes, i.e. three contact points, was 68 nΩ. For the stack with six tapes or five contact points, the total resistance was 136 nΩ.

MEESST-PROJECT

High heat flow and radio failure are well-known challenges that spacecraft have had to face since the early days of space travel when re-entering a planet's atmosphere. Thermal protection systems have been developed to protect spacecraft and astronauts, but these are often heavy and sometimes have to be replaced after each mission. In addition to possible damage to the spacecraft, the high temperatures of the compressed gas lead to partial ionization in the shock wave. The dense plasma can cause a radio blackout, i.e. an attenuation or reflection of radio waves, which can hinder data telemetry and communication with ground stations or satellites.

One approach to solving both problems is to influence the plasma through magneto-hydrodynamic effects using a strong magnet.

As part of the European MEESST (Magneto-Hydrodynamic Entry Systems for Space Transportation) project, a high-temperature superconductor (HTS) magnet was manufactured in 2022. In 2023, the magnet was initially equipped with sensors (Figure 5) and tested in the VATESTA facility.

The magnet at a temperature of 30 K could be operated with a current of 50 A. For the planned experiments to attenuate the heat flow and the radio blackout, this corresponds to a maximum field of around

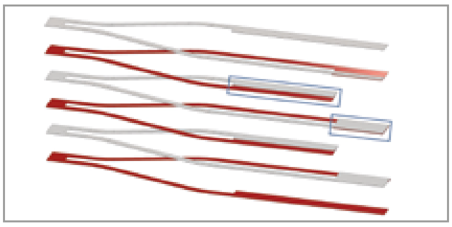

Fig. 3 Structure of a rectangular DUDA stack; red: Superconductor, grey: Substrate, outlined in blue are the contact points

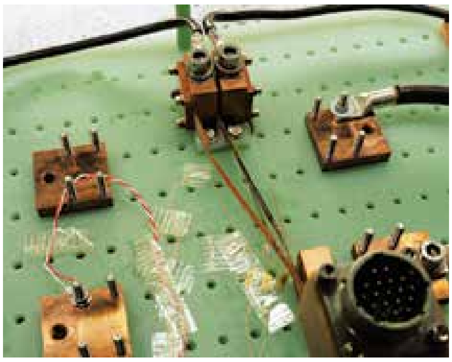

Fig. 5: MEESST magnet after equipping with sensors and voltage taps.

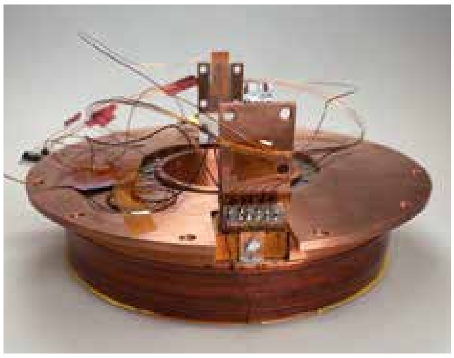

Fig. 5: MEESST magnet after equipping with sensors and voltage taps.

0.7 T in the plasma outside the water-cooled shell of the probe. After the tests at KIT, the MEESST magnet was delivered to Absolute Systems (France), where it was installed in the cryostat. In October/November, the magnet and its cooling system were installed and tested in the plasma channel of the Von Karman Institute for Fluid Dynamics (VKI) in Belgium (Figure 6). The first experiments to mitigate the radio blackout are planned by the end of 2023. Experiments to attenuate the heat flow are to be carried out at the Institute of Space Systems (IRS) in Stuttgart in the first quarter of 2024.

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HIGH-CURRENT COMPONENTS FOR HYDROGEN AND FUSION

In the research area of high-current components for hydrogen and fusion, there is research in the framework of EUROfusion respective to HTS high-current conductors for future fusion magnets and in the framework of the hydrogen lead project TransHyDE, there is conducted research into various topics relating to the transport and application of liquid hydrogen.

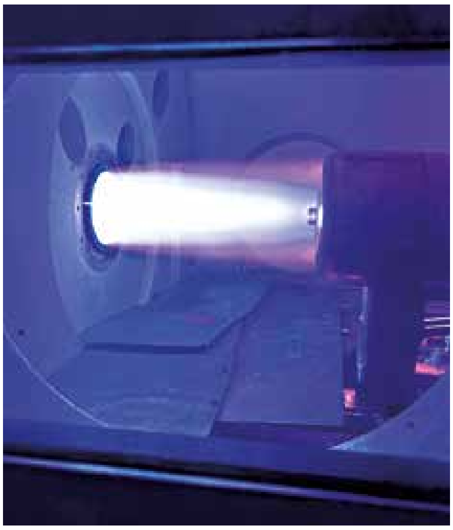

Fig. 6: First plasma test with the MEESST probe installed at the VKI.

LNG2HYDROGEN

The aim of the TransHyDE project LNG2Hydrogen, which was launched in 2023, is to develop a scientifically sound, sustainable database and recommendation as a basis for decision-making on the sustainable and long-term use of LNG terminal locations as logistical hubs for hydrogen and its derivatives. KIT ITEP is analyzing the transport vector liquid hydrogen (LH_2) and contributing to the development of a concept for an import terminal for LH_2, component evaluation, domestic LH_2 onward transport and further use scenarios.

APPLHY! – TRANSPORT AND USE OF LIQUID HYDROGEN

The work on liquid hydrogen is part of the BMBF's TransHyDE hydrogen lead project. ITEP is coordinating the work of the AppLHy! consortium on the transport and application of liquid hydrogen and is itself involved in all work packages of the joint project. Further results on research work from the AppLHy! project can also be found in the research topics STRUCTURAL AND FUNCTIONAL MATERIALS FOR CRYO APPLICATIONS and ROTATING MACHINES. In order to illustrate the wide range of possible applications, transport options and synergies from liquid hydrogen transport, an interactive model was created for the KIT Open Day in June 2023 on the question "How does liquid hydrogen get into the tank?" and the question was discussed with the interested public (Figure 7).

HYBRIDE PIPELINE

The advantages of superconducting cables over conventional solutions include the reduced space required for routing, lower electrical losses, higher power densities and the possibility of transmitting a specified power at a lower voltage level using higher currents. However, in order to maintain the superconducting state, the cable must be cooled below the transition temperature of the superconductor and kept at

Fig. 7: Liquid hydrogen transport model.

this temperature. When using liquid hydrogen with temperatures of around 20-25 K, this temperature level is supplied virtually without additional effort, so that chemical energy (LH_2) and electrical energy (superconducting cable) can be transmitted particularly efficiently in a hybrid pipeline.

DESIGN FOR OVERCURRENT BEHAVIOR

The design of a hybrid pipeline must ensure safe operation. This also includes the consideration of a short circuit in the electrical network.

The cable model simulates the behavior of the individual components in the event of a short circuit. The aim of the adiabatic 0D simulation is to calculate the effects of the assumed overcurrent curve on the temperature, resistance, voltage and the distribution of the current in the materials of the cable. These variables can be used to assess whether the assumed cross-section of the copper stabilizer is suitable for safely controlling the assumed short-circuit case. Hydrogen requirements in the Brunsbüttel/Hamburg region were taken as the basis for the framework conditions: Length approx. 75 km, installed electrical power 4 GW (±100 kV, 20 kA) and an installed LH_2 capacity of 617-869 MW. An input temperature of 20.4 K was assumed for the LH_2.

The results of the simulation show that a cable with a copper stabilizer cross-section of 190 mm² is able to meet the voltage and temperature requirements at a maximum current of 175 kA.

Figure 8 shows the current, voltage, temperature and resistance characteristics of the individual components in the above configuration. “Core” stands for the copper stabilizer, “AgHyCu” for all materials except the HTS in the tape, “L” for the cable inductance and “Cble” for the entire cable. A schematic overview of the cable geometry is shown in Figure 9.

DESIGN OF A 10 KA-PROTOTYPE PIPELINE

A detailed cable design was derived from the results of the overcurrent calculation

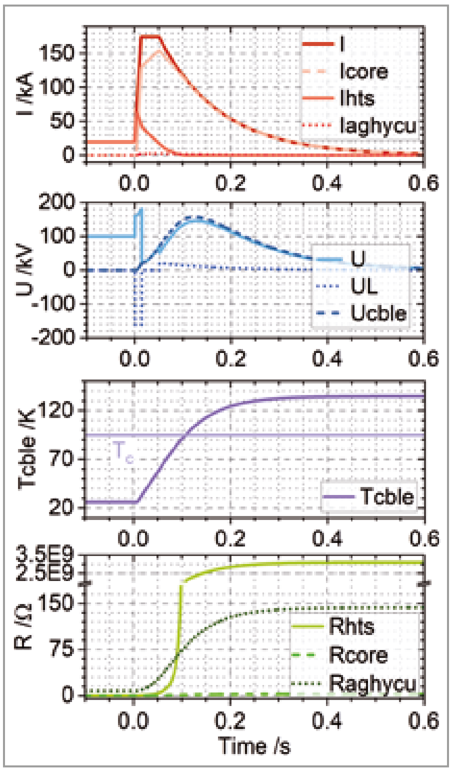

Fig. 8: Short-circuit behavior oft he cable.

and based on last year’s work. The model can be flexibly adapted to different requirements and serve as the basis for the planned pipeline demonstrator at the ITEP. The prototype is designed as a DC cable with high-temperature superconductors (REBCO tapes) and is intended to transmit 200 MW of electrical power (U_op = ± 10 “kV”,I_op = 10 “kA”). Figure 8 shows the schematic structure with concentric phases to minimise the stray electromagnetic field.

Due to the high dielectric strength and compatibility with both hydrogen and cryogenic temperatures, the electrical insulation consists of cross-wound polyimide film. Copper strand bundles form the cable core for thermoelectric and mechanical stabilization. An FE model was created with COMSOL to design the superconductor requirements - i.e. the width and number of REBCO tapes required. The model self-consistently calculates the electromagnetic field as a function of the current density (A formulation). The results shown in Figure 9 provide the radius of the inner copper stabilizer in agreement with the overcurrent calculation as well as the distance to the outer phase and thus determine the geometric dimensions of the cable.

In order to identify suitable tape conductors for the production of the cable prototype, extensive ageing tests were also carried out on material compatibility in gas-

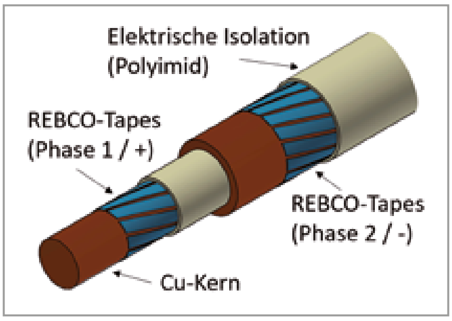

Fig. 9: Scheme of a 2-phase HTS-DC-cable.

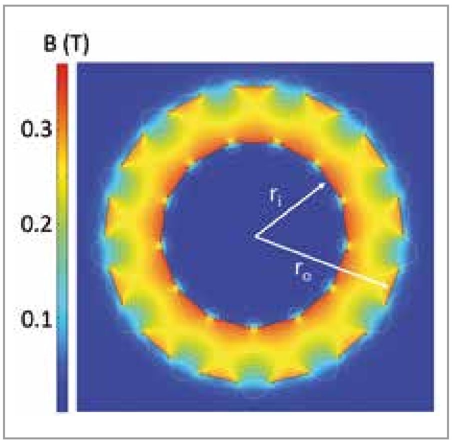

Fig. 10: Magnetic flux density B. ri = 7,4 mm, ro = 12 mm, Ic > 12 kA, 13 tapes per phase (width 3 mm).

eous hydrogen at room temperature. Figure 10 shows that the tapes from manufacturer B degrade after prolonged exposure to H2, while no effect on the critical current density was observed for manufacturer A. The observed effect will be analysed in further experiments.

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ROTATING MASCHINES

DUDA (DISK UP-DOWN ASSEMBLY)-COILS: A TOPOLOGY ON THE RISE

Systems that require compact magnets with high magnetic flux density, small dimensions, more efficient heat exchange and homogeneity of the material in the radial direction benefit greatly from this topology.

In 2023, the electromagnetic properties of DUDA coils and their AC losses in three-phase motors were discussed. By using simplified techniques such as parallel bifurcations and larger central openings, compact superconducting windings were created that showed a reduction in AC losses of up to 80 %.

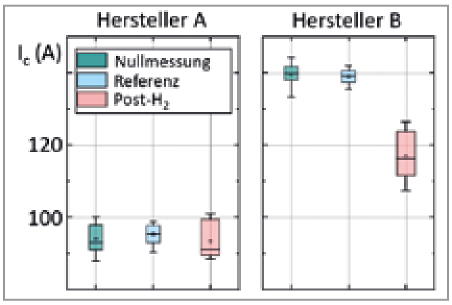

Fig. 11: Ic-measurements prior and post to a prolonged H2-exposition of REBCO-tapes by different suppliers.

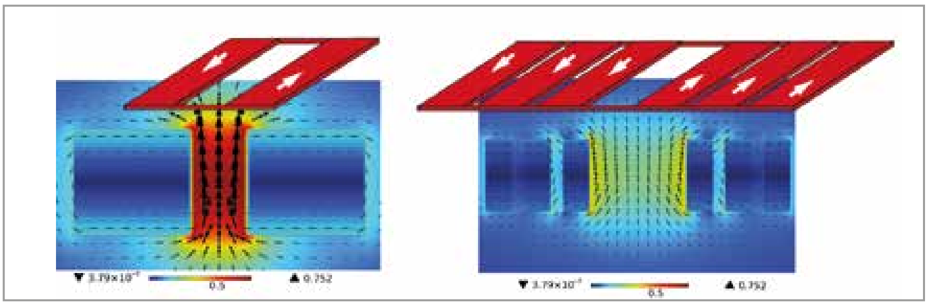

Fig. 12: Magnetic flux density [T] of a DUDA-coil by 50 tapes and a current of 90 A at 400 Hz. The left part shows a bore of 2 mm, the right part a bore of 10 mm. The distance between the 3-branch-topology is 0.75 mm.

Figure 11 shows the magnetic flux density in a stack with a DUDA coil consisting of 50 tapes. The central opening was 2 mm for the topology with one branch (left figure) and 10 mm for three branches (right figure).

The coils are shown as a thin line, the arrows represent the electrical current flow. The results of the AC current losses obtained by numerical simulation with a current of 90 A at 400 Hz and different opening widths and numbers of parallel branches are shown in Figures 12 and 13 respectively. An important conclusion from the results is that the opening must be enlarged depending on the frequency of the applied current. In addition, parallel branches should be used in systems with high current requirements in order to keep losses at an acceptable level.

Expectations for this new HTS coil topology and its use in electric motors are high. With low contact resistance, rectangular or disc-shaped forms and the possibility of completely new winding topologies, this technology promises an even more significant increase in motor efficiency thanks to lower losses and a higher magnetic flux density. Halbach aligned coils are particularly suitable for partially superconducting motors and enable a higher power density in these increasingly popular electrical machines.

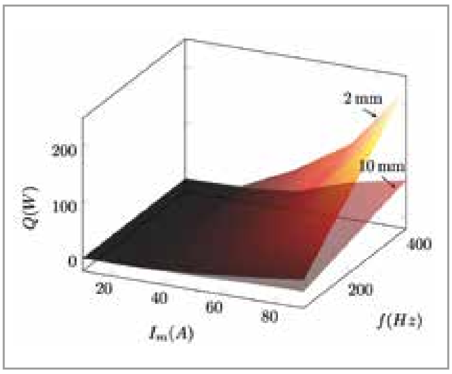

Fig. 13: AC-loss [W] in DUDA-coils by mit 50 tapes and a current of 90 A at 400 Hz, with only one branch and bores of 2 mm and 10 mm.

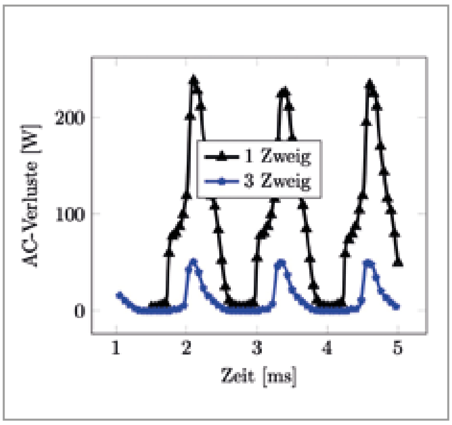

Fig. 14: AC-loss [W] in DUDA-coils by 50 tapes and a current of 90 A at 400 Hz for the 1-branch- and the 3-branch-topologie.

The production of coils with a high number of turns as well as the production of the superconducting stack levels present some challenges. HTS stacks can be used for the construction of motors with squirrel cage rotors, windings with a high number of parallel branches and lower losses.

SUPERCONDUCTING MOTORS: HIGH POWER DENSITY.

Superconducting motors are attractive for mobile applications such as monorails, airplanes and heavy-duty vehicles. The leading companies in these sectors are investing in the research and development of these electrical machines. In power generation, HTS machines are already being used in wind turbines, and advances in the production of 2G HTS tapes are supporting this development. The increasing importance of hydrogen in the energy system is also contributing to this trend. Auxiliary equipment, power electronics components and measurement sensors that complement control systems in cryogenic environments are developing rapidly.

Fully superconducting motors have been designed and simulated that have excellent performance for automotive applications. These motors generate a torque of 5 kNm and an output power of 260 kW (an example topology is shown in Figure 14). In a recent contract project, the DUDA coils were used in the field and armature windings, resulting in an efficiency of around 96%. The average AC losses per phase were estimated at 3.6 kW.

Usually, superconducting motors do not require ferromagnetic teeth, as their use in HTS machines offers no advantages due to saturation at magnetic fluxes of more than 2 T. However, studies carried out at ITEP suggest that ferromagnetic teeth can reduce AC losses in the armature winding of some machine types. This approach is based on DUDA coils in a semi-circular topology, whose concave or convex coil design (Figure 15) provides better results than conventional flat coils. The loss reduction can be up to 46 %.

This year, some superconducting machines were investigated, based on the 4 MW generator built by Siemens AG in 2012. Numerical simulation tools enable a detailed multi-physical analysis of the machines, including their electromagnetic, thermal and mechanical behavior. This also allows the geometry, use of materials and topology to be optimized.

Studies have also analyzed the topologies of partially superconducting motors with field winding in Halbach formation with DUDA-2G-HTS coils (Figure 16). It was found that motors with relatively low linear current density but with high magnetic field density can generate a torque of 6 kNm. These results were achieved with a significant reduction in rotor volume. The versatility of DUDA coils allows designers to realize machine windings with a wide range of magnetic field densities in small volumes.

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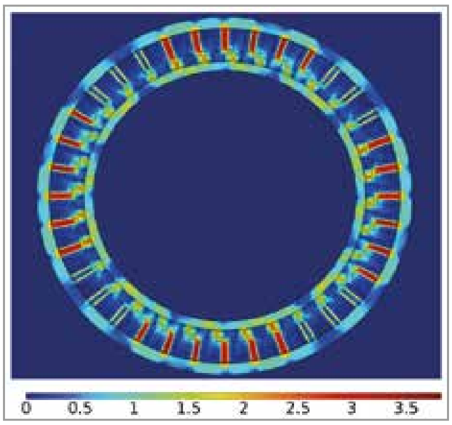

Fig. 15: Fully superconducting HTS-Motor with DUDA-Spulen in Rotor and Stator

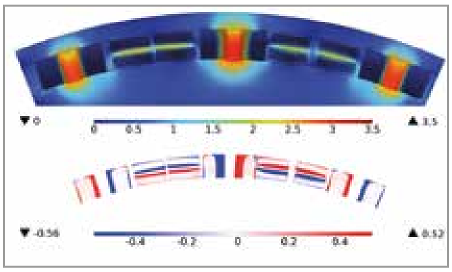

Fig. 17: Magnetic flux density [T] (top) and Jz/Jc (B) (bottom) of DUDA rectangular coils in a Halbach-configuration.

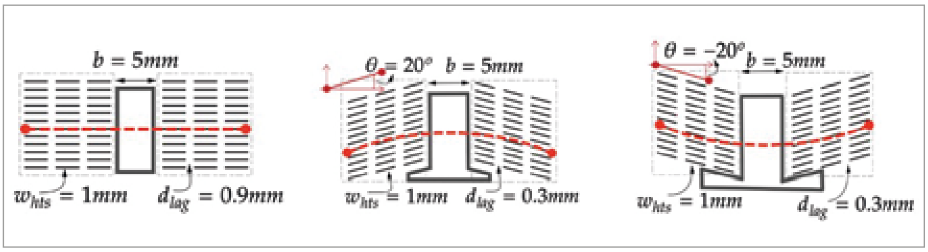

Fig. 16: DUDA rectangular coils with flat, concave or convex shape. Different shapes of teeth are shown, too.

Highlight

Preparation of an HTS fusion cable section for quench examinations

As part of the EU-CN collaboration agreement in the field of FUSION, ITEP is taking part in a measurement campaign to investigate the quench behaviour of HTS fusion conductors. Within this programme, samples with critical currents of ≤15 kA at 4 K and 11 T are to be tested by several research centres in the SULTAN facility of the Paul Scherrer Institute in Villingen, Switzerland. The aim of the test series is to gain a deeper understanding of quench propagation in HTS conductors for fusion applications. The geometry of the samples is specified by the system: it consists of two straight, approximately 3.6 m long sample legs that are connected in series via a clamping contact. The current path describes the shape of a "U", which means that both contacts of the sample to the system are at the same end of the sample. Each of the two legs is cooled by a separate helium cooling circuit. This design makes it possible to set individual test temperatures for each sample leg and to induce a targeted quench. This can be triggered either by a heater or by varying the helium temperature.

In 2023, the final stages of sample preparation were completed. These included the longitudinal welding to close the two stainless steel half shells of the jacket, the soldering of the connection contacts and the final assembly of the sample legs and the mechanical support to absorb the Lorentz forces of up to 165 kN/m during the experiment. The two sub-size fusion conductors consist of stranded HTS-CroCo triplets. A cross-section of the conductor can be seen in Figure 7. A temperature measurement system based on fiber Bragg gratings was set up and tested from 3.8 to 400 K in parallel with the sample production. This method enables a high sensor density with a small footprint, allowing temperature measurement directly on the superconductor inside the sample. A cascade of voltage taps and temperature sensors, both inside and on the jacket, should enable the quench propagation to be observed as accurately as possible.

At the end of the year, a functional test was successfully carried out at 77 K after completion of the sample. The critical current and all electrical contacts met expectations or were within the specifications for a successful test campaign in SULTAN. The critical current of the two legs was approximately 4800 A and 4500 A. The expected value was 4800 A without consideration of the magnetic fields of neighboring CroCos. The profile of the critical current along the sample is shown in Figure 6.

In spring 2024, two more cooling cycles down to 4.2 K are due to calibrate the glass fiber thermometers and the final leak test before shipping to Switzerland.

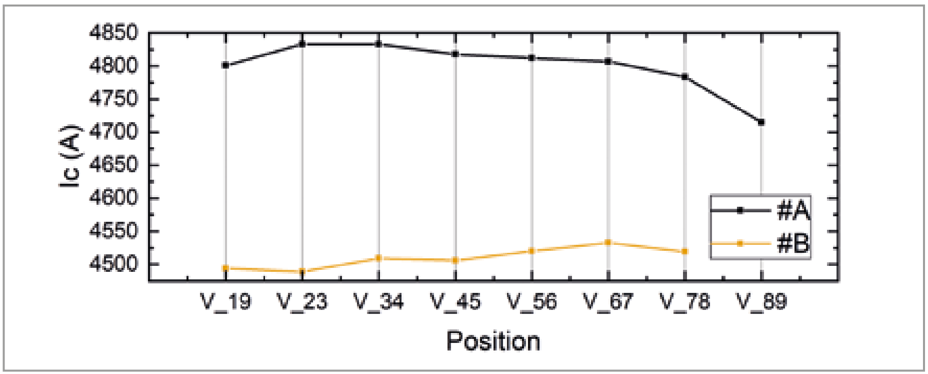

Fig. 19: Results of the Ic measurements along the sample. The difference between sample legs #A and #B is due to differences in the layout of the sub-conductors. In contrast to leg #A, the cross-shaped stack of the CroCo conductor in leg #B is additionally twisted.

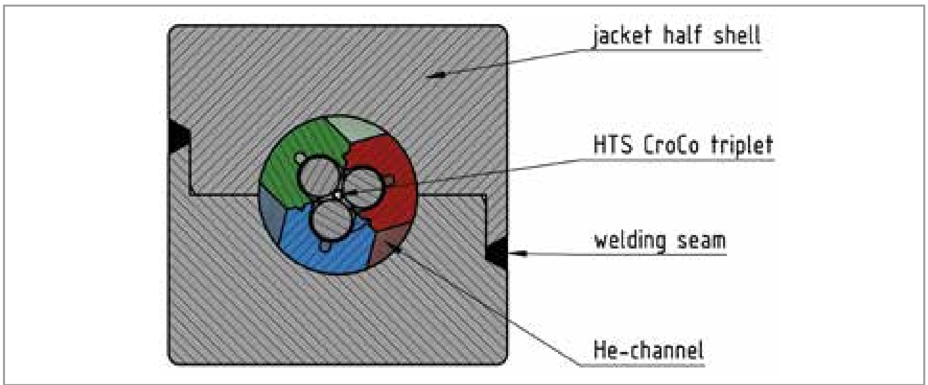

Fig. 18: Cross-section of the SULTAN cable conductor. The core consists of a CroCo triplet, with a copper profile soldered to each CroCo for stabilization. The jacket consists of two stainless steel half shells.

Results from the Research Areas

Gerd Fürniß, Martin Jäger and Jürgen Jung prepare the JASON set-up, the pre-experiment to DIPAK. JASON is named after the Greek hero who had to fight with Triton, just like us.

Technologies for the Fusion Fuel Cycle

Coordination: Dr.-Ing. Christian Day

In the research field "Fusion Fuel Cycle Technologies", ITEP is developing novel technologies to make the fuel cycle and associated neighbouring systems of a future fusion power plant more efficient, thereby ensuring that the tritium fuel produced in situ is optimally utilised. The research field covers all three key technologies of the fuel cycle: matter injection, vacuum technology and tritium processing technology.

The following research topics have emerged in the research field:

- Vacuum Technology and Process Integration,
- Rarefied Gas Dynamics,
- Vacuum Hydraulics and Hydrogen Separation.

The work is firmly anchored in the European Fusion Programme via the EUROfusion consortium, which will develop a concept design of the DEMO demonstration fusion power plant by 2027.

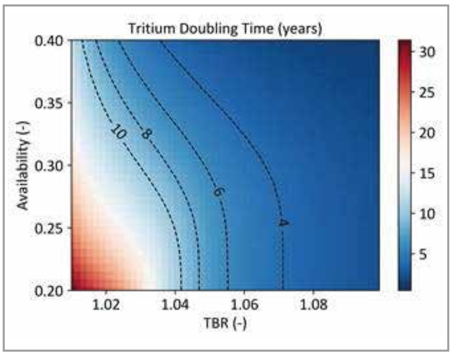

Fig. 1: Shown is the dependence of the time until the tritium inventory is doubled on the availability and the tritium breeding ratio, assuming a constant inventory of 2 kg for the operation of the fuel cycle.

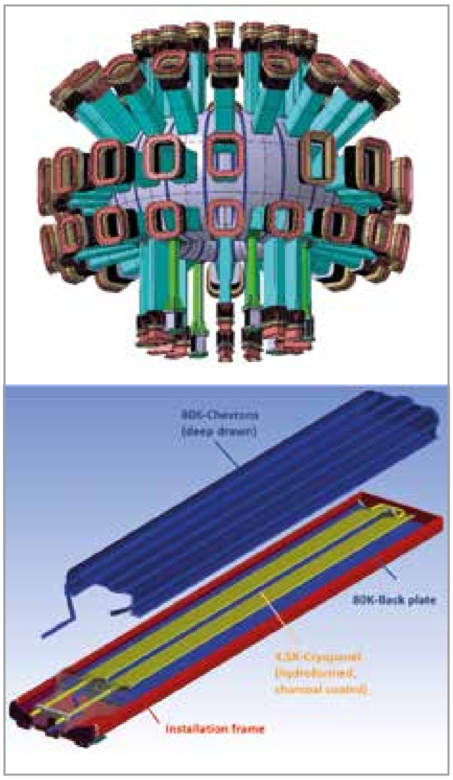

Fig. 2: The DTT vacuum vessel (for approx. 35 m³ plasma volume) with the lower vertical nozzles (top). Structure of the proposed cryopumps (bottom).

VACUUM TECHNOLOGY AND PROCESS INTEGRATION

The research topic "Vacuum technology and process integration" addresses all vacuum technology issues relating to a fusion facility and develops an integrative approach for their description. The work also covers vacuum technologies for other large-scale fusion facilities, such as the European neutron source IFMIF-DONES in Spain or the fusion experiments JT-60SA in Japan and DTT in Italy.

In 2023, the long-term development of the fuel cycle simulator was successfully completed. This is a tool based on the ASPEN process simulation software that describes all system blocks of the fuel cycle and the processes they contain in a self-consistent and time-dependent manner. This enables not only the dimensioning of subsystems or the identification and exploitation of optimization potential, but also the mapping of long-term processes in reactor operation. Figure 1 shows an example of a typical results plot for the life cycle of a fusion power plant. A key success factor for the roll-out of a fusion power plant-based energy generation strategy is to have the tritium inventory available for start-up before in-situ generation in the breeding blankets takes over tritium generation. Figure 1 illustrates how the overall plant availability and the tritium breeding ratio (the ratio of tritium produced to tritium consumed in the fusion reaction) contribute to minimizing the time required for tritium production.

Another focus of our work in 2023 was the further development of the cryopump vacuum systems at the Divertor-Test-Tokamak (DTT), a new fusion facility currently under construction near Rome in Italy, see Figure 2 (top).

DTT is to develop and demonstrate DEMO's divertor solution. The operation is without tritium, but to simulate a burning plasma, the divertor pump systems should also have a pumping speed for helium. This will be achieved using cryopump technology, which has been developed for ITER over many years in the Vacuum Technology Section at ITEP. In the present year, a concept design of the DTT cryopump system was initially developed, see Figure 2 (bottom). It comprises ten identical units that are installed in the lower vertical ducts of the machine. Each pump unit has two cryopanels, approximately 2 m long, which are arranged at an angle to each other and supplied with 4.5 K supercritical helium. A thermal shield is fitted towards the nozzle wall and a chevron shield is placed on the other side facing the gas load. The shields are operated at 80 K. The entire unit is arranged on a mounting frame, which ensures easy installation and removal.

The Vacuum Technology Section with its cryovacuum expertise is also involved in the Einstein Telescope (ET). The Einstein Telescope is a third-generation European gravitational wave detector that will be around 10 times more sensitive than today's instruments (LIGO, Virgo). The Einstein Telescope will be one of the largest ultra-high vacuum systems in the world.

The targeted improvement in sensitivity to gravitational waves for ET is based on the one hand on the fact that the pressure in the beam tubes should be significantly lower than in previous systems (10-10 mbar total pressure with partial pressures for heavy components below 10-14 mbar). On the other hand, the improvement in the low frequency range is essentially due to a cryogenically cooled detector mirror.
The gas particles impinging on the cryogenic mirror must be eliminated as far as possible, as they increase the background. Condensable species such as water must also be effectively pumped in order not to negatively influence the optical properties of the mirror and to keep the absorption of the laser energy acceptably low.

Figure 3 shows various simulations in which the cryopump lengths were varied on both sides of the cryogenic mirror. The resulting water partial pressures and the resulting operating times of the mirror until a monolayer is built up are shown. It can be seen that considerable cryopump lengths of several 10 m are necessary to ensure the target of one year of uninterrupted operation.

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RAREFIED GAS DYNAMICS

For the correct design of complex vacuum systems such as in the fusion fuel cycle, it is essential to be able to calculate rarefied gas flows quantitatively across all flow states. This is done exactly by solving the Boltzmann equation, which describes the flow in the entire range of rarefaction. To solve this equation for realistic applications (complex geometries, 3D, gas mixtures), various calculation tools have been developed at the Institute. Normally, the calculations are so complex that highly parallel supercomputers have to be used in order to arrive at convergence in an acceptable time (order of magnitude of weeks). For calculations in the divertor range, we have established the code DIVGAS.

In 2023, final calculations for the DTT divertor were carried out with DIVGAS. While in the concept development phase of the DTT vacuum systems in 2021 and 2022 it was only possible to roughly estimate the pumping speed achieved by the DTT cryogenic pumps, in 2023 the current design of the pumps was finally linked to the existing 3D model of the divertor, to hjave a fully accurate representation. As a result, we have shown that the collisionality of the flow (Knudsen numbers less than 1, see Figure 4) is sufficient to achieve a significantly higher pumping speed. This means that conductance-related losses in the divertor gaps can be almost completely compensated for. This is a very important result, as it confirms the

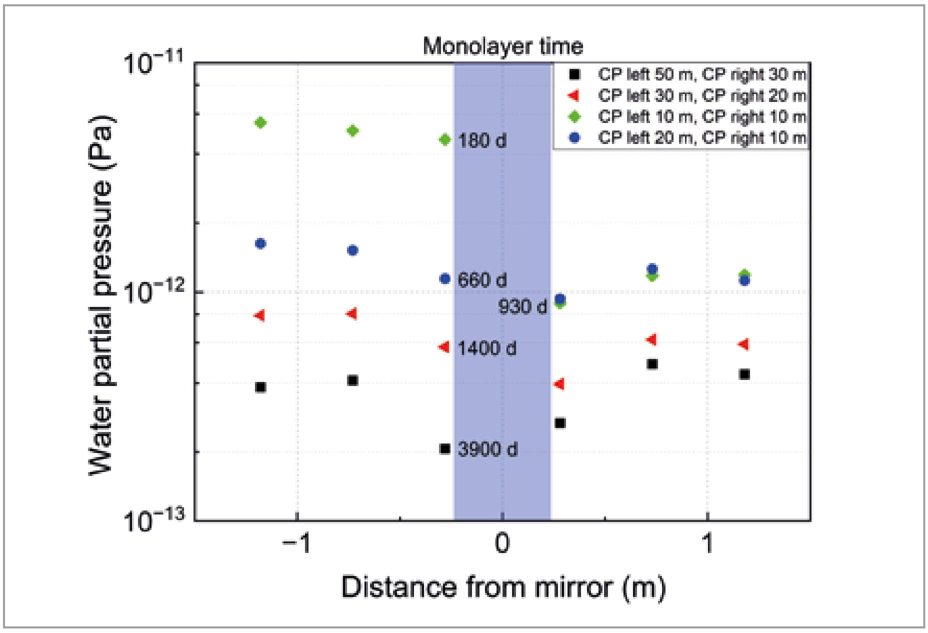

Fig. 3: Calculated water pressures in the environment of the cryogenic mirror.

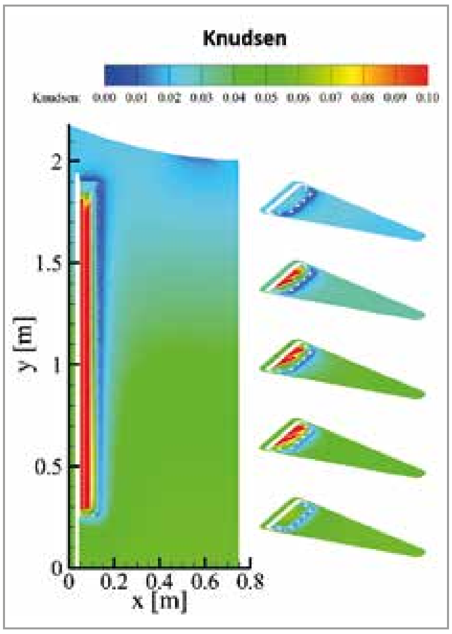

Fig. 4: Contours of the Knudsen number in one of the DTT pump ducts equipped with a cryopump.

experimental range tha machine can finally be operated at.

The divertor pump system of the W7-X stellarator was also further analyzed with DIVGAS in 2023. Together with the plasma physicists in Greifswald, we are trying to better understand how the island divertor used in W7-X operates, after it was discovered in the last test campaigns that the particle removal does not work as well as expected. Figure 5 shows the modelled section of the stellarator, which is equipped with cryopumps and turbopumps. The gray area in the sectional view in the lower part of the figure is the interface to the divertor, where the initial conditions of pressure and temperature are taken from plasma simulations.

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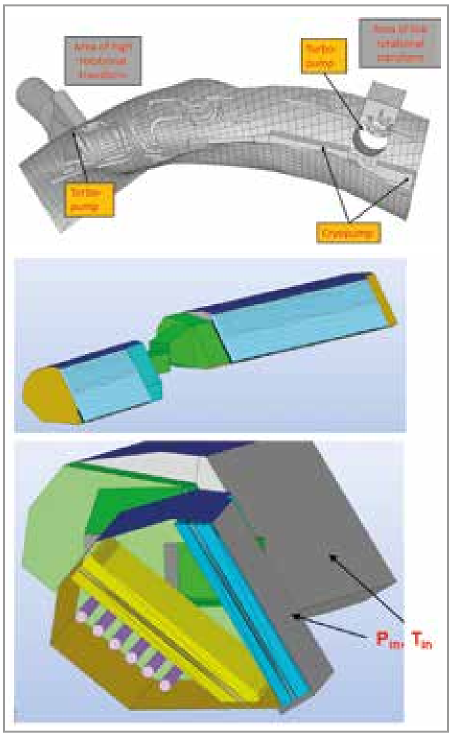

Fig. 5: Models of the divertor section of W7-X (top) and the cryopump (center). The section of the cryopump (bottom) shows pump elements at 4 K (pink), and shields at 80 K (yellow) and 300 K (light blue).

VACUUM HYDRAULICS AND HYDROGEN SEPARATION

The research topic "Vacuum hydraulics and hydrogen separation" includes work on hydrogen isotope separation through hydrogen-metal interactions as well as all work that deals with the flow behavior of liquids, especially liquid metals, in machines and processes under vacuum. The reference concept for the torus vacuum system of the European demonstration fusion power plant DEMO is based on three different pump types, which are being developed at ITEP exclusively.

Extensive simulations were carried out for the metal foil pump, which not only compresses the gas but also separates the majority of the unburned fuel in the exhaust gas, in order to derive scalable statements on the separation factor and pumping speed. For this purpose, a Test Particle Monte Carlo model was set up with a few specific parameters, the values of which were derived from experimental data from the HERMES system and our own parametric simulations of the plasma for generating the suprathermal particles. This made it possible to calculate various arrangements of plasma sources and metal foil surfaces in order to find the optimum configuration. In the next step, this will now form the basis for the design of a test pump in the DIPAK test facility described below.

Downstream of the metal foil pump is a combination of mercury-based diffusion pumps and associated rough vacuum pumps (ejector pumps, ring pumps). All pump types are new developments and have now reached an advanced design status. The current design of a three-stage linear diffusion pump is shown in Figure 6.

For further compression of the gas, ejector pumps are used, which are directly coupled to the diffusion pumps, see Figure 7. A test

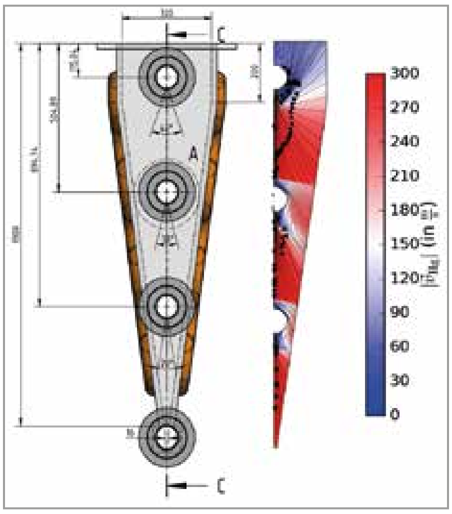

Fig. 6: Design of the mercury diffusion pump for DEMO, together with the streamlines of the mercury vapor.

design was developed for this, which is to be tested in the HgLab Karlsruhe.

In the field of hydrogen isotope separation using the thermal cycling process, a promising titanium-manganese-based alloy was found in collaboration with the Fraunhofer Institute, whose operating window fits well with the planned process in DEMO.

Over the next few years, the new developments described above will lead to prototype maturity. The next logical step will then be the construction and testing of the individual prototypes in their interaction in the fuel cycle. In order to be able to correctly map the dynamics of the overall process, it is necessary to completely realize the two inner of the three circuits, i.e. including the material supply via pellet injection. This requires a separate test environment. It is provided in the large-scale project DIPAK (Direct Internal Recycling Integrated Development Platform Karlsruhe), which has now gained momentum. During the reporting period, the construction project to provide the test hall was launched, as was the procurement of the central test vessel, which will simulate the torus of a

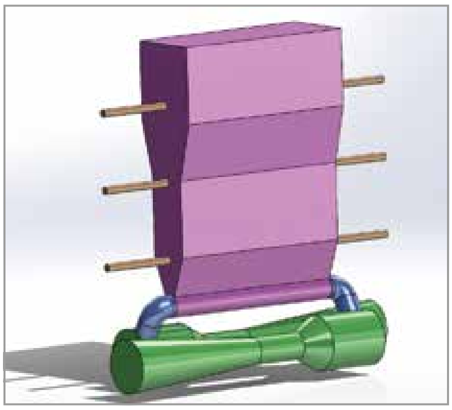

Fig. 7: Concept for the integration of a diffusion pump (pink) with an ejector pump (green).

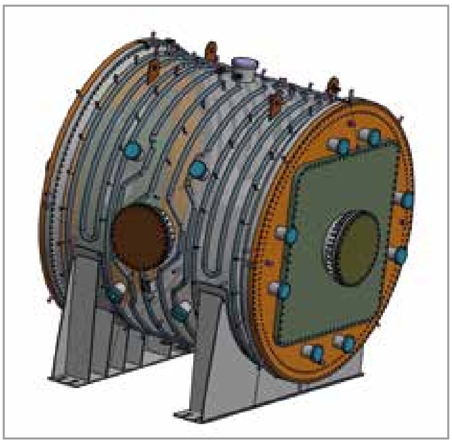

Fig. 8: The central test vessel of DIPAK.

Fig. 9: The JASON facility, a pre-experiment for DIPAK.

future fusion power plant, see Figure 8. It is an electropolished and all-metal sealed high-vacuum container made of stainless steel with a volume of around 20 m³ (LxD=3.5 m x 3.5 m) and a total weight of around 20 tons. The rectangular flanges on both sides of the vessel have a size of 2 x 2 m and therefore allow also the testing of pump casks for ITER or DEMO in 1:1 dimensions.

DIPAK is not expected to be completed before 2027. To make use of the time until then, we will characterize a novel, purely European design of a tritium-compatible reactor-relevant pellet injection system in a dedicated pre-experiment to DIPAK, called JASON.

A suitable centrifuge must be developed to accelerate the pellets. The test of this technology will therefore take place in a bunker that was originally built for the HTS-GENO project at the Institute. Figure 9 shows the JASON setup with the container in the foreground and the bunker in the background. Construction of the pellet injector and the necessary test infrastructure should be completed by 2025.

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Highlight

Divertor cryopumps for JT-60SA delivered

In a project lasting several years, the divertor pump system for the JT-60SA fusion machine in Japan was designed, constructed and finally built and successfully accepted together with Fusion for Energy and industrial partners.

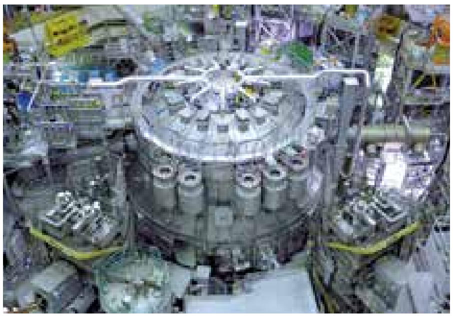


Fig. 10: The tokamak JT-60SA.

JT-60SA, see Figure 10, with a plasma volume of about 130 m³, is the largest superconducting tokamak besides ITER and pursues the ultimate goal of finally clarifying the open questions about the long-pulse operation of a tokamak.

The large-scale plant is located in Naka, Japan, on the site of the former JT-60U fusion machine. It is currently in its first operating phase. In 2024, the machine will be retrofitted with additional technical systems. This includes a powerful divertor pump system, which the Vacuum Section at the Institute is responsible for providing together with the fusion agency 'Fusion for Energy'. The pump project can be divided into three different phases.

Concept development phase (2012–2017). The JT-60SA project was initiated in 2007 as part of the "Broader Approach" agreement between the EU and Japan. The Vacuum Section has been involved in the development of the scientific program and the definition of the required technologies since 2012. As part of this work, the requirements for the divertor pump system could be defined. Deviating from the original plan to use cryocondensation pumps,

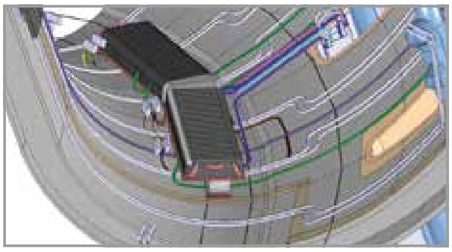


Fig. 11: The cryopump in the JT-60SA vacuum vessel.

the decision was made in 2017 in favor of a cryosorption system with activated carbon-coated 4 K pump surfaces. This required extensive calculations to predict the operating window of the pumps and to derive an initial cost estimate to check the plausibility of the effort required for manufacturing and operation.

Design phase (2017–2020). In several development stages with corresponding design reviews, a 3D CAD package with all individual parts, see Figure 11, and a set of 2D production drawings were finally developed. Based on this design, 'Fusion for Energy' carried out a tender and finally placed an oder for manufacturing at the German manufacturer Research Instruments.

Manufacturing phase (2021–2023). A total of 10 identical cryopumps were manufactured, together with a 'practice' cryopump to validate the manufacturing steps and their test procedures. Figure 12 shows the central elements of the cryopump. At its heart are the cryopanels, two of which are installed in each 'pump wing'. They are coated with activated carbon so that helium can be pumped well at the intended operating temperature of 3.8 K. There is a

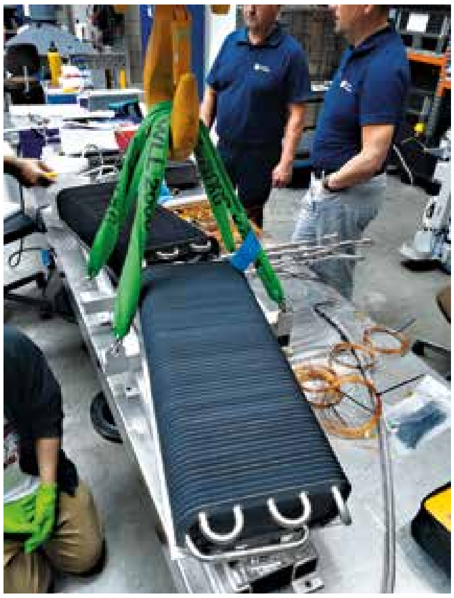


Fig. 12: The central construction elements of the cryopump: Panel (top), back shield (center) und front baffle (bottom).

closed thermal shield at 80 K on the back of the panel and a chevron baffle open to particles on the front.

In the course of production, a number of individual manufacturing steps had to be redeveloped. Nevertheless, the time had come on October 3, 2023: all cryogenic pumps had been delivered to Japan and had successfully passed the incoming inspection.

Honours and Awards

In 2023, the following awards, honors and prizes were presented to ITEP employees for their work.

In September 2023, our doctoral student **Quoc Hung Pham** was awarded the "ESAS Young Researcher Award" at the European Conference on Applied Superconductivity EUCAS2023 in Bologna. His conference paper entitled "Switching device with magnetically triggered high-temperature superconductors" is thus highlighted as the best contribution by a young scientist in the field of high-current applications. In this paper, Mr. Pham presents the world's first bridge circuit based on the dynamic resistance of high-temperature superconductors.

Fig. 1: Quoc Hung Pham (Mid) at the award ceremony

Prof. Dr. Tabea Arndt was awarded the IEEE Prize for Continuous and Significant Contributions in Applied Superconductivity at the Magnet Technology Conference in Aix-en-Provence in September 2023.

This award recognizes the many years of outstanding technical and scientific contributions and developments by individuals in the field of applied superconductivity. These include the development of the first generation of high-temperature superconducting tapes with very long lengths and to the highest industry standards, the supply of first-generation high-temperature superconductors for the LHC power supplies at CERN and the demonstration of superconducting Roebel cables in large-scale energy applications and her contributions to numerous high-temperature superconducting first applications such as MRI magnet demonstrators, fully integrated fault current limiters, rotating electrical machines for ships, airplanes and turbo generators, transformers for railroads and coils for industrial applications.

Fig. 2: Prof. Dr. Tabea Arndt (Mid) at the award ceremony

W1 TT Prof. Dr. Giovanni de Carne was appointed to a W3 professorship "Real-time energy systems" at our institute. His successes as a W1 professor and in the Helmholtz Young Investigator Group on the topic of "Hybrid Networks: a multimodal design for the future energy system" have contributed significantly to this. This ensures the long-term integration of his work in this field and once again recognizes the scientific quality of Prof. Giovanni de Carne.

Fig. . 3: Prof. Dr. Giovanni de Carne

We are very pleased about this recognition of the exceptionally good performance of our employees and thank them very much for their excellent work.

Dr. Carsten Räch

Investigation of AC losses of different high-temperature superconducting multi-tape concepts for three phase high-current applications

Given the energy transition in Germany and a general increase in electrical loads on the german grid, network operators face the significant challenge of providing reliable energy transmission. Conventional transmission technologies with VPE-insulated cables or overhead lines are often limited in their transmission capacity. Additionally it requires a substantial amount of space.

The use of superconducting cables is an alternative that has already been successfully implemented in projects worldwide. High-temperature superconductors enable high transmission power with significantly reduced space requirements and lower cooling costs. This means that power that was previously reserved for the high and extra-high voltage level can now also be transmitted at the medium voltage level.

For a three-phase superconducting medium-voltage cable with a transmission capacity of 173 MVA, differ-ent HTS multi-conductor concepts and their AC losses are investigated in this thesis. Attention is paid to a compact and loss-reduced design. In order to avoid capacitive asymmetries, a symmetrical installation of the phases in a three-wire arrangement is also assumed instead of the typical coaxial design. The individual phases are designed for a rated current I_{rms}=5 kA at a rated voltage of U_n=20 kV. The cable is cooled with liquid nitrogen (LN2), which is also used as a liquid die-lectric between the phases. The absence of other insu-lating materials results in a space-saving cable design. A multi-conductor arrangement consisting of cross-conductor arrangements (CroCo), stack arrangements or conductor-on-round-core arrangements (CorC) is used as the phase conductor. REBCO tapes, i.e. high-temperature superconductors (HTS), are used in all three arrangement variants. The aim is a loss-optimized and compact three-phase cable.

An adapted numerical calculation method based on the method presented by Brandt will be used to calculate the AC losses. Calculation models of superconductivity in combination with Maxwell's equations are set up in integral form as a system of ordinary differential equa-tions. The ordinary differential equations are only solved for the superconducting region, which drastically reduc-es the number of calculation nodes compared to a finite element method (FEM). The method can be used for two-dimensional models, such as a stack or CroCo arrangement, as well as for the three-dimensional model of a CorC arrangement. The results of the calculation models are compared with results from the literature. A final comparison of the three multi-conductor concepts shows that the use of CorC arrangements drastically reduces the required number of strip conductors com-pared to stack or CroCo arrangements. Ultimately, this also minimizes the cross-section of the three-phase cable.

In the final section, the critical current and the electrical losses of a CroCo and a CorC arrangement are deter-mined using a practical test setup. The values meas-ured in this way can be easily reproduced using the mathematical methods presented above. In addition, the CroCo arrangement already shows losses greater than 1 W/m as soon as the effective current reaches 20 % of the critical current, whereas similar losses only occur with a CorC arrangement from 55 % of the critical current.

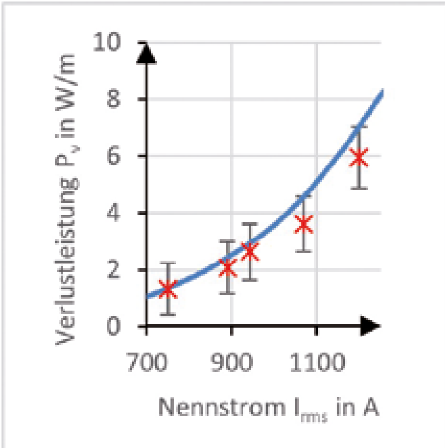


Fig. 1: Measured and calculated AC loss of a CroCo test conductor

Lectures, Seminars, Workshops

KIT-Fakultät Elektrotechnik und Informationstechnik

- **Projektmanagement für Ingenieure** (Noe, Day) SS 23
- **Praktikum Supraleitende Materialien** (Holzapfel, Hänisch) WS 22/23, SS 23, WS 23/24
- **Energy Storage and Network Integration** (Grilli, De Carne) WS 22/23, WS 23/24
- **Tutorial for Energy Storage and Network Integration** (Grilli, De Carne) WS 22/23, SS 23
- **Superconductivity for Engineers** (Holzapfel, Kempf) WS 22/23, SS23, WS 23/24
- **Exercise for superconductivity for Engineers** (Hänisch) WS 22/23, WS 23/24
- **Seminar on Applied Superconductivity** (Arndt, Holzapfel, Kempf) WS 22/23, SS 23, WS 23/24
- **Superconducting Materials Part I** (Holzapfel) WS 22/23, SS 23, WS 23/24
- **Superconducting Materials Part II** (Holzapfel) SS 23
- **Superconducting Magnet Technology** (Arndt) SS23
- **Seminar Strategieableitung für Ingenieure** (Arndt) WS 22/23, WS 23/24
- **Superconducting Power Systems** (Arndt, Pham, Müller, Grilli, Schreiner, De Sousa) WS 22/23
- **Praktikum Robotische Wickeltechnik für Supraleiterdrähte** (Arndt) WS 22/23, WS 23/24
- **Superconductors for Energy Applications** (Grilli) WS 22/23, WS 23/24
- **Übungen zu Superconductors for Energy Applications** (Grilli) WS 22/23
- **Electrical and Electronic Engineering for Mechanical Engineers** (De Carne) WS 22/23, WS 23/24
- **Tutorial Electrical Engineering and Electronics for Mechanical Engineers** (Grilli) WS 23/24
- **Accelerators and Detectors – Future Technologies for Research and Medicine** (Holzapfel) SS 23

KIT-Fakultät für Chemieingenieurwesen und Verfahrenstechnik

- **Vakuumtechnik** (Day, Varoutis) WS 22/23, WS 23/24
- **Übung zu Vakuumtechnik** (Day, Varoutis) WS 22/23

KIT-Fakultät Maschinenbau

- **Fusionstechnologie A** (Day, Größle, Fietz, Weiss, Wolf) WS 22/23
- **Magnet-Technologie für Fusionsreaktoren** (Weiss, Wolf) SS 23
- **Angewandte Kryo-Technologie** (Neumann, Weiss) SS 23

House of Competence

- **„Netzwerken – Verbindungen schaffen Freiheiten"** (Arndt), Tagesworkshop; WS 22/23

Seminare

Kryo-Seminare

- **23.–24.03.2023:** DKV-Seminar Kühlung von Rechenzentren (Neumann)
- **04.–05.05.2023:** DKV-Seminar Kältemittel (Neumann)
- **13.–15.09.2023:** VDI-Seminar Kryotechnik (Neumann)
- **27.–29.09.2023:** HdT-Seminar Kryostatbau (Neumann)
- **18.–19.10.2023:** DKV-Seminar Grundlagen der Kälte-, Klima- und Wärmepumpentechnik (Neumann)

Duale Hochschule BW – Fachbereich Maschinenbau

- **Arbeitssicherheit und Umweltschutz** (Bauer) WS 22/23

Completed PhD Theses

(* Academic supervisor)

ENERGIE

Carsten Räch
Entwicklung von hocheffizienten modularen Hochstromsystemen auf Basis von Hochtemperatursupraleitern zur Übertragung großer Leistungen von Windparks auf Mittelspannungsniveau
Betreuer: Prof. Dr.-Ing. M. Noe (KIT, ETIT)*

Completed Master Theses

(* Academic supervisor)

ENERGIE

Marco Verlohner
Implementation and Validation of Grid Codes Compliant Inverter for Grid Storage Applications
Betreuer: Prof. Dr. R. Bojoi (Politecnico di Torino), Prof. Dr. G. de Carne*

Fan Wu
Development of a Communication Architecture for Real-Time Application
Betreuer: M. Courcelle, Dr. G. de Carne*

Jan Hendrik Wüpper
Modelling Accuracy Evaluation of Power Electronics Converters for Power System Analysis
Betreuer: Prof. Dr. G. de Carne, Prof. Dr.-Ing M. Noe*

VAKUUM

Federico Constantin
A layout of the tritium subsystems for the European demonstration fusion power plant
Betreuer: Dr. T. Giegerich, Dr. C. Day

MATERIAL

Celine Apfelbach
Entwicklung des Brückenmoduls „Kernphysik“ für einen Quantenmechanik-Seminarkurs am KIT-Schülerlabor Energie
Betreuer: A. Rimikis, Prof. Dr. B. Holzapfel*

Julian Bell
Entwicklung des Moduls „Klima“ eines dualen Quantenmechanik-Seminarkurses am KIT-Schülerlabor für das Fach Geographie
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel*

Dawid Ciszewski
Superconductor Film Growth Tests of a Newly Commissioned Industrial High Temperature Superconductor R&D Deposition Line for High-field Coated Conductors with Application in Fusion-relevant Devices
Betreuer: Prof. Dr. B. Holzapfel*

Completed Bachelor Theses
(* Academic supervisor))

ADMIN

Marcel Armbruster
Machbarkeitsstudie zur Wirksamkeit eines zertifizierten Energiemanagementsystems in einem Forschungsinstitut
Betreuer: K. Bauer, Prof. Dr. D. Eidam (DH)*

Luca Tobler
Entwicklung eines praxisorientierten Leitfadens zur sicheren Installation und Nutzung von Wasserstofftestanlagen
Betreuer: Dr. K.-P. Weiss, Dipl.-Ing. Kohl (DH)

MATERIAL

Fabian Follner
Entwicklung für eines didaktischen Konzepts für die Station „Wirbelstrombremse" im KIT – Schülerlabor Energie
Betreuer: Dr. A. Jung, Dr. J. Hänisch, Prof. Dr. B. Holzapfel*

N.N.
Optimierung und Aufbau eines Elektromotors in modularer Bauweise im KIT-Schülerlabor Energie
Betreuer: A. Rimikis, Prof. Dr. B. Holzapfel*

ENERGIE

Antonia Huber
Development of a Communication Architecture for Real-Time Application
Betreuer: M. Courcelle, Prof. Dr. G. de Carne*

KRYO

Pascal Kubis
Entwicklung eines Wärmeübertragers zum Anwärmen von tiefkaltem gasförmigen Wasserstoff
Betreuer: S. Bobien, Dr. H. Neumann

Thomas Mack
Konstruktion einer kapazitiven Füllstandssonde für flüssigen Wasserstoff
Betreuer: S. Bobien, Dr. H. Neumann

MAGNET

Antonia Huber
Studie zum Einsatz von durchgehend kontaktierten Hochtemperatursupraleiter-Bandstapeln in kompakten Magneten
Betreuer: Dr. M. Kläser, Prof. Dr. T. Arndt*

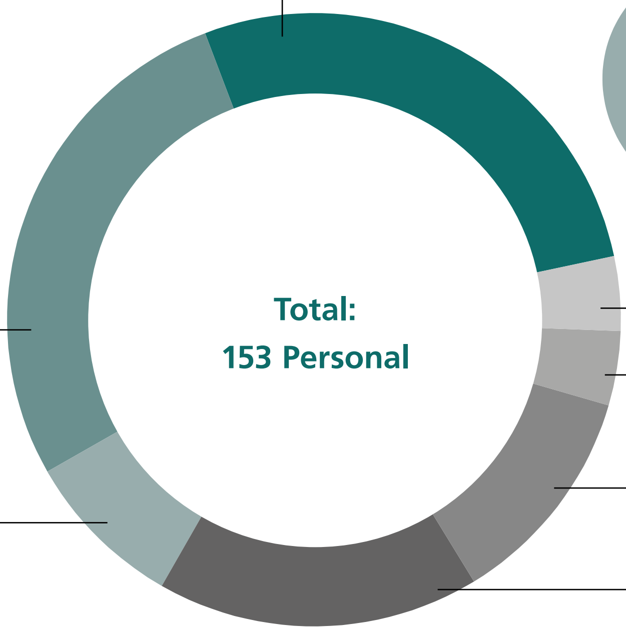
Figures, data, facts

Research Fields and Topics

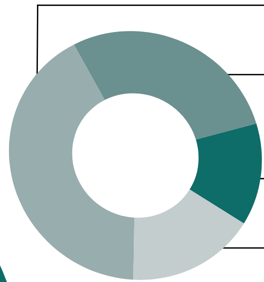
Superconducting and Cryomaterials (Holzapfel)	**Energy Applications** (Noe)	**Superconducting Magnet Technology** (Arndt)	**Fusion Fuel Cycle Technologies** (Day)
Superconducting Materials (Hänisch)	Superconducting Power System Components (Noe)	Coil and Magnet Technology (Hornung)	Vacuum Technology and Process Integration (Day)
Conductor Concepts and Technologies (Holzapfel)	Modelling of Superconductors and Components (Grilli)	High Current Components for H_2 and Fusion (Wolf)	Rarefied Gas Dynamics (Varoutis)
Materials for Cryogenic Applications (Weiss)	Real-Time System-Integration (De Carne)	Rotating Machines (Arndt)	Vacuum Hydraulics and Hydrogen Separation (Giegerich)

Personnel Status (m/f/d)

(December 31, 2023)



Additional staff in 2023:



Guest Researcher

K. Liu
09.01.–14.12.23
Southwest Jiaotong University, Chengdu, P.R. China

C. Iurlaro
16.01.–31.07.23
Polytechnic University of Bari, Bari, Italien

Z. Huang
13.04.–19.09.23
Southwest Jiaotong University, Chengdu, P.R. China

Ye Hong
13.04.–19.09.23
Southwest Jiaotong University, Chengdu, P.R. China

Dr. P. Zhou
23.08.21–22.08.23
Southwest Jiaotong University, Chengdu, P.R. China

A. Hussain
12.09.–29.11.23
Slovak University of Technology, Bratislava, Slowakei

F. Reissner
17.09.–20.10.23
Tel Aviv University, Tel Aviv, Israel

M. Di Pietrantonio
18.09.23–18.03.24
University of Tuscia, Tuscia, Italien

Lectures and Guest Presentations

21. Januar 2023,
Future-Proof Power Electronic Systems for Residential Microgrids
Prof. Dmitri Vinnikov, Dr. Andrii Chub, TalTech, Estland
Gastvortrag, IB Energie

14. Juli 2023
Resilient Micro-grids for the More Electric Aircraft
Prof. Buticchi, from Nottingham University Ningbo, China
Gastvortrag, IB Energie

16. November 2023
REBCO Coatings for High-Gradient RF Applications
Sergio Calatroni, Cern, CH
Gastvortrag, IB Material

Memberships

of relevant technical and scientific organisations

Tabea Arndt

- Programmkomitee der Tagung ZIEHL, 10.-11.04.2024, Berlin
- International Organizing Committee Conference Magnet Technology, MT
- International Organizing Committee Conference EUCAS, Large Scale
- Mitglied DKE TC90
- Delegierte zum Technology Cooperation Program High-Temperature Superconductivity der International Energy Agency
- Kuratorin BMWK „Forschungsfeld Hochtemperatur-Supraleitung
- Member program board

Nadja Bagrets

- Expertin innerhalb des Arbeitsfeldes TWA16 der VAMAS (Versailles Project on Advanced Materials and Standards bei ISO) zur Durchführung von Ringversuchen
- Expertin im Komitee K 184 „Supraleiter" der deutschen Kommission Elektrotechnik (DKE) im DIN
- Expertin im technischen Komitee TC90 „Supraleiter", Arbeitsgruppe WG5 der internationalen elektrotechnischen Kommission (IEC)

Kai Bauer

- Mitglied im Helmholtz-Arbeitskreis HSE „Health, Safety and Environment"
- Mitglied der Prüfungsausschüsse der Dualen Hochschule Baden-Württemberg, Standort Karlsruhe in den Fachbereichen „Maschinenbau" und „Wirtschaftsingenieurswesen"

Christian Day

- Mitglied des Vorstandsrates der Dt. Vakuumgesellschaft (DVG).
- Projektleitung des Bereichs Tritium-Materiezufuhr-Vakuum (TFV) im Europäischen Fusionsprogramm EUROFUSION
- Sprecher Topic ‚Vakuum und Tritium' der deutschen DEMO-Initiative
- Mitglied im International Advisory Committee der RGD (Rarefied Gas Dynamics Conference)
- Mitglied des Programmkomitees der ISFNT (international Symposium of Fusion Nuclear Technology).
- Chartered Engineer der American Vacuum Society (AVS).
- Mitglied im Team zur Erarbeitung des Forschungsplans von DTT, verantwortlich für Fusionstechnologie.

Giovanni de Carne

- Leiter des IEEE Power and Energy Society "Task Force on Solid State Transformer integration in distribution grids"
- Helmholtz Nachwuchsgruppen-Leiter – 2020
- Chairman der IEEE PES Task Force "Solid State Transformer integration in distribution grids"
- Sekretär und Mitglied der CIGRE Arbeitsgruppe B4.91 "Power electronics-based transformer technology, design, grid integration and services provision to the distribution grid"
- Mitglied der CIGRE Arbeitsgruppe A3.40 "Technical requirements and field experiences with MV DC switching equipment"
- Mitglied der IEEE Arbeitsgruppe P2004"Hardware in the Loop".
- Mitglied der IEEE Arbeitsgruppe "Modelling and Simulation with High Penetration of Inverter-Based Renewables"
- Subject Editor der IET Zeitschrift „IET Generation, Transmission & Distribution"
- Assozieirter Editor der IEEE Zeitschrift „IEEE Open Journal for Power Electronics"
- Assoziierter Editor der IEEE Zeitschrift "IEEE Industrial Electronic Magazine"
- Assoziierter Editor der Springer Zeitschrift "Electrical Engineering – Archiv für Elektrotechnik"
- Mitglied beim „Institute of Electrical and Electronics Engineers"
- Mitglied beim Verband der Elektrotechnik, Elektronik und Informationstechnik

Francesco Grilli

- Vorstandsmitglied der Europäischen Gesellschaft für angewandte Supraleitung (ESAS)

Jens Hänisch

- Superconductor Science and Technology, Mitglied im Editorial Board
- European Magnetic Field Laboratory EMFL, Mitglied im User Proposal Selection Committee

Bernhard Holzapfel

- European Conference on Applied Superconductivity, Member of International Program Committee
- International Symposium on Superconductivity (ISS), Member of International Program Committee
- Member of the Scientific Advisory Board of ICMAB-CSIC
- Coated Conductor for Applications (CCA), Member of International Program Committee

Holger Neumann

- Member of the ICE Commitee
- Altvorsitzender des DKV
- Gastprofessur in China an der Zhejiang University in Hangzhou (China)

Mathias Noe

- Deutscher Abgesandter der International Energy Agency, Technology Cooperation Programm Hochtemperatur-Supraleitung
- Mitglied des internationalen Beratungsgremiums des IRIS Projektes
- Mitglied des Interessenverbandes Supraleitung (ivsupra)
- Mitglied beim Verband der Elektrotechnik, Elektronik und Informationstechnik

Sonja Schlachter

- Mitglied des „International Cryogenic Material Conference (ICMC) Board of Directors“
- ICMC Conference Chair bei der CEC/ICMC Conference 2023, 9.–13. Juli 2023, Honolulu, HI
- Technischer Editor der Zeitschrift IEEE Transactions of Applied Superconductivity

Wescley T. B. de Sousa

- Vorstandsmitglied des „HTS Modelling Workgroup“.
- Vorstandsmitglied des COST ACTION CA19108 – „High-Temperature Super-Conductivity for AcceLerating the Energy“
- Experte in der CIGRE Arbeitsgruppe B4/A3.86 – Strombegrenzungstechnologien für DC-Netze
- Technischer Editor der IEEE Zeitschrift IEEE „Transactions on Applied Superconductivity“

Stylianos Varoutis

- Mitglied im Auswahlkomittee des EU High Performance Computers MARCONI
- Mitglied im Europa/Japan-Auswahlkommittee für Großrechnersimulationen im „Broader Approach“
- Mitglied der Deutschen Vakuumgesellschaft (DVG)
- Vorsitzender des Fachverbandes Vakuumphysik und –technik der Dt. Physikalischen Gesellschaft (DPG).

Klaus-Peter Weiss

- DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE Referat K 184 „Supraleiter“, Obmann
- IEC International Electrotechnical Commission/Technical Comittee 90 „Superconductivity“, Mitglied
- DIN NA 062-01-42 AA „Zug- und Duktilitätsprüfung für Metalle“ Mitglied
- ISO ISO/TC 164/SC 1 “Uniaxial Testing” Mitglied
- Member of the International Technical Program Committee – Workshop on Mechanical and Electromagnetic Properties of Composite Superconductors
- Board Member ICMC (International Cryogenic Materials Conference) & Subcommittee International Cryogenic Material Library
- ICMC Program Chair bei der CEC/ICMC Conference 2023, 9.–13. Juli 2023, Honolulu, HI
- Experte im EUROfusion Scientific & Technical Adivisory Committee (STAC)

Fusion

Journal article

S. Hanke, Chr. Day, T. Giegerich, et al.
Experimental Characterization of an NEG Pump of Novel Size – A Major Step toward Its Application in DEMO Neutral Beam Injectors, Energies 16 (2023) 3148.
Doi: 10.3390/en16073148 // open access

C. Tantos, V. Hauer, S. Varoutis, et al.
3D numerical study of neutral gas dynamics in the DTT particle exhaust using the DSMC method, Nucl. Fusion 64 (2024) 016019.
Doi: 10.1088/1741-4326/ad0c80 // open access

C. Tantos, E. Kritikos, S. Varoutis, et al.
Kinetic modeling of polyatomic heat and mass in rectangular microchannels, Heat and Mass Transfer 59 (2023) 167–184.
Doi: 10.1007/s00231-022-03224-z // open access

Y. Kathage, A. Vazquez Cortes, S. Merli, et al.
Experimental Progress in the Development of a Metal Foil
Pump for DEMO, Plasma 6 (2023) 714–734.
Doi:10.3390/plasma6040049 // open access

B. Ploeckl, P.T. Lang, Chr. Day, et al.
Testbed for the Pellet Launching System for JT-60SA, Fusion Engineering and Design 186 (2023) 113370.
Doi: 10.1016/j.fusengdes.2022.113370 // Open Access

B. Ploeckl, P.T. Lang, Th. Giegerich, et al.
Proposal of a control scheme for testing a centrifuge-based pellet injection system in DIPAK-PET, Fusion Engineering and Design 199 (2024) 114142.
Doi: 10.1016/j.fusengdes.2023.114142 // Open Access

P.T. Lang, L.R. Baylor, R. Dux, et al.
Admixed pellets for fast and efficient delivery of plasma enhancement gases: investigations at AUG exploring the option for EU-DEMO, Fusion Engineering and Design 196 (2023) 114020
Doi: 10.1016/j.fusengdes.2023.114020 // Open access

P. T. Lang, M. van Berkel, W. Biel, et al.
Targeting a Versatile Actuator for EU-DEMO: Real Time Monitoring of Pellet Delivery to Facilitate Burn Control, Fusion Science Technology 80 (2024) 24-37.
Doi: 10.1080/15361055.2023.218893 // open access

I. Ivanova-Stanik, P. Chmielewski, Ch. Day, et al.
Divertor power spreading in the Divertor Tokamak Test facility for a full power scenario with Ar and Ne seeding, Plasma Physics Controlled Fusion 65 (20239) 055009.
Doi: 10.1088/1361-6587/acc2e3 // open access

J.C. Schwenzer, A. Santucci, Chr. Day
Modeling of the HCPB Helium Coolant Purification System for EU-DEMO: Process Simulations of Molecular Sieves and NEG Sorbents, Fusion Science Technology 79 (2023) 1208-1218.
DOI: 10.1080/15361055.2023.2189550

T. Teichmann, X. Luo, T. Giegerich, et al.
Study of the Effective Torus Exhaust High Vacuum Pumping System Performance in the Inner Tritium Plant Loop of EU-DEMO, Fusion Science Technology (2023)
Doi: 10.1080/15361055.2023.2229679 // open access

E. Sartori, M. Siragusa, P. Sonato, et al.
Development of non evaporable getter pumps for large hydrogen
throughput and capacity in high vacuum regimes, Vacuum 214 (2023) 112198.
Doi: 10.1016/j.vacuum.2023.112198 // open access

Book essay

C.F.G. Neugebauer
Investigation on the Semi-Continuous Separation of Hydrogen Isotopes for Fusion; KITopen, Mai 2023.
DOI: 10.5445/IR/1000158827

Chr. Day
Vacuum Pumping and Fuelling, in: G. van Oost (Ed.), Fundamentals of Magnetic Fusion Energy, pp. 483-564, ISBN 978-92-0-110721-3, IAEA, 2023

Presentation

J.C. Schwenzer, Chr. Day
Tritium inventory evolution modelling for demonstration and future fusion power plants, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

S. Hanke, X. Luo, K. Battes, et al.
Cryopump concept development for the cryogenic mirror region of the Einstein Telescope – the future gravitational wave observatory, Cryogenic Engineering Conference CEC-ICMC, Hawai, USA, July 2023.

K. Battes, S. Hanke, C. Day, et al.
Design development of the cryogenic pumps for the low frequency interferometer of the Einstein Telescope, Gravitational Wave Advanced Detector Workshop 2023, Isola d´ Elba, Italy, May 2023.

S. Hanke, K. Battes, X. Luo, et al.
Cryopumps at the extremities of the ET beampipes, Gravitational Wave Telescopes 2023, 27-29 Mar 2023, CERN, Switzerland, 27-29 Mar 2023.

F. Ravelli, M. Fillion, A. Kuang, et al.
Overview of the Vacuum Pumping Systems for the SPARC Tokamak, 26th Conf. of the Italian Vacuum Society AIV XXVI, Rome, Italy, 7-10 Nov 2023.

M. Fillion, A. Kuang, Chr. Day, et al.
Overview of the Vacuum Pumping Systems for the SPARC Tokamak, American Vacuum Society 69th International Symposium, Portland, OR, USA, 5-10 Nov 2023.

Chr. Day, V. Hauer, P. Innocente, et al.
Design of the DTT divertor cryopumps, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

S. Roccella, R. Neu, P. Innocente, et al.
A Versatile Divertor for the Italian Divertor Tokamak Test Facility, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

B. Butler, G. Karajgikar, A. Santucci, et al.
Reynolds, Tritium related challenges to be overcome in order to deliver fusion power plants, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

J. Ayllon-Guerola, C. Sozzi, G.L. Falchetto, et al.
European Machine Enhancements for the JT-60SA Tokamak, Asia-Pacific Conference on Plasma Physics (APPS), Nagoya, Japan, 12-17 Nov 2023.

S. Merli, Y. Kathage, A. Schulz, et al.
Numerical and experimental investigations of a linear microwave plasma source for metal foil pumps for DEMO, 49th European Conference on Plasma Physics (EPS), Bordeaux, France, 3-7 July 2023.

I. Podadera, S. Becerril, M. García, et al.
IFMIF-DONES facility: a fusion-oriented 5 MW superconducting CW linear accelerator, 14th Int. Particle Accelerator Conference (IPAC), Venice, Italy, 7-12 May 2023.

Posters

Y. Kume, Chr. Day
Plasma Exhaust Processing System with a Tritium Compatible Reciprocating Pump, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

V. Narcisi, J.C. Schwenzer, T. Giegerich, et al.
On the possibility to recover Plasma Enhancement Gases from DEMO tokamak exhaust stream, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

X. Luo, Y. Kathage, T. Teichmann, et al.
Assessment of Metal Foil Pump Configurations for EU-DEMO, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

T. Teichmann, Chr. Day, T. Giegerich, et al.
Simulation and concept design of continuous mercury-driven vacuum pumps for EU-DEMO, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

V. Hauer, Chr. Day, P. Cara, et al.
Gas flow modelling of the IFMIF-DONES beamline, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

A. Uihlein, J. Schwenzer, T. Giegerich, et al.
Process Design of Hydrogen Isotope Separation using Temperature Swing Absorption in the EU-DEMO Fuel Cycle, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

Yu. Igitkhanov, S. Hanke, Y. Kathage, et al.
Energetic neutral screening of the metal foils in metal foil pumps, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

P.T. Lang, L.R. Baylor, R. Dux, et al.
Admixed pellets for fast and efficient delivery of plasma enhancement gases: investigations at AUG exploring the option for EU-DEMO, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

B. Ploeckl, P.T. Lang, Th. Giegerich, et al.
Proposal of a control scheme for testing a centrifuge-based pellet injection system in DIPAK-PET, 15th Int. Symp. On Fusion Nuclear Technology ISFNT, Las Palmas de Gran Canaria, Spain, 10-15 Sept 2023.

T. Kremeyer, D. Boeyaert, C. Day, et al.
Particle and heat exhaust with the island divertor in Wendelstein 7-X, 29th IAEA Fusion Energy Conference, London, UK, 16-21 Oct 2023.

C. P. Dhard, V. Haak, T. Bräuer, et al.
First operation and validation of simulations for the divertor cryo-vacuum pumps in W7-X, 29th IAEA Fusion Energy Conference, London, UK, 16-21 Oct 2023.

C. Tantos, S. Varoutis, V. Hauer, et al.
Innocente, 3D numerical evaluation of the DTT divertor pumping performance, 29th IAEA Fusion Energy Conference, London, UK, 16-21 Oct 2023.

P. Innocente, R. Ambrosino, L. Balbinot, et al.
Design of the divertor for the DTT facility optimized for power exhaust experiments, 29th IAEA Fusion Energy Conference, London, UK, 16-21 Oct 2023.

Y. Igitkhanov, T. Giegerich and Chr. Day
Burn-up fraction in DEMO operation with the Direct Internal Recycling, 29th IAEA Fusion Energy Conference, London, UK, 16-21 Oct 2023.

F. Crisanti, R. Albanese, E. Alessi, et al.
Physics basis for the DIVERTOR TOKAMAK TEST FACILITY, 29th IAEA Fusion Energy Conference, London, UK, 16-21 Oct 2023

T. Kremeyer, D. Boeyaert, R. Duligal, et al.
Design criteria for a particle exhaust optimized divertor for Wendelstein 7-X, 49th European Conference on Plasma Physics (EPS), Bordeaux, France, 3-7 July 2023

Materials and Technologies for the Energy Transition (MTET)

Journal article

A. Lani, V. Sharma, V. F. Giangaspero, et al.
A Magnetohydrodynamic enhanced entry system for space transportation: MEESST
Journal of Space Safety Engineering 10 (2023) pp. 27–3, https://doi.org/10.1016/j.jsse.2022.11.004

Cayado, Pablo, Hänisch, Jens, Iida, Kazumasa, et al.
Focus on recent advances in superconducting films
38.05.03 (POF IV, LK 01)
Superconductor Science and Technology
0953-2048, 1361-6668
10.1088/1361-6668/ace997

Cayado, Pablo, Namburi, Devendra K., Erbe, Manuela, et al.
Transport measurements in single-grain GdBCO+Ag bulk superconductors processed by infiltration growth
38.05.03 (POF IV, LK 01)
0947-8396, 1432-0630
10.1007/s00339-023-06402-w

Chow, Calvin C. T., Grilli, Francesco, Chau, K. T.
Numerical modelling of HTS tapes under arbitrary external field and transport current via integral method: review and application to electrical machines *
38.05.03 (POF IV, LK 01)
0953-2048, 1361-6668
10.1088/1361-6668/ace701

de Sousa, Wescley T. B., Noe, Mathias Huwer, Stefan, et al.
Design of a 110-kV 2.0-kA SmartCoil Superconducting Fault Current Limiter
38.05.03 (POF IV, LK 01)
1051-8223, 1558-2515
10.1109/TASC.2023.3246818

Freitag, W., Erbe, M., Hänisch, J., et al.
Optimization of the Crystallization Process of TFA-MOD ErBCO Films on IBAD-Substrate Under Low-Pressure Conditions via DSD Approach
38.05.03 (POF IV, LK 01)
1051-8223, 1558-2515
10.1109/TASC.2023.3259922

Hänisch, Jens
Superconducting undulators: permanent magnets after all
38.05.03 (POF IV, LK 01)
0953-2048, 1361-6668
10.1088/1361-6668/aced71

Iida, Kazumasa, Hänisch, Jens, Hata, Satoshi, et al.
Recent progress on epitaxial growth of Fe-based superconducting thin films
38.05.03 (POF IV, LK 01)
0953-2048, 1361-6668
10.1088/1361-6668/acccb2

Li, Chao, Xing, Yuying, Xin, Ying, et al.
Time-dependent development of dynamic resistance voltage of superconducting tape considering heat accumulation
38.05.03 (POF IV, LK 01)
2772-8307
10.1016/j.supcon.2023.100066

Oliveira, R., Zeng, X., Pei, X., et al.
HTS-Tape Magnetic Bearing for Ultra High-Speed Turbo Motor
38.05.03 (POF IV, LK 01)
1051-8223, 1558-2515
10.1109/tasc.2023.3253064

Oliveira, Roberto, Pei, Xiaoze, Nilsson, Emelie, et al.
Performance Analysis of Resistive Superconducting Fault Current Limiter Using LN 2 and GHe Cooling
38.05.03 (POF IV, LK 01)
1051-8223, 1558-2515
10.1109/TASC.2023.3237642

Oswald, Johannes W., Behnke, Alexander, Herdrich, Georg, et al.
Assessment of MHD-relevant parameters in high enthalpy air plasma for flow manipulation experiments
38.05.03 (POF IV, LK 01)
0042-207X
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Petroušek, Patrik, Kvačkaj, Tibor, Bidulská, Jana, et al.
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Invited Papers

Tabea Arndt

- 20.04.2023, Invited, T. Arndt, Supraleiter & Wasserstoff – Defossilisierung und Sektorkopplung, Rheinland-pfälzischer Supraleitungskongress, Mainz
- 02.05.2023, Invited, T. Arndt, Large Scale Superconducting Applications - Status and Prospects, Gordon Research Conference "Superconductivity", Les Diablerets
- 06.09.2023, Contributed, T. Arndt, 3-LS-MC2-02S Common Challenges and goals when using HTS in power engineering and accelerators, EUCAS, Bologna
- 06.09.2023, Invited, T. Arndt, Room Temperature Superconductivity – Impact on Power Engineering- a dream or a nightmare?, EUCAS, Bologna
- 20.09.2023, Invited Plenary, T. Arndt, Superconducting Magnet Technology – status, trends and prospects, FGMR conference, Konstanz

Christian Day

- J.C. Schwenzer, The fuel cycle simulator of the EU-DEMO fuel cycle, 30th IEEE Symp. Fusion Engineering (SOFE), Oxford, UK, 9-13 July 2023.
- Chr. Day, Progress in maturation of critical technologies for the EU DEMO fuel cycle, 30th IEEE Symp. Fusion Engineering (SOFE), Oxford, UK, 9-13 July 2023.

Jens Hänisch

- J. Hänisch, S. Tokatlidis, D. Li, Vortex matter, anisotropy, and electrical transport in (Li,Fe)OHFeSe thin films, invited talk, MRM2023, Kyoto, Japan, 11.-16.12.2023

Bernhard Holzapfel

- KC4: The KIT-CERN REBCO laboratory, 1st HiTAT workshop, 9.3.23, Geneva, „Teilchenphysik und Energiewende", Physik im Rathaus, 3.7.23, Karlsruhe

Mathias Noe

- Mathias Noe, "Ressourcen schonen und Energie sparen – Supraleiter für Netztechnik und Industrie", Rheinland-pfälzischer Supraleiterkongress – Zukunftstechnologie mit wirtschaftlichem Nutzen, 20. April 2023, Mainz
- Mathias Noe, Christof Humpert, Stephan Pöhler et al., "Technical and economic feasibility of a 380 kV, 5 kA resistive type SFCL", European Applied Superconductivity Conference 2023, September 3rd-7th, 2023, Bologna, Italy
- Mathias Noe, Bernhard Holzapfel, Tabea Arndt, "Supraleitung in der (Hybrid-) Elektrischen Luftfahrt", Workshop „Potenziale klimaneutrales Fliegen 2045 und Fähigkeitslücken bei Schlüsseltechnologien", 10.2023, Bonn

Patents Held

- Vorrichtung zur Strombegrenzung mit einer veränderbaren Spulenimpedanz
  Noe, Mathias; Schacherer, Christian
  DE 2532016
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- Verfahren und Vorrichtung zur kontinuierlichen Wiederaufbereitung von Abgas eines Fusionsreaktors
  Day, Christian; Giegerich, Thomas
  CN 105706175
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- Design of Superconducting Devices By Optimization Of The Superconductor's Local Criticial Current
  Holzapfel, Bernhard; Rodriguez Zermeno, Victor
  DE 2983218
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- Schienengebundene Magnetschwebebahn
  Holzapfel, Bernhard; Noe, Mathias
  CN 2016800101353
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- Transformator, Wickelkörper dafür und Verfahren zur Herstellung eines Wickelkörpers
  Hellmann, Sebastian
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- Supraleitfähiger Leiter und Verwendung des supraleitfähigen Leiters
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- Design of contacts for superconducting busbars and cables
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- Verfahren und Vorrichtung zur Anreicherung oder Abreicherung mindestens eines Wasserstoffisotops in einem Gasstrom
  Day, Christian; Giegerich, Thomas; Hörstensmeyer, Yannik; Müller, Ralf; Peters, Benedikt
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- Stromschienensystemelement mit einem Supraleiterstrand und einem Verbindungsstück sowie Stromschiene mit einer Vielzahl von solchen Elementen
  Kudymow, Andrej; Rodriguez Zermeno, Victor; Strauß, Severin
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  EP 18720292.4

- Bitterprinzipbasierte Magnetvorrichtung und Verwendung einer bitterprinzipbasierten Magnetvorrichtung
  Arndt, Tabea
  DE 102020124852.0
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  US 18/245,899

- Bandleitervorrichtung und Kabel, das die Bandleitervorrichtung aufweist
  Arndt, Tabea
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- Hochtemperatur supraleitende Schaltvorrichtung
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- Method for determining load parameters
  Courcelle, Maeva; De Carne, Giovanni; Tao, Qiucen
  EP 23195368.8

- Verfahren zum Betrieb eines elektrischen Energieversorgungsnetzes, Computerprogramm, Leistungselektronikeinrichtung
  De Carne, Giovanni
  DE 102016119422.0
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