ITEP – Institute for Technical Physics

Results of Research and Development
2024 Annual Report

IMPRINT

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

Phone +49 721/608-23501

www.itep.kit.edu

TEXTS:
Tabea Arndt, Nadezda Bagrets, Giovanni De Carne, Stefan Fink, Thomas Giegerich, Francesco Grilli, Stefan Hanke, Volker Hauer, Jens Hänisch, Frank Hornung, Bernhard Holzapfel, Marion Klaeser, Andrej Kudymow, Ralph Lietzow, Mathias Noe, Quoc Pham, Wescley de Sousa, Christos Tantos, Klaus Weiss

EDITORIAL OFFICE:
Ingeborg Meyer

PHOTOS AND CHARTS:
Karlsruhe Institute of Technology (KIT)

COVER PHOTO:
Installation of the superconducting 110kV, 500MVA cable system including terminations at the Menzing substration of Stadtwerke Munic

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

July 2025

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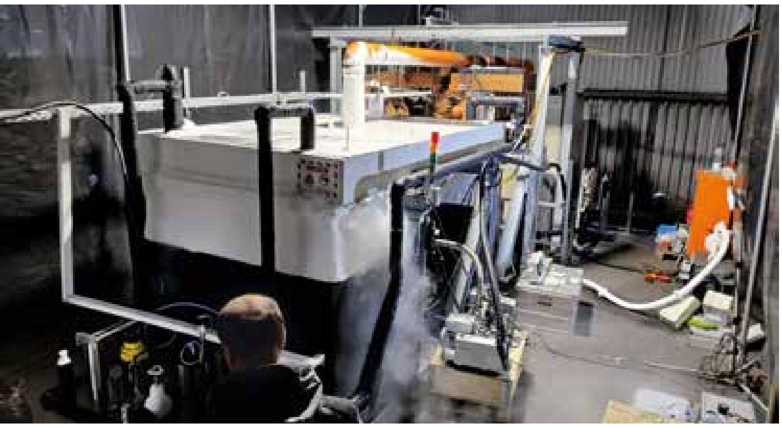


Contents

Foreword

The Institute of Technical Physics (ITEP) sees itself as a national and international competence center for superconducting, energy and fusion technologies with the research fields:

- Superconducting and cryogenic materials
- Energy applications of superconductivity
- Real-time systems for energy technologies
- Superconducting magnet technology and
- Vacuum and Fusion Technologies

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

- Laboratory for the development of superconducting components for energy technology,
- a technical center for the development of superconducting materials,
- a magnet laboratory for the development of specific superconducting windings and magnets,
- a cryogenic high-voltage laboratory for investigating the high-voltage characteristics of cryogenic insulating materials,
- a cryogenic material laboratories for the investigation of electrical and mechanical properties at very low temperatures and the power-hardware-in-the-loop laboratory of the KIT Energy Lab.

In 2024, 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 warmly congratulate Prof. Dr. de Carne on this appointment and look forward to continuing our collegial collaboration.

In 2024, our institute also achieved very pleasing scientific results, many successful development projects and some special challenges and events, which we will briefly discuss below.

The investigation of new superconductors is an important focus of **research in the field of superconductors and cryogenic materials.** In 2024, a paper was published in which X-ray diffraction was used to determine the oxygen content of high-temperature superconducting strip conductors. The lead author Mr. Kai Walter was awarded the Jan Evetts Prize of the journal Superconductor Science and Technology at the Applied Superconductivity Conference in Salt Lake City in 2024. We warmly congratulate Mr. Walter on this award.
As part of a long-standing cooperation with CERN, in 2024
the former pilot production of high-temperature superconductors by Bruker was transferred to routine operation at KIT. The first longer tapes up to 15 m and the first wider samples up to 3 cm wide with good properties were produced.
In the CryoMaK laboratory for the investigation of mechanical material properties at low temperatures, work in 2024 focused on tensile tests on hollow specimen in a hydrogen environment. In particular, the hydrogen-induced fatigue of the material was investigated on samples made of copper, austenitic and ferritic steels, thus extending the test options to measurements with a hydrogen environment in gaseous or liquid form.

In the **research field of energy technology applications of superconductivity,** a technology demonstrator for a high-temperature superconducting industrial busbar was successfully tested with industrial partners as part of the BMWK joint project DEMO200. During the test at Trimet's aluminum plant in Voerde, a current of up to 190 kA was achieved. This confirmed the basic design and the development and permanent use of a 600 m, 200 kA busbar for use in an aluminum plant in Hamburg could be started as part of the BMWK SuprAl real-world laboratory. ITEP is providing scientific support for the real-world laboratory and is responsible for data collection and evaluation.
Furthermore, many high-voltage measurements and AC loss measurements were carried out on various configurations in the BMWK joint project HighAmp to develop a new type of superconducting medium-voltage cable. The aim is to develop an optimum arrangement of the 3-phase conductors at the highest possible voltage.
Continuous operation was demonstrated in the development of a superconducting bridge circuit using the dynamic resistance of superconductors. This means that the basic work has now been completed.
In the modeling of superconducting components, a new method has reduced the simulation time for calculating the AC properties of a superconducting cable on a round core from several hours to a few minutes, with the same accuracy.

In the **research field of real-time systems for energy technologies,** important research topics include the modeling of grids, the investigation of dynamic energy storage systems and the integration of hydrogen into future energy systems.
In the SuperLink joint project, the calculation of the 110 kV grid of Stadtwerke Munich was completed by investigating the influence of a superconducting 110 kV cable on a restructured grid. Compared to the

existing system, around 10 % of the cable length could be saved. Furthermore, the 110 kV, 500 MVA prototype cable was successfully put into operation for a pre-qualification test in October.
A hybrid energy storage system consisting of a battery and a fast flywheel offers advantages for the service life of a battery storage system. Various control strategies for frequency and power control were developed for this purpose.
In the KIT EnergyLab, the so-called "Hydrogen Integration Platform" is the main part for the investigation of hydrogen-based energy technologies. The construction site was further prepared for several large demonstration projects and the planning was detailed. For example, the connection of the H2-in-the-loop laboratory is planned for 2025, as is the commissioning of a hydrogen liquefaction plant.

An important task in the **research field of superconducting magnet technology** is the development of high-temperature superconducting magnets. The institute has a laboratory for the robotic winding of non-planar high-temperature superconducting magnets. The first attempts to produce a non-planar winding were made with this apparatus in 2024. The EU project MEESST was completed in 2024, in which the magnet developed at ITEP was successfully tested in the plasma channel.
The concept for a hybrid energy pipeline for electricity and liquid hydrogen was finalized, and the first components were ordered.
In the joint project SPEEDY_HTS for the development of a 1:1 demonstrator for a superconducting mid-speed wind generator, the design was finalized, and a patent was filed for the pitch control. In this type of wind generator, the generator output can be doubled from 6 to 12 MVA by replacing the conventional rotor with a superconducting rotor. In the further development of superconducting rotating machines, the modeling of the asynchronous machine with squirrel cage rotor was started.

In May 2024, Dr. Thomas Giegerich took over the management of the **Vacuum and Fusion Technologies research field** from Dr. Christian Day, who has accepted a management position at a company. We would like to thank Dr. Day very much for the excellent leadership and establishment of his working group and look forward to continuing our fruitful work with Dr. Giegerich.
As part of the BMBF's call for fusion research, two new projects with industrial partners have been acquired and started. The SyrVBreTT project is concerned with the development of the fuel cycle and important components for a stellarator and the KaliAS project is developing a strategy for lithium-6 production.
Two important goals were achieved in the development of cryogenic vacuum pumps. A design was created for the pump in the Italian Divertor Test Tokamak project and the concept for the pumps in the Einstein Telescope project was also created and reviewed.
In the DIPAK project, in which a completely new laboratory for large vacuum technologies is being built, the preliminary planning of the building was finalized, and the overall and general planning was commissioned. Furthermore, production of the large vacuum container for the central test unit was started.

In 2024, a total of 37 doctoral students were supervised by employees of our institute, as well as 22 Master's students and 11 Bachelor's thesis.

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

Giovanni De Carne

Results from the Research Areas

Test Chamber for mechanical tensile or fracture tests in cryogen hydrogen (gaseous or liquid)

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 first half of 2024, we published our work on the correlation of crystal structure and oxygen deficiency δ of $SmBa_2Cu_3O_{7-\delta}$ [1], which earned us third place in the Jan Evetts Award 2024 of the IoP journal Superconductor Science and Technology. This award was presented to Kai Walter at ASC 2024 in Salt Lake City, where we presented findings on mixed $REBa_2Cu_3O_{7-\delta}$ (mREBCO) thin films. m*RE*BCO can be realized by a mixture of rare earth *RE* (e.g. Er, Ho, Dy, Gd, Eu, Sm) used to form thin films. Chemical solution deposition (CSD) made it extremely easy to change the chemical composition. It turned out that the crystal structure could be predicted very accurately by the mean ionic radius calculated from the R*E* ratios of the solution used, Fig. 1a. This made it possible to create five different sets of samples, all of which had similar lattice parameters but different amounts of R*E* mixing. Our assumption that this increasing *RE* mixing would change the pinning properties could not be confirmed so far. Nevertheless, the R*E* mixing seems to influence the microstrain along the c-axis, Fig. 1b. With increasing R*E* mixing, the microstrain decreased significantly. This was very surprising as we expected the R*E* mixture to increase the microstrain. We attribute this decrease to an additional degree of freedom during film growth, which helps the growing film to optimize itself. The additional degree of freedom comes at a price, as the deposition process becomes more complex and therefore more difficult to control to obtain thin films with good crystallinity, which is reflected in a slight decrease in the critical temperature, Fig. 1c. A great opportunity arises from this decrease in microstrain. mREBCO could have the potential to increase pinning capacity by optimizing the interfaces between artificial pinning centres (APCs) and the REBCO matrix, as more or more effective APCs could be incorporated through optimized interfaces.

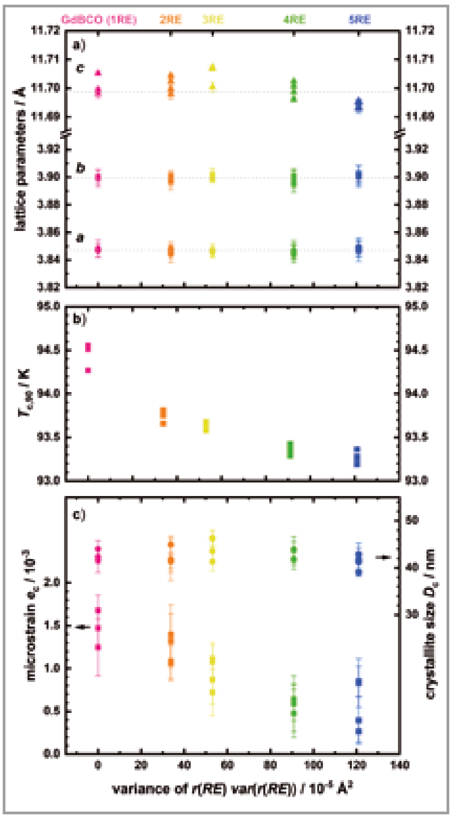


Fig. 1: Dependence of the lattice parameters (a), the critical temperature (b) as well as microstrain and grain size (c) on the variance of the rare earth ion radius in mREBCO thin films (single column)

In previous work, we showed that $BaHfO_3$ (BHO) can dramatically increase the critical current density of superconducting $GdBa_2Cu_3O_{7-\delta}$ (GdBCO) thin films. Due to strain-induced effects, BHO grows in pulsed laser deposited GdBCO thin films in the form of nanocolumns that extend through the entire film. Thin films of GdBCO+2.5wt% BHO grown on (100)-oriented $LaAlO_3$ single crystals show the highest J_c values for 800 °C deposition temperature and 5 Hz laser frequency. In order to close the gap between laboratory and industrial production of coated conductors using GdBCO, it is therefore necessary to investigate the transport properties of GdBCO films with 2.5 wt% BHO on technical substrates. Therefore, GdBCO thin films with 2.5 wt% BHO were grown on IBAD-MgO tapes from Sunam with a $LaMnO_3$ final buffer layer at different deposition temperatures T_{dep} and laser frequencies *f*. Increasing T_{dep} first leads to the development of well-aligned BHO nanocolumns extending throughout the film and then to lateral growth of the nanocolumns. The same is true for f. Therefore, one would expect that for each frequency there is a T_{dep} at which an optimal defect morphology can be achieved.

Fig. 2 shows the dependence of the pinning force density (F_p) on the magnetic field at 77 K and 30 K for the optimized samples deposited at a) 820 °C, 10 Hz, b) 800 °C, 5 Hz, and c) 780 °C, 2 Hz. Each 2-fold reduction of f requires a reduction of the deposition temperature by about 20 °C to obtain superconducting GdBCO+2.5 wt% BHO films with comparable maximum pinning force densities ($F_{p,max}$). $F_{p,max}$(77K) = 16.5 GNm^{-3} for the

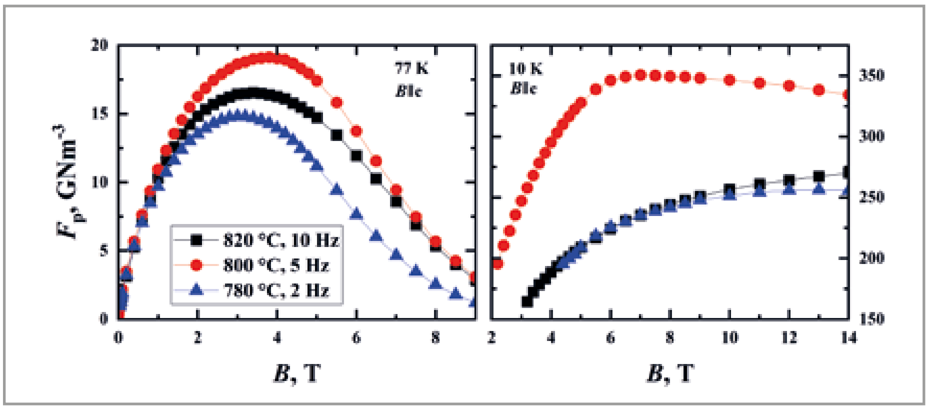


Fig. 2: Field dependence of the pinning force density at 77 K and 30 K for three different sets of deposition parameters. (two-column)

sample deposited at 820 °C, 10 Hz, $F_{p,max}$(77K) = 19.1 GNm-3 for the sample deposited at 800 °C, 5 Hz and $F_{p,max}$(77K) = 14.8 GNm-3 for the sample deposited at 780 °C, 2 Hz. At 30 K, however, the differences in $F_{p,max}$ are more pronounced. The sample deposited at 800 °C shows a value of 350.6 GNm^{-3}, which is 1.5 times higher than for the other samples. These differences in $F_{p,max}$ are due to the differences in density and size of the BHO nanopillars. Possibly, 800 °C and 5 Hz lead to the optimum size of the BHO nanopillars, resulting in the highest J_c and $F_{p,max}$ values.

As part of the SFB project HyPERiON, which deals with the development of compact NMR devices, R*E*BCO films on $SrTiO_3$ substrates were optimized for future pinning increases, which are essential to achieve the targeted 10 T. These substrates are being surface-modified at a neighbouring institute (IMT).

As part of the KeraSolar project, new types of ceramic solar cells are to be developed to provide alternatives to the current standard silicon. The project is funded by the Carl Zeiss Foundation and brings together an interdisciplinary team from various institutes. The ITEP is responsible for the production of thin films using PLD. The first ceramic produced in the course of the project at ITEP is $BaNbO_2N$, an oxynitride with a band gap of 1.7 eV. A barium niobium oxide was used as a target and the required nitrogen was added via N_2 process gas during laser deposition. Although a phase-pure layer could not yet be deposited, the feasibility is already evident in the initial results.

IRON-BASED SUPERCONDUCTORS

As a partner in an Italian joint project, Co-doped $BaFe_2As_2$ films were produced on metallic tapes as part of a master thesis. The aim of the project is the cost-effective production of Fe-based superconducting coated conductors by modifying the buffer layer architecture and deposition methods, namely CeO_2 films deposited by chemical solution deposition on NiW RABiTS tapes. Our task was to determine whether $BaFe_2As_2$ is as suitable as Fe(Se,Te).

Epitaxial $Ba(Fe,Co)_2As_2$ films on IBAD-MgO-coated metallic substrates have already been realized using an iron buffer layer architecture. However, the deposition of $Ba(Fe,Co)_2As_2$ on CeO_2 has not yet been performed. The first films showed misoriented growth and only partial superconductivity. To improve the quality of the films, seed layers of differently doped Ba122 were introduced, as already used for Fe(Se,Te), which create good growth conditions and prevent the oxygen diffusion of CeO_2. Films with an 8 % doped buffer layer show the best results in terms of the width of the superconducting transition, the film quality and T_c (18.8 K). A thickness dependence of the superconducting layer was observed on both the undoped and the 3% doped Ba122 buffer layer, from which a co-diffusion from the main superconducting layer into the seed layer can be concluded. Variations of the laser repetition rate during the deposition of 3 % doped seed layers to reduce the effects of co-diffusion lead to an improved film texture, but also to an increased formation of misorientations. A comparison of the lattice parameters of Ba122 and CeO_2 showed that especially the (103) and (110) misorientations compete with the desired (00l)-oriented growth. In addition, annealing experiments were carried out to improve the structural quality of the films.

For the production and characterization of Fe(Se,Te) thin films, the PLD system was optimized with regard to maximum energy densities on the target by shortening the laser beam path and installing a telescope, and the electrical contacting of these thin films and single crystals was significantly improved.

In a collaboration with several Japanese universities, the growth of Fe(Se,Te) on vicinal templates (CeO_2-buffered $SrTiO_3$ bicrystals) was elucidated, Fig. 3, and the behaviour of [100]-tilt grain boundaries in Fe-based superconductors was investigated for the first time [2]. Due to the geometry coherency model, the grain boundary angles in $SrTiO_3$, CeO_2 and Ba122 are different in one sample, and due to domain matching epitaxy, Ba122 layers grow c-axis-textured on bicrystals with grain boundary angles ≥ 24°, i.e. without grain boundary. Small-angle grain boundaries of this

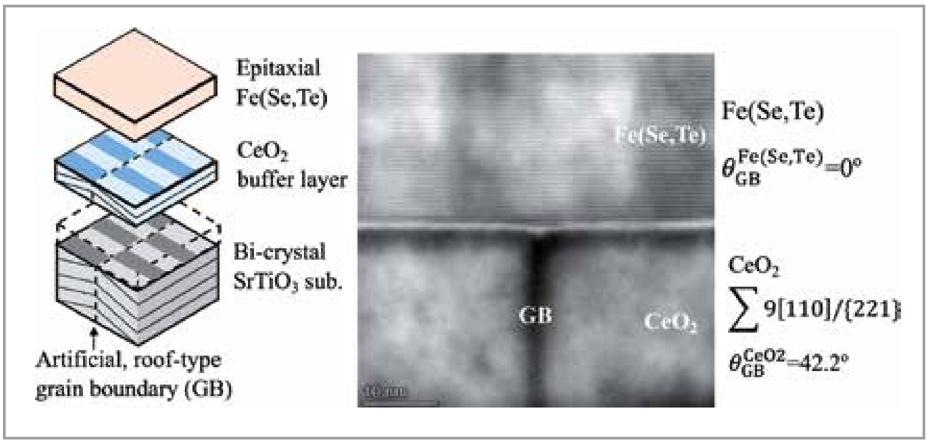


Fig. 3: Schematic diagram and electron micrograph showing the c-axis-oriented growth of Fe(Se,Te) layers on bicrystals with [010] large-angle tilt grain boundaries. (two-column)

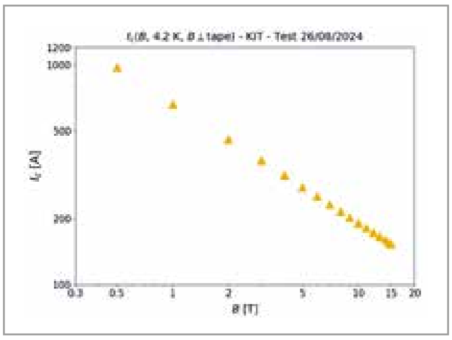


Fig 4: Field dependency of J_c at 4.2 K on magnetic field

geometry behave similarly to [001]-tilted grain boundaries with a critical angle of at least 9° for non-reduced critical current densities.

[1] K. Walter et al, Supercond. Sci. Technol. 37, 075002 (2024)
[2] K. Iida et al, Sci. Technol. Adv. Mater. 25, 2384829 (2024)

Contact: jens.haenisch@kit.edu

CONUCTOR CONCEPTS AND TECHNOLOGIES

KC4 line The KC4 line has reached regular production operation, with sample lengths up to 15 m with performance of 450 A/cm² at 4.2 K, 10 T (see Fig. 4). Short length experiments are running along with long lengths production in order to optimize deposition conditions for regular Y123 coatings, to test IBAD tapes from Faraday, SUNAM, HTSI and Shanghai SC, and test pinning options to improve tapes performance at high magnetic fields. The production of wide (30-40 mm) tapes was successful, showing good homogeneity over the width of the tape (see Fig. 5).

The characterization of tapes is ongoing, including standard transport properties, mechanical performance, and measurements of current transfer length and barrier resistance between superconducting and stabilizing layers. Very good homogeneity was observed both across the width and along the length for these parameters, with values also lower compared to commercial HTS tapes

In Fig. 6 J_c values of KC4 sample S2401-018/019 at different T and magnetic fields 0-14 T are shown. High values of J_c over 5 MAcm^{-2} at 30 K and 10 T, and over 9 MAcm^{-2} at 10 K and 10 T are achieved. The I_c values are over 180 A at 77 K s.f. for YBCO+3%BZO films show that introduction of such defects may lead to the slight reduction of J_c values at 0-5 T magnetic field and 77 K. However, BZO nanocolumns have the ability to pin the vortices along their entire length, therefore, compared to pristine YBCO, 2-3-fold increase in the low-temperature and high-field J_c is achieved for these tapes.

KC4 tapes show low variation in CTL (current transfer length) and Rb (barrier resistance) along the length and over the width. Measurement configuration of these parameters is very sophisticated, including several steps, like measurement of spatial distribution of voltage drop in surrounding metal layer of the HTS tape on very short distance less than 1 mm (see Fig. 7), and measurement of the resistance of the metal layer with resistivity option of Physical Properties Measurement System. Compared to commercial HTS tapes these parameters are relatively low. Experiments on influence of air or hydrogen exposure of REBCO layer are running, for understanding the factors influencing barrier resistance and CTL, that are relevant for various applications of HTS tapes.

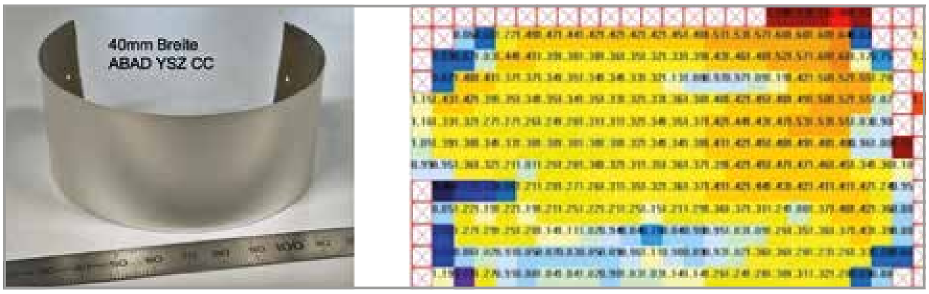


Fig. 5: 40 mm wide Bruker templates show a decent, homogeneous Jc distribution of >1 MA/cm² at 77 K.

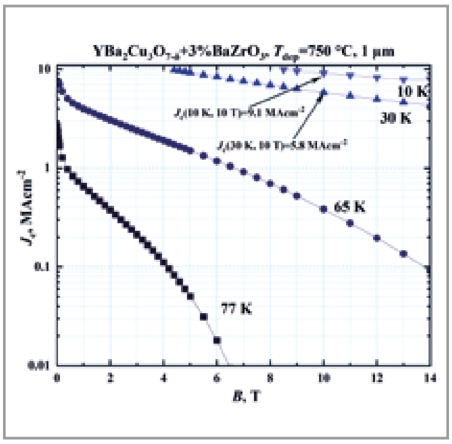


Fig. 6: J_c of KC4 sample S2401-018/019 at different temperatures and magnetic fields.

In framework of master thesis thermal contacts resistance between HTS tapes, and HTS tapes and contacting structural materials was measured for several HTS cables in the temperature range 4-300 K, and for various applied pressures. For this, special extension for thermal transport option of Physical Properties Measurement System war used (see Fig. 8). These measurements provide very important, and, up to now, missing, data for simulation of a quench propagation in HTS cables.

Contact: bernhard.holzapfel@kit.edu, nadezda.bagrets@kit.edu

STRUCTURAL- AND FUNCTIONAL MATERIALS FOR CRYOGENIC APPLICATIONS

CHARACTERIZATION OF SUPERCONDUCTORS

As part of the KC4 project for the production of special high-temperature superconductor (HTS) tapes, various characterizations were carried out on the superconductors for process optimization and quality assurance. The work is described in the research topic Superconducting cables.

As part of a master's thesis, the thermal contact resistance between HTS tapes and between HTS tapes and the structural materials in contact with them was measured for selected HTS cable configurations in the temperature range from 4 K to 300 K and as a function of the contact pressure. A special extension for the "Thermal Transport" option of the Physical Properties Measurement System was used for this purpose. These measurements provide very important and previously missing data for the simulation of quench propagation in HTS cables.

PROJEKT „APPLHY – MATERIAL ASPECTS"

Hollow tensile specimens (inner diameter of 2 mm and outer diameter of >5 mm) allow a fast and efficient investigation of the influence of hydrogen on a material. The inner environment of the hollow tensile specimens was filled with either hydrogen or helium at a pressure of 0 bar or 200 bar. Tensile tests with a reduced strain rate of 3.8×10-4 s-1 were carried out in the temperature range between room temperature and 77 K. Hollow tensile specimens were made of materials relevant for different hydrogen applications.

- Austenitic steel 1.4571 (316Ti): In order to investigate the influence of pressure on the mechanical behavior, tensile tests were carried out with a helium pressure of 1 bar, 100 bar and 200 bar at room temperature in the capillary tube of the samples. The stress-strain curves showed a difference in elongation before fracture at different pressures. At 1 bar, the samples showed a higher elongation to failure compared to the samples tested at 100 and 200 bar. However, no significant difference in elongation was observed between 100 and 200 bar. The experiment was also conducted using hydrogen as a medium. At a pressure of 1 bar, no significant differences in mechanical behavior were observed due to the ambient conditions. A hydrogen pressure of

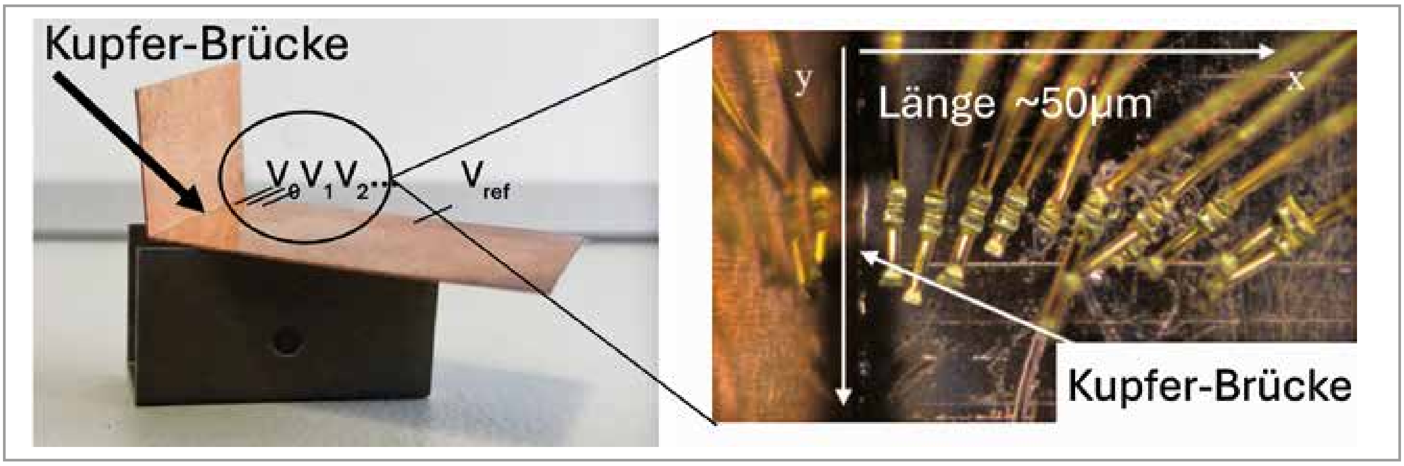


Fig. 7: CTL measurement configuration of the current transmission length on an HTS strip (left) and the detail of the voltage contacts applied using a wire bonder (right)

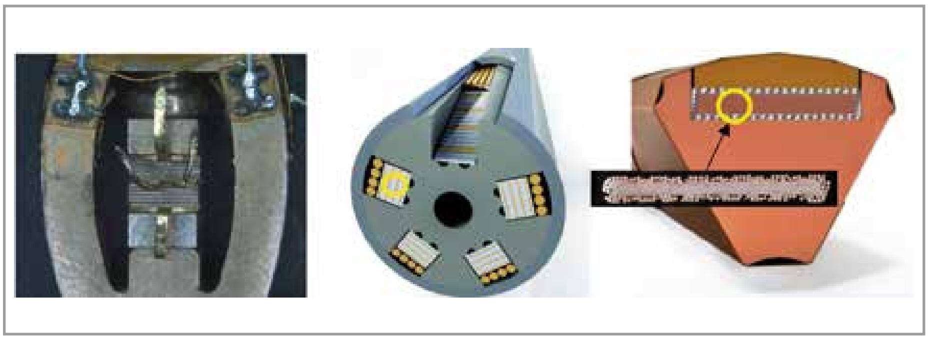


Fig. 8: Measurement configuration (left), an relevant cable configuration (center and right)

100 bar corresponds to 100 bar in helium; however, at 200 bar hydrogen a significantly reduced elongation to fracture was observed. This result underlines the detrimental effect of hydrogen on the mechanical properties of steel (see Fig. 9). However, it is known that austenitic steel is only slightly susceptible to hydrogen embrittlement at room temperature, mainly due to the low diffusion rate of hydrogen in this material.

Examination of the samples in longitudinal section after the test revealed large cracks on the inner surface at the points where pressure was applied. In the case of hydrogen, the cracks were significantly deeper and more frequent, particularly in the heavily deformed area of the sample (see Fig. 10). In addition, coarse traces were observed in the undeformed area, which were caused by the machining of the inner capillary. EBSD analysis of the longitudinal sections revealed the presence of a martensitic phase with a thickness of up to 20 micrometers from the inner diameter. This phase could have been formed due to induced deformation during mechanical processing of the inner capillary. Further studies are required. Fractographic analysis of the sample tested at a hydrogen pressure of 200 bar showed brittle fractures at a distance of 50 micrometers from the inner diameter, while the rest of the fracture was ductile. At 1 bar, no brittle fracture layer was observed, while at 100 bar, brittle fractures were observed at about 10 micrometers. The tensile tests performed at 77 K in hydrogen and helium at a pressure of 200 bar showed no significant differences in the stress-strain curves.

- Copper was tested at 0 bar and 200 bar in different environments at room temperature. The material exhibited a hardness of 125 HV. An increase in pressure inside the capillary led to a decrease in tensile strength and a slight reduction in elongation, which was observed in both hydrogen and helium environments. When comparing the two gases, the deformation in hydrogen led to an increase in tensile strength. Tests were carried out on the annealed samples with hydrogen at pressures of 0 and 200 bar both at room temperature and at 77 K. Further experiments are planned for in-depth investigation.
- Ferritic X60 steel: Due to the limited number of samples, only two tests were performed: one at room temperature under 200 bar hydrogen and another

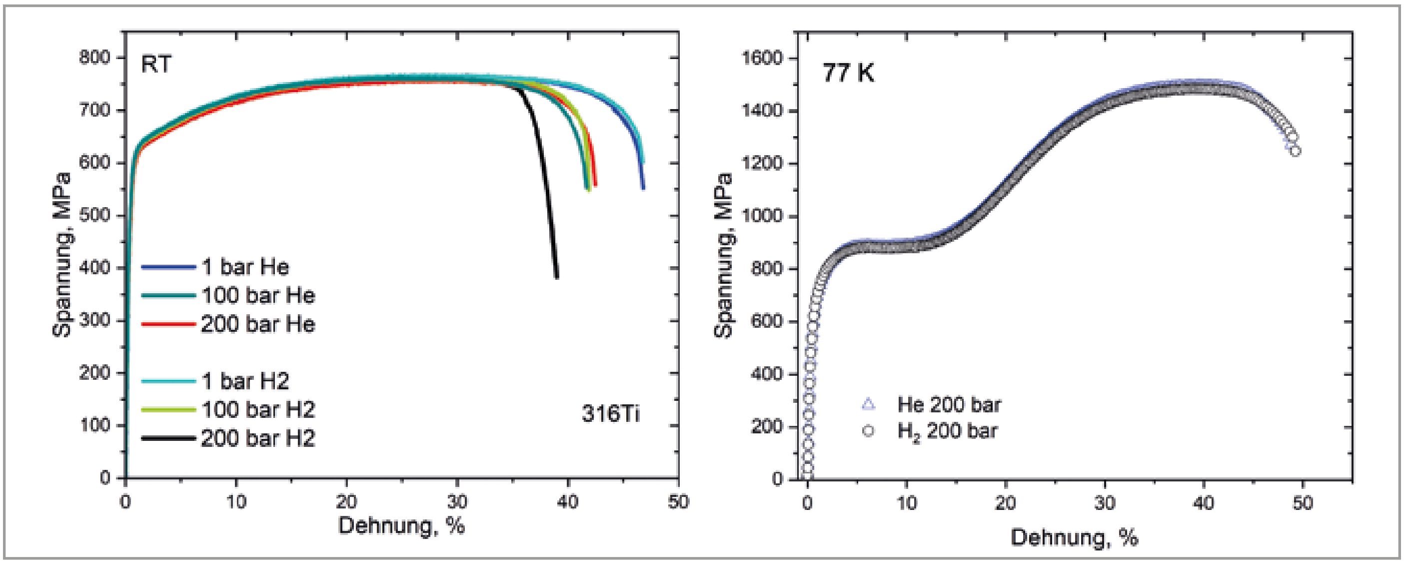


Fig. 9: Tensile tests on 316Ti hollow tensile specimens at RT and 77K, different test gases and pressures in the capillary. At RT, a significantly reduced maximum elongation can be seen with 200 bar hydrogen, which is no longer present at 77K.

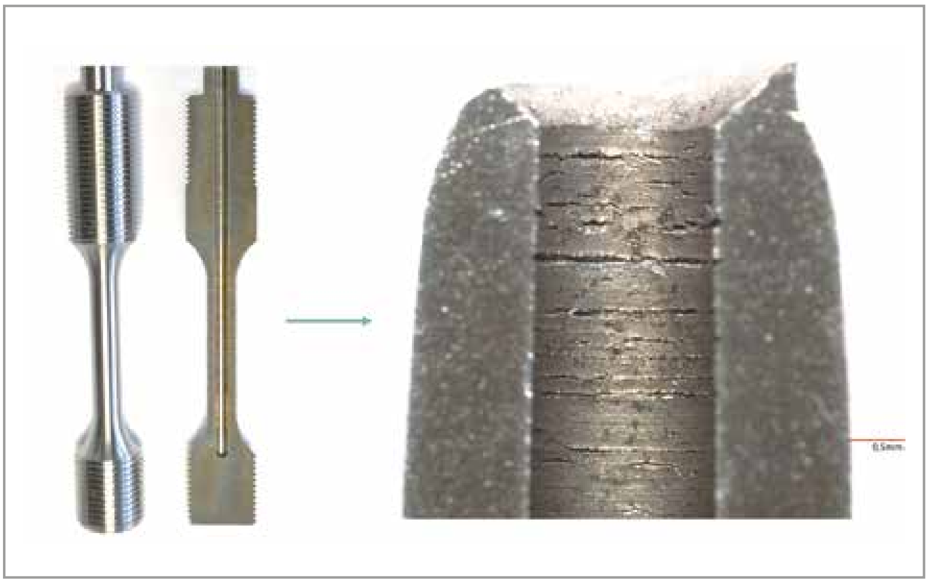


Fig. 10: Detailed view of the 316Ti hollow tensile specimen before (left) and after (right) testing. Horizontal grooves are clearly visible in the left image, which appear to promote failure in a hydrogen atmosphere.

under helium. The sample tested in hydrogen showed a slightly shorter elongation compared to the sample tested in helium, and fractographic analysis revealed a significant amount of brittle fracture. Studies of the longitudinal sections identified hydrogen-induced cracks on the inner surface, while the helium sample did not show any cracks and resulted in ductile failure. A fine-grained layer up to 20 micrometers thick was detected in the hydrogen tested sample, which was not present in the helium sample. Further investigations are required.

PROJECT „CRYOGENIC SCALMALLOY CX“

Electric drives for aircraft based on hydrogen as an energy source are a key technology that was developed, for example, in the completed AdHyBau project (see Annual Report 2023) and is to be developed into a prototype in a follow-up project AdHyBau-2 by 2027. Specific lightweight construction materials must be considered for this purpose. Scalmalloy (high-strength aluminum alloy developed by Airbus for additive manufacturing) is certainly interesting, but due to its significant low-temperature embrittlement, it cannot yet be used for cryogenic applications. Together with AP-Works as a manufacturer of additively manufactured coponents, sample material of a modified manufacturing process was examined, which is intended to open up the cryogenic temperature range as Scalmalloy-CX.

For this purpose, microstructure investigations were carried out on standard and CX samples to understand the influence on the mechanical properties. The microstructure was specifically changed by heat treatment of the CX samples at 350 °C for 4h and 24h (see Fig. 11). Microhardness measurements after the different time steps show an increase especially in the horizontal build-up direction. In additional EDX analyses, a second phase with finely distributed Mg-rich particles was observed. Further heat treatments should reveal the systematic influence on the mechanical properties.

Contact: klaus.weiss@kit.edu

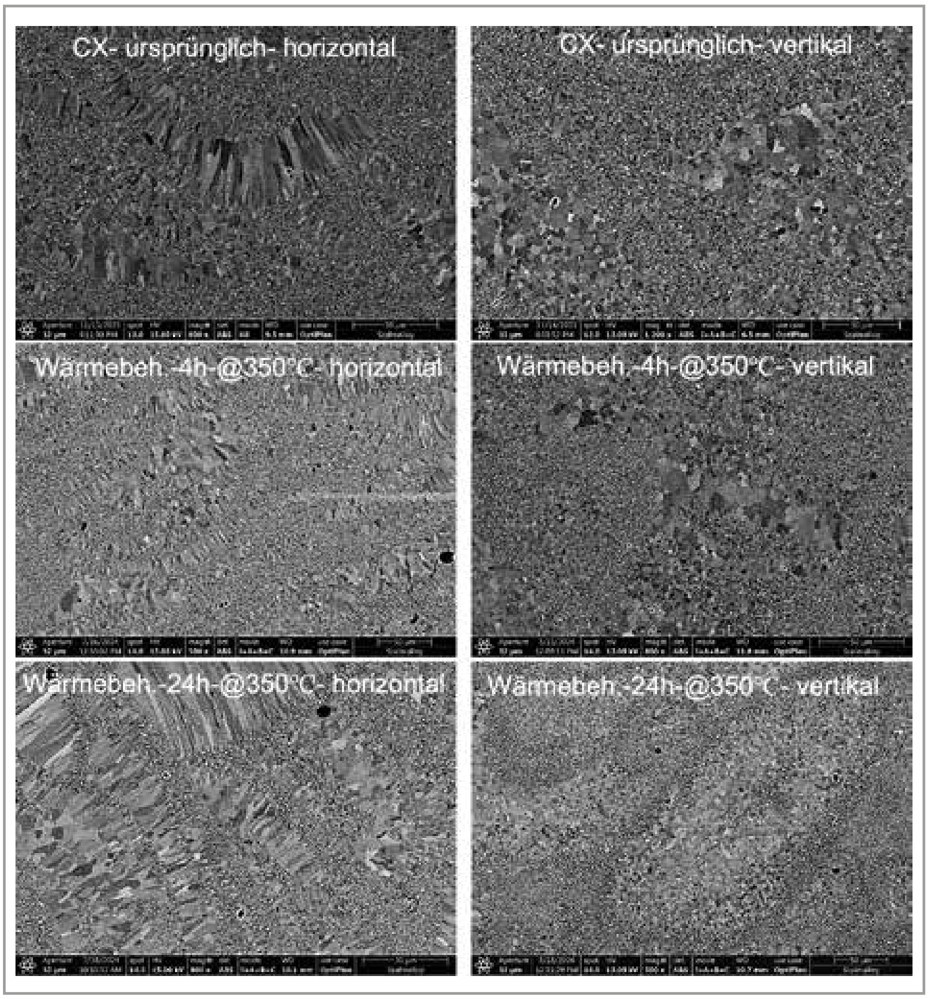


Fig. 11: Microstructure of a Scalmalloy-CX sample in horizontal (left) and vertical (right) direction in the original state and after 4h and 24h at 350°C (from top to bottom). In the horizontal direction there is an expansion of coarse grains, in the vertical direction a refinement of the grains with longer heat treatment.

Results from the Research Areas

Installation of a technology demonstrator for a superconducting 200kA industrial busbar being at Trimet in Voerde

Superconducting Power Applications

Coordination: Prof. Dr.-Ing. Mathias Noe

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

- Superconducting grid and energy components
- Modeling of superconductors and components

The focus of the topic "Superconducting power applications" is on the development of new types of equipment for electrical energy systems and the application-oriented development of user-friendly simulation models of this equipment. The following results were achieved in 2024

SUPERCONDUCTING GRID AND ENERGY COMPONENTS

SUPERCONDUCTING CONVERTER

Superconducting switching is a promising application for REBCO tape conductors.

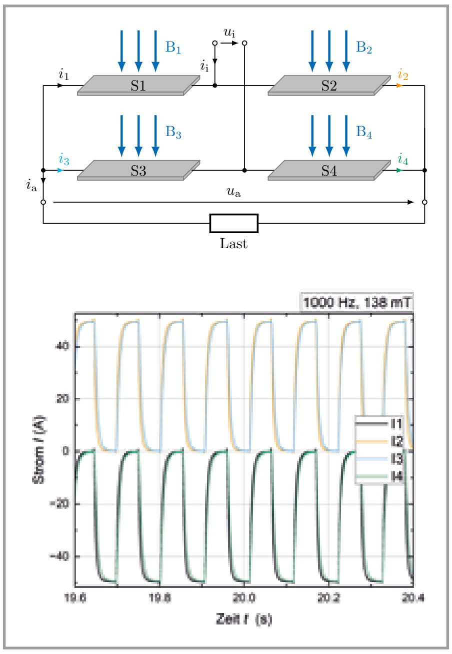


Fig. 1: Top: Basic structure of the bridge circuit with two parallel, superconducting paths. Bottom: Current flow in the individual current branches of the bridge circuit during continuous operation

This uses the dynamic resistance of the superconductor, which occurs when the superconductor is in an alternating magnetic field. A superconducting bridge circuit was demonstrated in 2023 as part of a doctoral thesis. By selectively controlling the switches S1-S4 (see Figure 1 above with HTS tape conductors), a converter can be constructed in the same way as semiconductors.

In 2024, the circuit was tested in continuous operation and the experimental work on basic understanding was completed. As shown in Fig. 1 below, the desired current conversion was demonstrated. By increasing the superconducting resistance, the commutation time and thus the frequency can be increased and the achievable voltage of the circuit can be adjusted.

Contact: quoc.pham.kit.edu

BMWK PROJECT HIGHAMP

In inner-city energy distribution networks, it is necessary to replace existing cables with systems with higher currents. The aim is to develop innovative systems with which the existing pipelines of the existing AC gas pressure cables can continue to be used, but with higher specific power. As part of the HighAmp joint project, a high-performance HTS system is being developed to replace existing pressurized gas cables. The aim of the project is a 3-phase HTS cable for retrofitting (conversion in existing floor ducts):

- Length: approx. 15 m
- Transmission capacity: approx. 100 MW
- Voltage: 20 kV
- Current: 3 kA
- Operating temperature: 70 K
- Insulation: supercooled liquid nitrogen

Unlike in other HTS cables, the three phases are not arranged coaxially, but in a triangular structure. This has advantages in terms of high-voltage resistance and electrical symmetry. On the other hand, this arrangement requires suitable HV-resistant support structures that fix the position of the phases in the cryostat tube, particularly with regard to the repulsive Lorentz forces.

As simulations at KIT have shown, stacked tape conductors are out of the question with regard to AC losses. Currently, the only feasible alternative is CORT conductors (conductor on round tube), HTS tapes helically wound on a round copper carrier. Trial conductors are available for such conductors and are currently being tested. The simulations of AC losses were further refined in 2024. According to the current status, the total losses at rated current in a three-phase cable made of CORT conductors remain manageable.

An experimental setup for the calorimetric measurement was set up and the calibration measurements were completed. With the AC source used so far, it has only been possible to excite currents of up to 1 kA in the test specimen, which is too low to generate calorimetrically measurable losses. Accordingly, we have further developed the test stand for AC losses; the AC source was equipped with a more powerful transformer in order to achieve the target value of 3 kA at frequencies of 30 to 70 Hz.

High-voltage tests on 3-phase short samples were carried out using the Combutt (Cryogenic One Meter Build-Up for Tube Testing) system with liquid nitrogen. Withstand voltage tests with single-phase AC

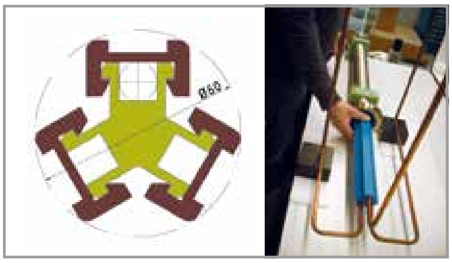


Fig. 2: Cross-section sketch (left) and picture of the insertion (right) of a milled continuous insulation made of PE-UHMW into the Combutt corrugated tube. Routing the three copper tubes upwards outside the electrical insulation allows the inner conductors to be connected to high voltage during the test in the cryostat.

voltage, three-phase current and standard lightning impulse voltage were carried out in continuation of previous work on test specimens with continuous electrical insulation. This continuous insulation ensures continuous support of the three inner conductors within the corrugated tube.
Two variants with milled PE-UHMW insulators were investigated (Fig. 2).

A "hose" variant was then investigated, in which pressure hoses, laying pipes and an external wastewater pipe were used for support (Fig. 3). The components used were made of PE material and are available at low cost in long lengths.

All five continuous variants examined in Combutt were successfully subjected to bending tests. The withstand voltage results achieved last year (AC: 72 kVrms, three-phase current: √3*50 kVrms, lightning impulse: 145 kV) for the two test specimens with discrete insulators in the smooth tube could not be achieved by any continuous type in the corrugated tube. A test was therefore carried out with a discrete insulator in the corrugated tube.

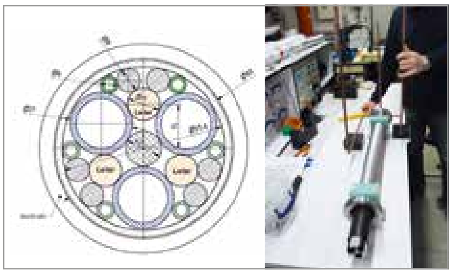


Fig. 3: Cross-sectional drawing (left) and picture of the assembly of the test specimen (right) in which the inner conductors are held in the correct position inside the corrugated tube with hoses and tubes made of PE.

Overall, in the high-voltage tests in the corrugated tube, the discrete insulator variant showed a higher dielectric strength than the continuous insulators tested. However, one disadvantage of the discrete insulator variant is the difficulty of installing the insulator arrangement in the corrugated tube as the length or number of insulators increases. Criteria such as ease of installation are therefore also taken into account when selecting the insulator variant for the 10 m demonstrator.

A milled PE type and the hose variant are considered to be potentially the most suitable variants for the continuous insulators. A modification of the discrete PE variant is currently being investigated, which also allows it to be drawn into corrugated pipes of greater length with many discrete insulators.

Contact: andrej.kudymow@kit.edu and stefan.fink2@kit.edu

BMWK PROJECT ROWAMAG

The aim of the BMWK project RoWaMag (Robust and low-maintenance magnetic heater with high-temperature superconductor coils for hot forming processes) is to develop a robust and low-maintenance magnet with 2nd generation HTS conductors (REBCO tape conductors) for magnetic heaters. In addition, proof of the technical and economic suitability for the industry for heating cylindrical workpieces (billets) for extrusion presses is to be provided. A test of the cryogenic system and the magnet was carried out at the beginning of the year. It was found that the thermal coupling of the coil is strongly dependent on the strength of the magnetic field generated by the coil, as the individual partial coils are pressed better against the cold plates of the cold bus due to the attractive interaction between the iron yoke and the coil as the magnetic field increases.

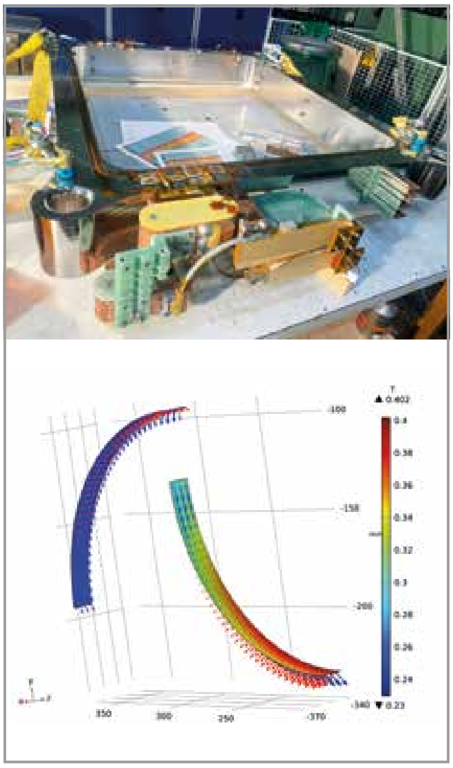


Fig. 4: Top: Solenoid with power supply before installation. Below: Calculation of the magnetic field strength (color scale and blue vectors) and the Lorentz forces (red vectors) at the HTS tapes of the current leads at a current of 500 A.

After cooling down, the solenoid was first subjected to currents of 200 A or 250 A over several days and the cooling behavior was investigated. The temperatures measured at the solenoid and at the warm end of the current supply lines at 250 A (corresponding to about half the operating current) were below the design temperatures of approx. 25 K at the solenoid and 80 K at the current supply lines. However, when the current was increased further, at approx. 286 A, one of the HTS current feeders quenched and was destroyed. Simulation calculations (Fig. 4) showed that the influence of the magnetic field on the current-carrying capacity of the HTS current feeders was underestimated by the manufacturer. At the ITEP, the current feeders were therefore redesigned with additional superconductor strips and 3D-printed supports to absorb the Lorentz forces. In addition, a concept was developed to improve the thermal connection of the current feeders to the first stage of the cryocooler so that the temperature at the warm end of the HTS current feeders does not rise above 80 K during current operation.

The installation of the magnet in the cryostat will take place in Q4/2024 so that the magnet can be tested in Q1/2025.

Contact: sonja.schlachter@kit.edu

BMBF PROJEKT FPP-MC

As part of the BMBF joint project "Contributions to the creation of a concept design for a fusion power plant based on magnetic confinement", acronym: FPP-MC, we are working in our sub-project mainly on the development of demountable, low-resistance and high-current-capable superconductor contacts for use in fusion magnets. The project was launched in February 2024 with the partners IPP Garching, Proxima Fusion and Gauss Fusion. The requirements for the contact were first defined in 2024. For a current of 100 kA, a nanoohm of resistance must be achieved at a temperature of 20 K or 4.5 K and a magnetic field of around 12 T. After a pre-selection of possible conductor and connection concepts, the first partial conductors were commissioned and the production of our own test connections began. Our work focuses exclusively on high-temperature superconducting tape conductors, as these are now sufficiently available and, in contrast to low-temperature superconductors, enable operation at 20 K. Furthermore, initial simulation models have been created with the project partners and the testing of partial conductor connections has been closely coordinated. Numerous tests are in preparation and will be carried out in 2025.

Contact: mathias.noe@kit.edu

MODELLING OF SUPERCONDUCTORS AND COMPONENTS

The current distributions in CORT (conductor-on-round-tube) cables carrying AC current were further studied by means of 3D simulations based on the H-formulation of Maxwell's equations.

The geometry under analysis was a one-layer CORT composed of three HTS tapes. It was found that, for such a geometry, it is not necessary to simulate a full twist pitch with periodic boundary conditions: one can instead simulate an arbitrarily short longitudinal section of the cable with appropriate boundary conditions for the magnetic field at the end. Such boundary conditions account for how the field changes along the longitudinal direction, as a result of the twist pitch. The simulated length can thus be made very short. The computation time of one AC cycle takes only minutes instead of several hours for the whole twist pitch length.

Figure 5 shows the longitudinal, azimuthal, and radial current density components for the simulated geometry of a one-layer CORT cable with 45-degree twist pitch. As expected, the current flows in the longitudinal direction in the outer part of the superconductor and in the azimuthal direction in the inner part. The two components connect by means of radial currents at the edges. The figure also shows the mesh discretization, which consists of only two elements in the extrusion direction, thus enabling short simulation times.

Last year, the Minimum Electro-Magnetic Entropy Production (MEMEP) method was used for 3D simulations aimed at calculating the levitation force between a permanent magnet and a double stack of HTS tapes. Good agreement with experiments conducted both in zero-field-cooling and field-cooling conditions was obtained. This year, the numerical model was further improved and shown to be much more computationally efficient than the so-called segregated H-formulation model proposed in the literature by other research groups.

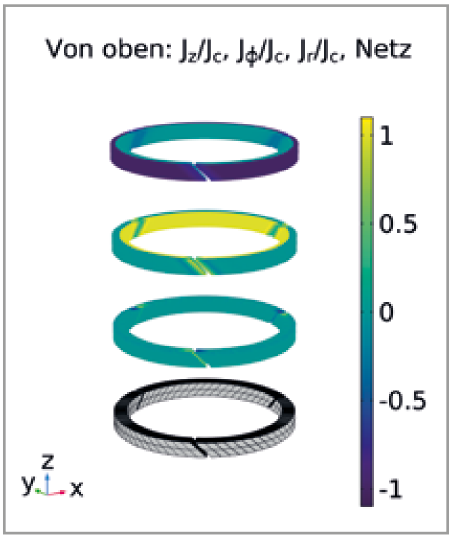


Fig. 5. Current density components and mesh in a CORT cable (peak AC current).

Figure 6 shows a comparison of the levitation force calculated with the two models, with MEMEP being 15 times faster. Further computational advantage could be gained by parallelizing the computation on large computer clusters.

In the framework of the FPP-MC project, we setup a 2D numerical model for investigating the temporal evolution of the current components in no-insulation coils. Within this model, the current can flow in the azimuthal and radial direction, and the behavior of the coil is essentially determined by the value of the contact resistance between the turns as shown in Fig. 7. This modeling approach will be used to study current distributions in practical coils developed by Proxima Fusion.

In a project with Siemens, we studied the mitigation of AC losses in a 15 MVA HTS transformer for wind energy applications

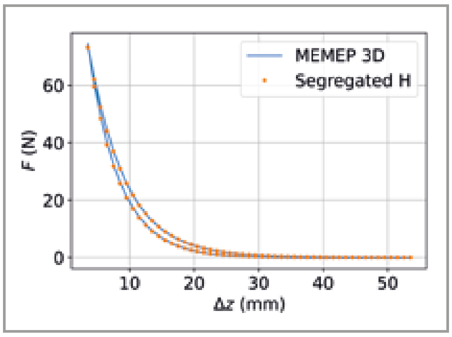


Fig. 6. Levitation force (F) as a function of the separation (Dz) between a permanent magnet and a stack of HTS tapes: comparison between the MEMEM 3D and Segregated-H models.

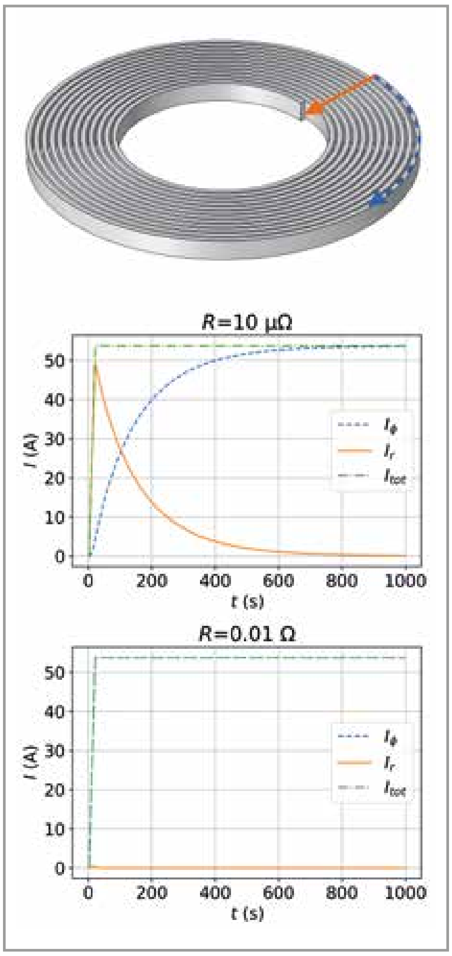


Fig. 7. Current components in a pancake coil for a different values of the turn-to-turn contact resistance.

by means of numerical simulations based on the finite-element method.

Employing an efficient 2D axisymmetric T-A formulation, we estimated the AC losses across up to thousands of turns of HTS tapes within a full transformer. To address the substantial transport current required on the low-voltage side, we utilized several parallel Roebel cables. Our analysis covered AC loss mitigation from individual tapes and Roebel cables to the entire electromagnetic components of the transformer, including the core and magnetic flux diverters. For each component, we investigated factors affecting the AC loses and proposed strategies to reduce them. Eventually, we proposed three distinct designs operating at temperatures of 20 K, 70 K and 77 K.

We participated in a collaborative work aimed at benchmarking different numerical models for the electromagnetic-thermal behavior of high-temperature superconducting coils. The cases under study were HTS coils of different shape (racetrack, circular) experiencing overcritical currents in different working conditions. One goal of the study was to investigate the possibility of homogenizing the electric and thermal properties of the different layers composing the HTS tapes, in order to greatly reduce the complexity of the simulated geometry and the computation time. This collaboration, which involved researchers from thirteen different research groups around the world, resulted in the publication of a joint article in Superconductor Science and Technology (DOI:10.1088/1361-6668/ad8315).

We collaborated with ENEA Frascati toward the development of analytical formulae for computing the instantaneous power dissipation in HTS stacked cables with a limited number of tapes per stack.
Those formulae, although not as accurate as the models based on finite-element calculations, achieve sufficient accuracy at high fields. This enables a sufficiently accurate assessment of the power dissipation in particular instants of a plasma scenario where the variation of the field is very high, such as during the critical initial discharge period of the plasma initiation. This collaboration too resulted in the resulted in the publication of a joint article in Superconductor Science and Technology.

Contact: francesco.grilli@kit.edu

Highlight
BMWK Project DEMO200

The aim of the project is to demonstrate the feasibility of a superconducting DC busbar for use as a return conductor in an aluminum electrolysis plant for a current of up to 200 kA.
As part of the project, the feasibility will be shown with a demonstrator for the full current of 200 kA DC but with a short transmission length of around 2.5 m. In an aluminum plant of the company Trimet near Voerde, we have built and tested a full-scale technology demonstrator with the consortium Vision Electric SuperConductors (VESC) as system integrator and knife for the cryogenic supply. KIT's contribution was the selection and validation of suitable 2G HTS material, the layout of the conductor arrangement, simulations, the testing of a subscale demonstrator at KIT at 77 K, as well as the metrological support of the final tests in Voerde.

The main challenge of such a demonstration: hardly any test facility can provide a direct current source of 200 kA DC with a low voltage.

As a solution, we designed the busbar as a circular arrangement of 10 modules, each with a current capacity of 20 kA in a common cryostat tube. The modules were connected in series for test purposes. The total current as well as the local magnetic fields and Lorentz forces are thus the same as in the parallel-connected target arrangement, but a current of 20 kA is sufficient to demonstrate the required DC current carrying capacity.

In 2024, work focused on setting up and carrying out the DEMO200 full-scale test in Voerde (see Fig. 8).

KIT prepared and supported the full-scale test with its own data acquisition, quench detection and a control system for the cryogenic valves. KIT also contributed to setting up the power supplies.

In detail, the measurement concept provided for low-induction measurement of the low voltages in the µV range, thermal anchoring of the plugs and bushings and a variable field to control the instrumentation during assembly. In addition, redundant temperature sensors, a nitrogen level probe and flow control ensured the safe operation of the power supply.

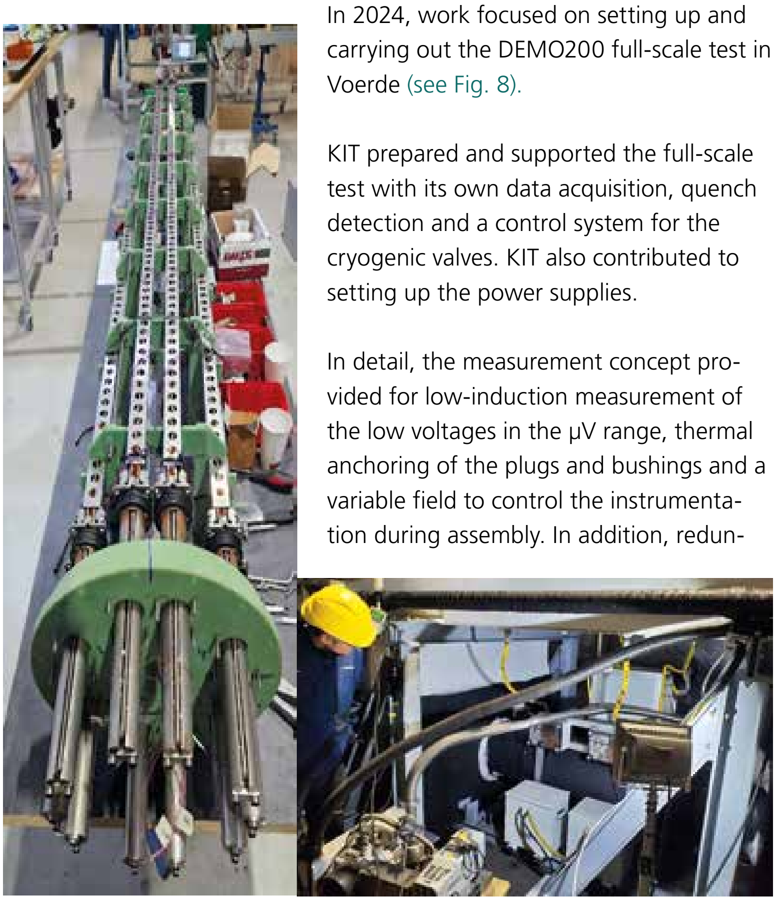


Fig. 8: Top: 200 kA module (image Vision Electric SuperCondustors. Below: DEMO200 setup during test operation in Voerde

KIT was also responsible for the power supply, control, monitoring and current measurement in "tandem" operation. The tests were accompanied by an AC ripple measurement of the alternating current components in the test object and the current equalization between the two current sources operated in parallel.

The measurement and control system functioned in a LabView environment. The voltage measurement on individual 20 kA HTS modules in the pressure vessel was set up redundantly. Recorded data can be displayed during testing as time plots, as X-Y diagrams (e.g. voltage vs. current) or as current values on the implemented RI diagrams. Trends such as temporal or spatial temperature gradients can also be displayed and quantified. The complete computer-aided measurement system was used in Voerde and is now being used for other ITEP projects.

The final test of the DEMO200 full-scale demonstrator took place in September 2024 at a TRIMET aluminum plant in Voerde. A current of 190 kA was achieved in the busbar at 77 K. At the targeted temperature of 70 K, more than 200 kA can therefore be transmitted. This has never before been achieved in a DC busbar with high-temperature superconductors and was the prerequisite for the SuprAl project, in which the 600 m, 200 kA conventional busbar is now being permanently replaced by a superconducting busbar. ITEP is providing scientific support for the project and is responsible for recording and analyzing the data.

Contact: andrej.kudymow@kit.edu

Results from the Research Areas

Power Hardware In the Loop Hall in Energy Lab

Real Time System for Energy Technologies

Coordination: Prof. Dr.-Ing. Giovanni De Carne

In the research field of real-time systems for energy technologies, ITEP scientists are working on the following topics:

- Design and control of future energy grids
- Experimental Validation of energy technologies

The focus of the topic "Real-time systems for energy technologies" is on the design and control development for energy technologies and their experimental validation under realistic system conditions using real-time simulation and power hardware in the loop approaches. The following results were achieved in 2024:

REAL TIME SYSTEMS FOR ENERGY TECHNOLOGIES

FAST REAL TIME MODELS FOR ENERGY SYSTEMS

The Real Time Systems for Energy Integration (RTSET) group works extensively on energy components and grids 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 extended the existing 3-phase equivalent dynamic load model to a single-phased version. Respect to the state of the art, we have reduced of the 50% the needed computational time, making comparable with passive load models (Fig. 1). Similarly, to the three-phase version, 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 with the large unbalanced IEEE 34-bus test feeder grid, showing improved computational performance.

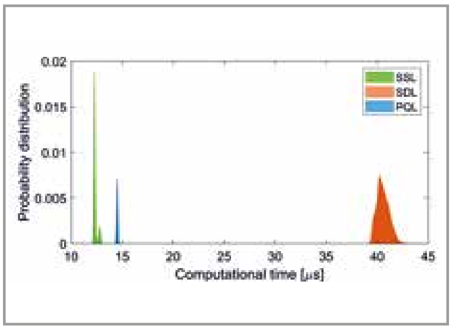


Fig. 1: Computational time for computing the IEEE 34-bus test feeder grid with the proposed and existing approaches.

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 generators. Our recent activites have focused on testing the load dependency on voltage and frequency on larger scale, involving the KIT experimental facility "Energy Smart Home Lab" with commercially available loads and in realistic household conditions. We have conducted extensive experiments involving more than 30 different loads, and the reproduction of a realistic 1-day test case of household load. As a result of this testing, the load sensitivity to voltage of a typical apartment has been derived, showing how the load in average is still linearly dependent on the voltage (Fig. 2). Considering the frequency, instead, we determined the behavior of the loads in a very large frequency range (40-60Hz). The loads are able to survive in this large frequency range, however, their behavior is not anymore linear and strong non-linearities occur.

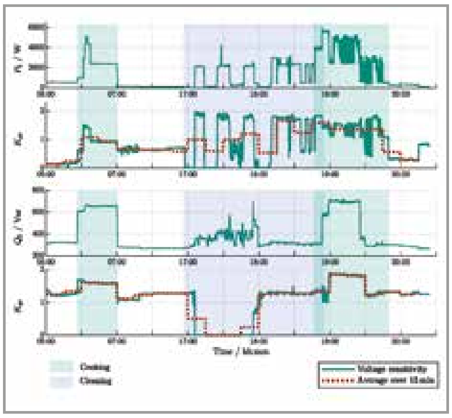


Fig. 2: Example of the load sensitivity day-profile at the Energy Smart Home Lab.

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. One of the major challenges for PHIL testing is the accuracy of the results. Due to the realization of a loop consisting of power amplifier, filtering, digital/analog conversion, the PHIL testing differs slightly from the reality. For this reason, we are working on using impedance-based stability approaches for assessing the accuracy and stability of PHIL testing. As can be seen in Fig. 3, we are able to verify the correctness of the impedance-based stability approach by means of experimental results.

HYBRID ENERGY STORAGE SYSTEMS

Energy storage systems play an important role in supporting the grid stability and

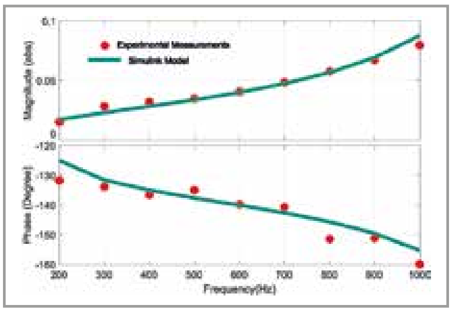


Abb. 3: Impedance Profile of the converter under test in PHIL.

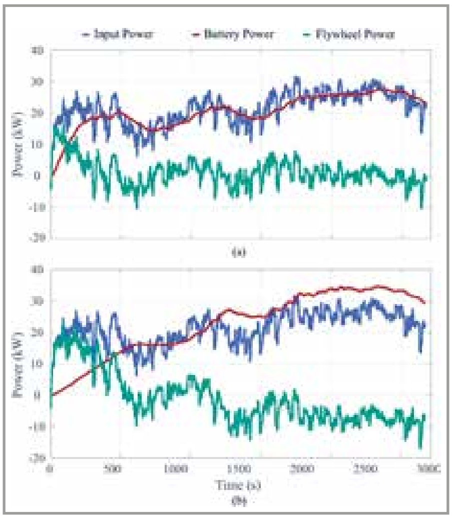


Fig. 4: Power profile of the hybrid flywheel / battery HESS during deliver of grid services. Experimental comparison of power in two methods (a) Filter method (b) Fuzzy-Moving average Method

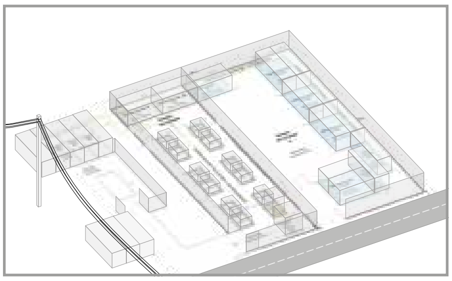


Fig. 5: H2-Rail lab in current development for experimental validation of hybrid train technologies.

guarantee supply reliability. However, using batteries to address both slow and fast power dynamics may strongly affect their lifetime. Battery energy storage systems can be integrated by power-intensive (but with low energy density) energy storage systems, such as flywheel or supercaps. At the RTSET group, we have expanded our knowledge 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). A recent publication showed that, using tailored fuzzy-logic-based approaches, the power dynamics can be easily decoupled between the two energy storage systems (in this case a battery and a supercap), enabling a better management of the power and the resources state of charge (Fig. 4). In our current studies, we are analyzing the potential in extending the battery lifetime by means of HESS. Cooperating with the University of Perugia in Italy, we are developing a new aging-analysis approach based on power hardware in the loop, that allows a more realistic assessment of the battery aging.

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. The RTSET group is leading the Hydrogen Integration Platform, the newly developed platform at Energy Lab to develop and test hydrogen technologies in realistic conditions, by means of the PHIL connection. Two laboratories have been planned from RTSET: the H2-in-the-loop lab, where a 50kW electrolyzer, compressor, tank, and a 10kW fuel cell system are currently connected and in operation. The goal is to study with this reduced-scale plant the integration of hydrogen plants in the electrical grid. In particular, we are focusing on providing frequency support modulating the power demand in low-inertia grids. The second lab ((Fig. 5) is the H_2-Rail lab, where a 1.2MW fuel cell and a 1.8MW, 1,2MWh battery will be installed this year to emulate the performance of hybrid cargo trains (hydrogen+batteries). This is a joint project with Siemens Mobility to develop optimal energy and power management solutions.

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

Particle accelerators are energy-intensive facilities, that needs to prioritize the experiments and require high power quality standards. On the other side, the grid is becoming more volatile and there is higher pressure to reduce energy costs and improve the energy usage. The RTSET group, together with the particle accelerator KARA at KIT, are leading nation-wide the topic on sustainability of research infrastructure by means of newly-develop research infrastructure KITTEN. The main focus of KITTEN is to address these energy efficiency and stability challenges in accelerators and offer solutions in the broad physic and energy engineering aspect. As a result, a 5M€ Horizon Europe project "Research Facility 2.0" is currently on-going at KIT, 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 are studied, focusing on concrete solutions in the area of digital twins, permanent magnets, solid state amplifier, and AI-based control of accelerators. The main result for the RTSET group lies in having developed a fast communication infrastructure (4kHz sampling rate) that allows the real-time communication between the KARA and the KARA digital twin realized at Energy Lab. First voltage and current data have been transmitted and the system is currently being expanded for more than 30 measurement points in the KARA accelerator (Fig. 6).

Contact: giovanni.carne@kit.edu

TRANSIENT MODEL FOR SUPERCONDUCTING POWER CABLES

The growing global demand for electricity and the increasing integration of renewable energy sources are challenging power

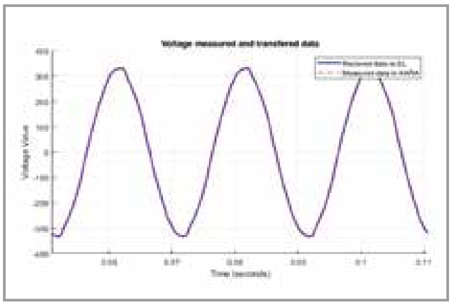


Fig. 6: KITTEN first voltage waveform at 4kHz transfer between KARA and Energy Lab.

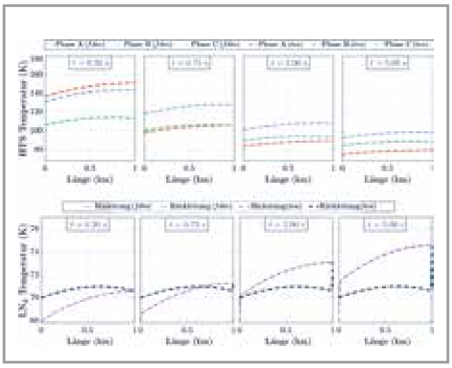


Fig. 7: Temperature along the length of the cable (a) for the HTS tapes and (b) for the forward and return LN2 flow in the three-phase concentric design. Comparison between results of FDM scheme and TEA method.

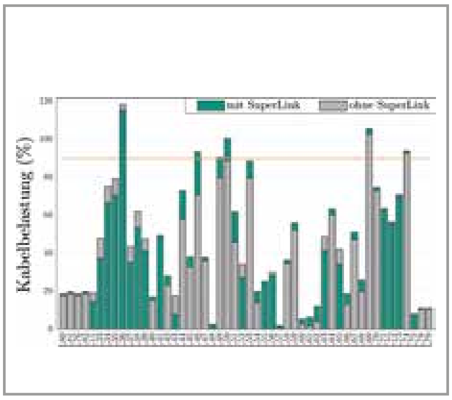


Fig. 8: Impact of SuperLink Cable Integration on Load Flow in the 110 kV Grid: Comparison of Cable Loading with and without the SuperLink Cable.

grids and driving the need for network expansion and modernization. To address this, several superconducting cable projects have been launched, showcasing the potential of this technology. Understanding the role of HTS cables in power grids is crucial, yet traditional studies often rely on simplified models. Our team developed a simulation method compatible with large-scale power system simulators, offering detailed analysis of electrical and thermal performance of HTS cables during electromagnetic transients. Using the three-phase concentric design we demonstrated that analogies between electrical and thermal variables enable accurate HTS cable simulation in power networks.

Figure 7 compares this thermal analogy method (TEA) with the more precise finite-difference method (FDM) from the literature, showing good agreement in thermal behavior. Additionally, the TEA method calculates cable electrical resistance, which will be used by the power system simulator to analyze the impacts of the cable in the network.

Besides being faster and requiring less computational effort, the model automatically incorporates the boundary conditions between the cable layers. This leads to a straightforward implementation, which is highly attractive for real-time simulators used in power hardware-in-the-loop environments.

GRID OPTIMIZATION DUE INTEGRATION OF A 110 KV HTS CABLE

A key objective of the SuperLink Project is to develop a 15 km superconducting power cable for the 110 kV grid in Munich. Initial analysis (Figure 8) shows the cable reduces load on some lines but may shift power flow, potentially overloading previously unaffected cables.

Figure 8 highlights the need for a new distribution network due to rising power demand. The future grid design incorporates the superconducting cable developed in the framework of the SuperLink Project, potentially avoiding new substations and reducing transmission line lengths. Two network designs were developed and compared.

Both grids reduce total cable length from the current 383 km. Compared to a network using only copper cables, Net.02 highlights the space and cost advantages of superconducting technology. Net.02 also allows decommissioning thermal power plants at MS-02 and SB-06 and cuts SB-21 generation to 65%. LN represents normal cable length, LHTS superconducting connection length, and LT total grid cable length.

Contact: sousa@kit.edu

Results from the Research Areas

Winding tests in the robotic winding cell for the production of non-planar coils from the second generation of high-temperature superconductor tapes (2G-HTS). A particular challenge is the degradation-free guidance over the high edge of the tapes with a high geometric aspect ratio.

Superconducting Magnet Technology

Coordination: Prof. Dr. Tabea Arndt

In 2024, the infrastructure components and technology modules developed in previous years were brought together. The interaction between the various research groups enabled special results to be achieved.

The three research topics "Coil and magnet technology", "High-current components for hydrogen technologies and fusion" and "Rotating machines" of the research field "Superconducting magnet technology" showed both great individual results and successful interaction in 2024.

For example, the DUDA coils originally initiated from magnet technology and cooling by cryogenic thermosiphon are essential for research work in the field of rotating machines, as well as important links for compact applications in the field of liquid hydrogen in the energy system. (A neon-based thermosiphon allows advantageous coupling via heat exchanger to liquid hydrogen without the challenges of hydrogen directly in the application). The experience with the developed fusion composite conductors also provides essential preliminary work and basic expertise for the hybrid energy pipeline.

The favorable positioning is now evident both in the combination of the three research topics and beyond the research field "Superconducting Magnet Technology" to the other research fields in the ITEP.

COIL AND MAGNET TECHNOLOGY

ROBOTIC WINDING TECHNOLOGY

Dipole magnets for accelerators, distributed windings for stators and stellarator magnets are examples of magnets made from non-planar coils. The development of non-planar coils wound from tape-shaped high-temperature superconductors (HTS) poses a particular challenge due to the sensitivity of the HTS material to mechanical stress and magnetic field alignment.
A robot-supported winding system was set up at the ITEP for the production of non-planar coils. The robot cell consists of a workpiece positioner for holding the coil body and two six-axis articulated robots for handling the winding tool, the so-called winding hand. The winding hand feeds the HTS tape from a supply reel and regulates the winding tension.

Programming the robots for winding non-planar coils via a digital twin requires the path, rotation and inclination of the winding hand to be defined according to the specific shape of the coil to be wound.
Winding tests were successfully carried out for a super ellipse-shaped coil with raised ends (see Fig. 1). Valuable knowledge was gained about the design of the winding body for a non-planar coil. Based on this preliminary work, the production of the first non-planar coil is being prepared. This coil shape is the first in a series of increasingly complex designs that are to be wound using the robots. The aim is to develop a flexible robot programme that is capable of winding a variety of non-planar coil shapes.


Fig. 1: Test winding of a coil with erected winding heads on a superellipse-shaped winding body.

COOLING CONCEPT: THERMOSIPHON WITH CRYOCOOLER

The temperature range between 20 and 30 K is relevant for a large number of technical applications for high-temperature superconductors (HTS). In addition, hydrogen, an important future energy vector, boils in this range, namely at 21 K.

It is therefore necessary to make this temperature range available for experiments and investigations as simply and efficiently as possible. Due to the further increase in the price of liquid helium, dry cooling with cryocoolers is the first choice here. In contrast to the usual connection of a test object to the cryocooler via heat conduction through solid copper, the coupling via a thermosiphon is to be investigated in this system. A thermosiphon (heat pipe) basically consists of an evaporator (on the object to be cooled), a condenser (on the cold head of the cryocooler) and a connecting pipe or hose between the two. This closed system contains a small amount of a cryogen (in this case neon) that boils in the desired temperature range. The material flow and the phase transitions of the neon at the cold and warm ends ensure extremely effective heat dissipation.

After the construction of the thermosiphon test stand was completed in 2023 (see Fig. 2), in 2024, the experiment was successfully commissioned as part of a master's thesis.

The heat pipe was specifically driven to the system limits and its stability and resil-

Fig. 2: Thermosiphon test stand with cryostat and cryocooler (left), measuring rack (center) and PC with LabView measuring program (right).

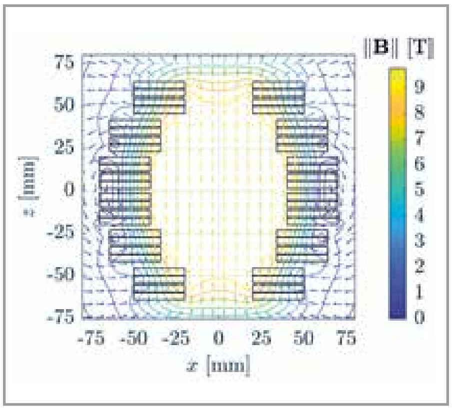


Fig. 4: Magnetic field B in the cross-sectional plane of the hyperion magnet design (the z-direction corresponds to the symmetry axis).

ience tested. For this purpose, a matrix of heat loads was applied to the condenser and evaporator. It was found that up to 130 W can be safely dissipated in a stationary state without any problems. This corresponds to the cooling capacity of the cryocooler at 28 K. At the other extreme – i.e. without a heat load – the system freezes: The neon inventory becomes solid (see Fig. 3). After condensation of the first neon droplets, a liquid level forms after some time. The full cooling capacity leads to solidification of the neon (at a timestamp of approx. 10:40). Heat dissipation is no longer possible in this state. To prevent freezing, a heater with PID temperature control was successfully implemented on the evaporator. This reliably prevents freezing and thus ensures heat dissipation.

COLLABORATIVE RESEARCH CENTER HYPERION

Nuclear magnetic resonance spectroscopy (NMR) is the most chemically precise method for obtaining detailed information about the molecular structure. The Collaborative Research Center 1527-HyPERiON deals with the basic challenges to improve the NMR-Spectroscopy in a pronounced interdisciplinary project.

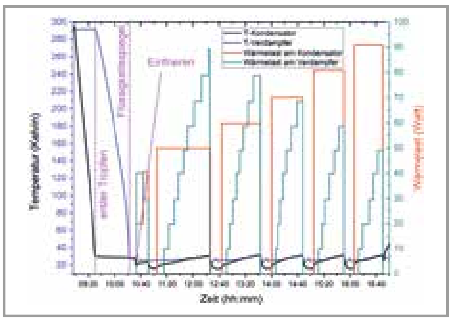


Fig. 3: Cooling protocol of the thermosiphon test stand. After condensation of the first neon droplets, a liquid level forms after some time. The full cooling capacity leads to solidification of the neon (approx. 10:40). The system was then tested with different heat loads on the condenser and evaporator.

One focus of HyPERiON is the miniaturization of NMR systems in order to develop compact NMR benchtop solutions. This includes the miniaturization of various components, including the NMR magnet, the compensation coils, the cryogenic system and other essential elements.

The aim of the work package "Compact superconducting high-field magnets" is to design and build a compact magnet that can generate a strong, homogeneous magnetic field that is suitable for NMR spectroscopy "on the table".

A conceptual design for such a magnet system was developed. The magnet consists of six coil modules, each containing two double pancake coils, as shown in Fig. 4. The modules are arranged in such a way that the inhomogeneity of the magnetic field in the center of the bore is minimized. The construction of a coil prototype for this magnet is being prepared.

EU-PROJECT MEESST

The EU-Project MEESST (Magnetohydrodynamic Enhanced Entry Systems for Space Transportation, funding number 899298) was successfully completed in 2024. At the beginning of the year, experiments were carried out in the plasma channel of the Von Karman Institute for Fluid Dynamics (VKI, Belgium) to demonstrate the attenuation of the radio blackout using magnetohydrodynamic effects. The magnet robotically wound by ITEP with HTS tapes from THEVA and the cooling system designed by Absolut Systems continued to function stably during the experiments, but the data and power cables in the plasma chamber were irreparably damaged during the final experiment, in which the plasma chamber of the VKI was heated to several hundred degrees Celsius.

Before the magnet and cryosystem could be brought to the Institute of Space Systems (IRS) at the University of Stuttgart for heat shielding experiments, new cables with heat-resistant insulation had to be manufactured. The cryosystem with the MEESST magnet and the measurement and control electronics were installed and put into operation in the PWK1 wind tunnel at the IRS in collaboration with Absolut Systems (see Fig. 5).

The MEESST magnet also functioned smoothly at the IRS, so that numerous experiments could be carried out over a period of several weeks. As with the experiments at the VKI, the data acquisition and magnet control could be carried out both on site and remotely from the KIT, so that the ITEP scientists were able to provide assistance at all times.

The plasma experiments carried out at the IRS (see Fig. 6) showed impressively that the heat shielding improves with increasing magnetic field. Under plasma condi-

Fig.5: MEESST magnet and cryostat during installation in the PWK1 plasma channel of the IRS.

tions corresponding to re-entry under lunar-like conditions, a shielding effect of 36% was observed at the maximum coil current of 50 A, while the shielding under Mars-like conditions was as high as 83%. The simulations carried out by partners as part of the project were able to successfully reproduce the observed changes in the shock wave impact distance as well as a tunnel effect in the direction of the magnetic axis.

To summarize, the MEESST probe has proven its relevance with astonishing results, even if further studies are needed to advance the technology, for example for tests under flight-relevant conditions.

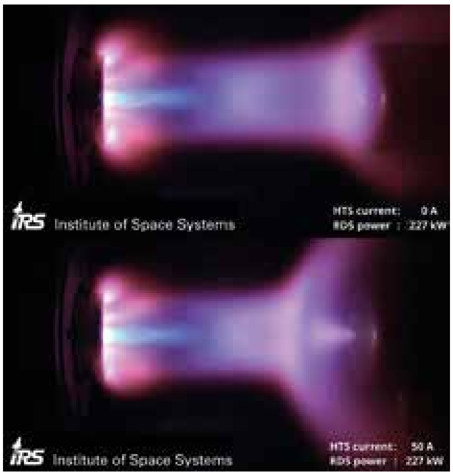


Fig.6: Sectional view of the plasma experiment at the IRS without magnetic field/coil current (top) and with a coil current of 50 A (bottom). The cryostat with the magnet can be seen on the right.

SHIP-PROJECT

Undiscovered particles that go beyond the Standard Model of particle physics are either very heavy or belong to a class known as Feebly Interacting Particles (FIPs), which interact only very weakly with known particles.

The "Search for Hidden Particles" (SHiP) experiment at CERN is a general-purpose experiment to search for FIPs. In 2024, the construction of SHiP in the high-intensity beam dump facility in the CERN ECN3 experimental area was approved and is scheduled to go into operation in 2032. The proton beams of the Super Proton Synchrotron (SPS) are directed at a fixed target and produce particle showers that can contain FIPs. To enable the detection of FIPs, all strongly or electromagnetically interacting particles must be removed from the particle shower before it reaches the detector system. This is achieved by installing a hadron absorber and a muon shield between the beam target and the detector system.

In 2024, ITEP joined the SHiP project to develop an HTS magnet for the muon shield. This magnet is intended to deflect muons from the detector volume. The work is currently in the design phase, with the current magnet design shown in Fig. 7. The length of the 5 Tesla magnet is 7 meters, with a width of 1 meter and a height of 0.6 meters. This would make the magnet one of the largest HTS magnets in the world.

In order to develop and test new winding and production technologies for the SHiP myon shield magnet, a series of test and prototype coils are planned.

Contact: frank.hornung@kit.edu

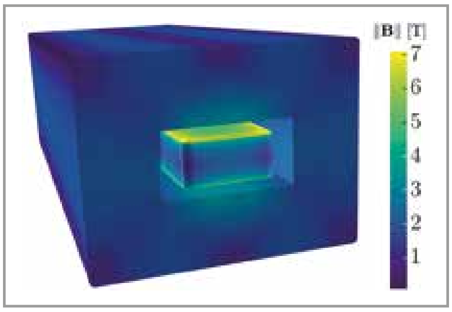


Fig. 7: 3D view of the magnetic field strength B in the superconducting SHiP myon shielding magnet system (HTS coil system with iron core and outer iron yoke; according to the current concept design).

HIGH-CURRENT COMPONENTS FOR FUSION AND LIQUID HYDROGEN

In 2024, work continued in national and European projects on the research topic of high-current components for hydrogen and fusion. For fusion, work was carried out as part of EUROfusion on a sample to investigate quenching in high-temperature superconductors in high-current cables for fusion, and for hydrogen applications as part of the TransHyDE hydrogen lighthouse project on the combined transmission of liquid hydrogen and electrical energy via superconducting cable.

EUROFUSION – QUENCH IN HTS

After several failed attempts to repair a leak in the sensor feedthrough at the upper contact of the SULTAN probe, this area was redesigned. The two contact half-shells were redesigned and manufactured for this purpose (Fig. 8). Instead of a frontal manifold feedthrough, separate feedthroughs for voltage taps and glass fiber thermometers were introduced in the revised version. This reduces the complexity of each individual bushing to a level that can be safely handled. In consultation with the operating personnel at the SULTAN test facility in Villingen (CH), the voltage feedthroughs are led out of the sample in a radial direction.

To carry out the repair, the upper 450 mm of each leg was carefully dismantled and cut open. To do this, the specimen had to be completely dismantled and the individual legs taken to the technical building. During dismantling, it was particularly important that all wires and capillaries

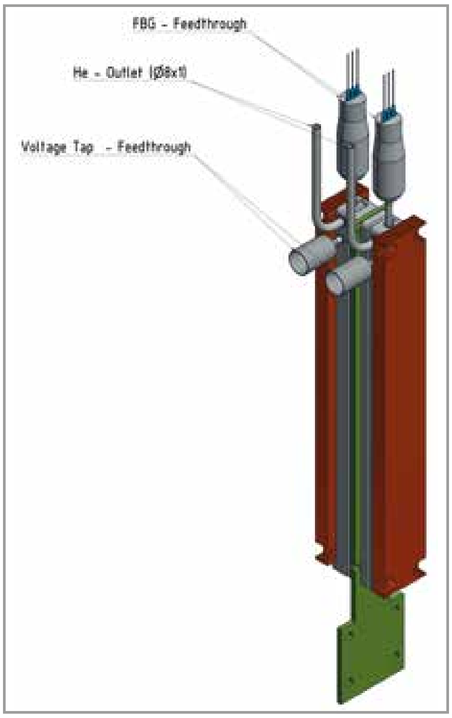


Fig.8: CAD model of the revised upper contact of the SULTAN sample.

Fig. 9: Photo of the state of repair at the end of 2024. The wires (above) will have to be removed and replaced with glass fibers. The wires were used to prevent contamination of the capillaries.

within the sample retained sufficient length after the cast sample parts were separated. The contact could then be de-soldered and the conductor prepared for re-soldering into the reworked contact. Parallel to this work, the stainless steel and copper components of the new contact were manufactured and brazed together under vacuum. Once the conductor had been soldered into the new contact half-shell, work could begin on reassembling the voltage taps. As of January 2025, the voltage taps of both legs are fully assembled (Fig. 9).

Once the glass fibers have been threaded into the new bushings, the contact can be welded to the second half-shell. Once the sample clamp for the mechanical support has been refitted, the repair is complete.

TRANSHYDE-PROJEKT APPLHY! – TECHNO-ECONOMIC ANALYSIS OF A HYBRID PIPELINE

The AppLHy! project deals with the utilization and transport of liquid hydrogen (LH2). In this context, we are investigating the synergetic transmission of LH2 and electricity via high-temperature superconductors in a joint hybrid pipeline. One of the main research questions is: Under which conditions can a hybrid pipeline be more favorable than conventional alternatives? To answer this question, not only the costs for the construction and operation of the hybrid pipeline are relevant. The context and the costs for all other system components required for the transmission of both energy sources are just as crucial.

A great need for new infrastructure for the transmission of electrical power and hydrogen is expected to arise on the German North Sea coast. Due to the potentially high demand for liquid hydrogen in urban centers such as Hamburg, it would make sense to deliver the liquid hydrogen imported via ports by tanker to users in liquid form and not just in gaseous form. For this case study, the system boundaries were defined as shown in Fig. 10.

We compare two transmission alternatives: the hybrid pipeline and a conventional alternative consisting of high-voltage direct current underground cables and a pipeline for gaseous hydrogen. The components required and the technical details are shown in Fig. 10. The results to date show that, under these assumptions, the investment costs for the hybrid pipeline can be around half as high as for the conventional alternative. The operating costs and other configurations will be investigated as the project progresses. A second case study also looks at gaseous hydrogen as an end product. The difference in investment costs between the alternatives is currently much smaller here.

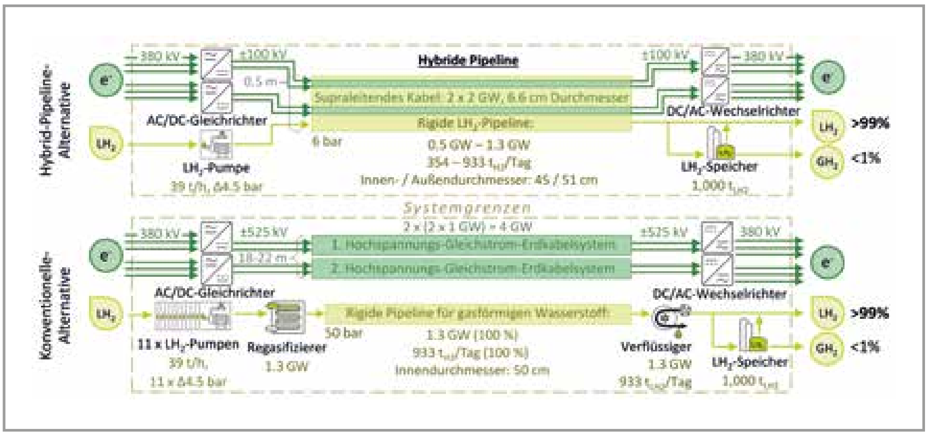


Fig. 10: Detailed configuration for the techno-economic comparison of a hybrid pipeline with a conventional alternative over a length of 75 km in the event that liquid hydrogen (LH2) is required at the end point.

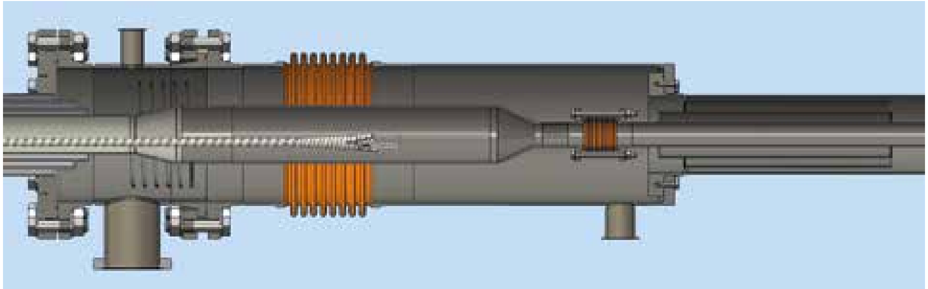


Fig. 11: Termination point of the hybrid pipeline demonstrator at the end closure.

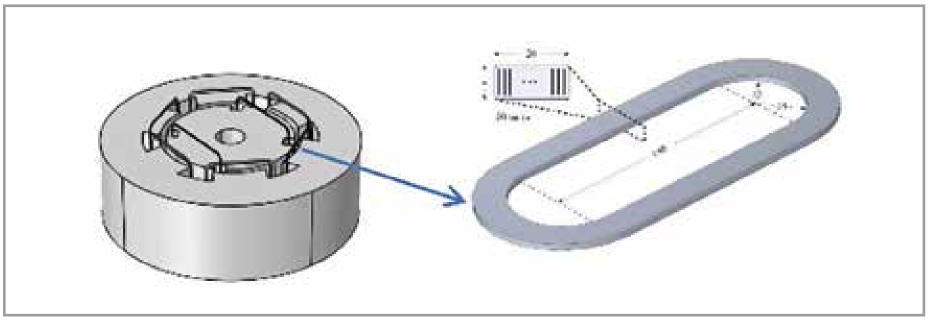


Fig. 12: Coil design and an example of the homogenization of a racetrack coil.

TRANSHYDE-PROJEKT APPLHY! – REALIZATION OF A DEMONSTRATOR FOR THE HYBRID PIPELINE

A key role in the realization of the hybrid pipeline demonstrator is the connection of the superconducting cable and the LH2 pipeline to the terminations. In the limited installation space, the superconducting cable must first be connected to the conductors of the terminations with low contact resistance and electrically insulated. For this purpose, a screw connection is used for contacting, which is easy to implement in the test field. The liquid-hydrogen line must then be closed in accordance with the requirements of the Pressure Equipment Directive. For this purpose, the design was optimized so that the pipeline could be closed exclusively using reducers, standard parts and standard welds in accordance with the AD2000 regulations. Finally, the vacuum jacket for thermal insulation must be produced; this is realized using a bell-shaped component. Fig. 11 shows a CAD model of the contact point concept.

Contact: michael.wolf@kit.edu

ROTATING MACHINES

SUPERCONDUCTING GENERATORS

In the SupraGenSys 2 project (start 01.04.2024), a scaled 250 kW generator based on the optimized 10 MW full HTS generator is being developed as a demonstrator and built under laboratory conditions. The project thus follows on seamlessly from the predecessor project SupraGenSys. The aim is to validate the results obtained using a test setup in the laboratory, to demonstrate the function and to further deepen the findings.

The AC losses in the machine winding of a full HTS generator are dependent on the radial and tangential fields that penetrate the conductors. This means that the AC losses are strongly dependent on the geometric machine design. Therefore, an analysis of the “end effects” of the iron core on the AC losses of the superconducting coils was carried out using a 3D simulation in a homogenized T-A formulation. Fig. 12 shows the coil design and an example of the homogenization of a racetrack coil.

A different concept is being pursued in the “Speedy_HTS” project (start date 01.10.2023): a medium-speed geared generator for wind turbines with a superconducting rotor and oil-cooled high-current stator is being developed, built and tested. To this end, the permanent magnet rotor of an existing generator is being replaced by a superconducting rotor with 24 double HTS coils (poles). A detailed design of the superconducting rotor consisting of a rotatable cryostat, the rotor with 24 double coils, the mechanical support of these coils and their electrical and cryogenic supply with the aid of a neon thermosyphon and a copper cold bus was created (see Fig. 13).

Due to the tight installation space, a window frame coil design was specified. Possible HTS suppliers were identified by conducting a market analysis with regard to the technical specifications, availability and price of the required HTS strip conductors. An ITEP decision template regarding the properties of superconducting coils, advantages and disadvantages in the winding and generator system, led to the specification of uninsulated, 12 mm wide HTS tape conductors and a so-called NI winding technology (NI = non-insulated).

A milestone defined as a termination criterion, in which a conceptual solution for the double-concentric implementation of pitch control and rotor cryogenic supply/electrics had to be developed, was fulfilled by a novel technical solution developed by ITEP. This innovation has been filed as a patent application. Work is currently underway on the contactless transmission of temperature probe readings.

DUDA (DISK UP-DOWN ASSEMBLY) COILS

Simulations of variants of DUDA coils have shown that they can generate a strong magnetic field with acceptable AC losses. The losses were calculated using data from the critical currents of various manu-

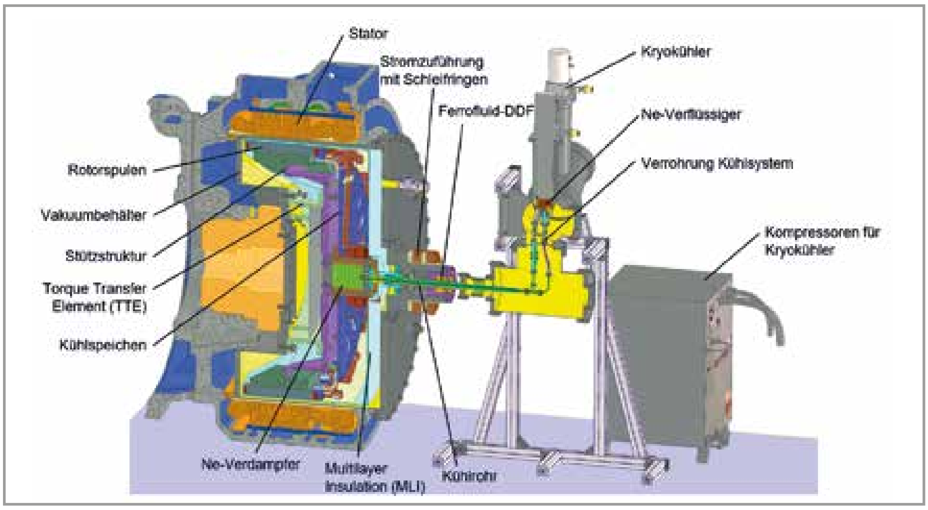


Fig. 13: Concept of the medium-speed generator with superconducting rotor (version for the test stand).

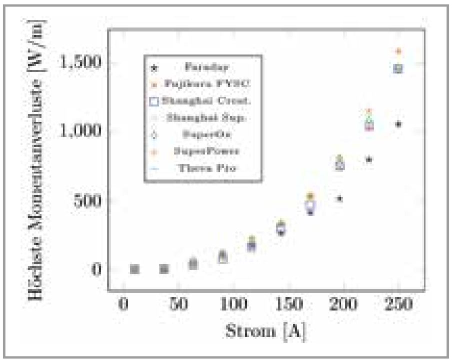


Fig. 14: Dependence of AC losses in rectangular DUDA coils on the operating current (various conductor manufacturers at f=50 Hz and T=30 K).

facturers, taking into account their performance at an operating temperature of 30 K (see Fig. 14).

AC losses increase with higher current. An increase in frequency would further increase the AC losses.

The dimensions of the coil, in particular the width of the current path w_s and the size of the hole b, have a considerable influence on the losses. A larger bore can reduce the AC losses – see Fig. 15.

Initial magnetization tests were performed at 77 K on a stack of five DUDA-HTS to investigate coil susceptibility to an external magnetic field.

The experimental setup consists of an alternating current source and a high-speed data acquisition system. The angle of the external magnetic field to the plane of the DUDA stack can be varied in steps of 10° (see Fig. 16).

Superconducting motors with HTS stacks
Superconducting squirrel cage motors are being investigated for the first time this year.

Analytical and numerical analyses are being carried out and experimental work is in preparation. The concept uses short-circuited DUDA stacks in the rotor,

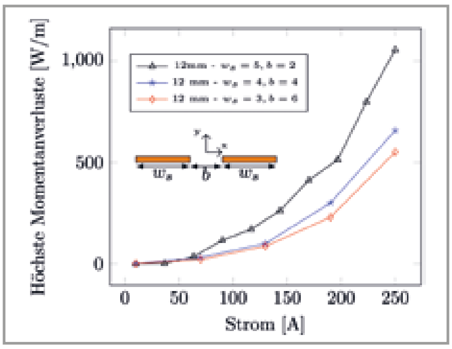


Fig. 15: AC losses of rectangular DUDA coils plotted against the current (50 turns, 50 Hz, 30 K, exemplary for HTS from the manufacturer Faraday). Three different variants (variation of the coil leg width w_s and the bore b with a total width of 12 mm) are shown.

which are cooled to an operating temperature of approx. 30 to 80 K by means of heat conduction. The anticipated magnetic field in the air gap is approx. 0.8 T. Further work is to be pursued in a partnership with the KIT ETI and the Fraunhofer-Gesellschaft.

As part of an industrial collaboration, the ITEP is developing fully superconducting motors with small dimensions and high torque. A full or partial DUDA winding system is being pursued for this purpose.

Contact: marion.klaeser@kit.edu

Fig. 16: Setup for angle-dependent AC magnetization measurement on DUDA coils.

Highlight

Invention of a concept for the central pitch tube feed-through in HTS wind power generators

In the "Speedy_HTS" research project (development of an HTS test stand machine in the housing of a conventional generator), a demolition milestone was set for the summer of 2024: development of a conceptual solution for the central passage of a control tube (rotational speed approx. 11 rpm) through the cryogenic HTS rotor (rotational speed approx. 600 rpm) of the wind power generator with integration of the stationary cooling system and passage of the cryogenic refrigerant. As the axis of symmetry of a wind power generator is inclined by approx. 8°, there is the additional challenge of allowing the cryogenic coolant to overcome the corresponding height difference. This problem has not been solved satisfactorily for more than 20 years. However, the team was able to outline and further develop a solution – even before the project work began – that met the termination milestone and for which a patent application was filed at the end of 2024.

Another advantage of this technical solution is that it frees up both shaft ends of a rotating machine for free use in the application.

Illustration: Drive side (gearbox side) of a medium-speed wind power generator with central feed-through for the blade adjustment ("pitch tube") of the wind turbine. In the final product, this pitch tube must also be able to be passed through an HTS rotor - the invention allows this.
The picture shows the housing of the conventional machine (Flender/Winergy).

Results from the Research Areas

The central test vessel of DIPAK – the development platform for the fuel cycle of fusion reactors currently under construction at ITEP – during production. Manufacturing with all-metal sealed flanges of up to 3.2 metres in diameter poses enormous challenges for the production by the tight tolerances of this welded construction.

Vacuum and Fusion Technology

Coordination: Dr.-Ing. Thomas Giegerich

In the research field "Vacuum and Fusion Technology", ITEP is working on the development of new technologies and processes to make future fusion power plants a reality. In addition, general work is being carried out in the field of vacuum and cryovacuum technology, in particular to support other research institutions and industry. A central major project in this field of research is the construction and operation of a test and development platform for the fuel cycle of fusion power plants.

TECHNOLOGIES OF THE FUSION FUEL CYCLE

The fuel cycle is responsible, among other things, for providing and supplying the fuel required for the fusion reaction (the hydrogen isotopes deuterium and tritium are converted to helium), as well as for maintaining the required vacuum in the reactor vessel. From the point of view of the fuel cycle, the most promising reactor concepts (tokamaks and stellerators) currently under development are very similar - but not identical: stellerators work with very long phases in which the plasma burns. This can lead to an accumulation of impurities in the reaction mixture, which in turn makes it impossible to operate the plasma. This effect has begun to be investigated by means of plasma physics calculations and the creation and application of a new code that allows new fuel cycle architectures to be investigated quickly and quantitatively. This work is part of the SyrVBreTT (Synergie-Verbund Brennstoffkreislauf Tritium Technologien) project, in which the above-mentioned work is being carried out together with an industrial partner (Gauss Fusion) and using a specific example (the GIGA reactor concept from Gauss Fusion, a machine with approx. 3 GW thermal and 1 GW electrical power).

As part of another project, KaLiAS (Karlsruhe Lithium-6 Enrichment Strategy), work has begun on another topic that is essential for the success of nuclear fusion: the development of a process for the large-scale production of lithium enriched in the isotope 6Li. Fusion reactors have to produce ("breed") the hydrogen isotope tritium required as fuel themselves, which is achieved inside the reactor in so-called breeding blankets by neutron irradiation of the above-mentioned lithium isotope 6Li. Unfortunately, only a few percent of this is found in natural lithium and must therefore be enriched up to a few 10 percent. For this purpose, the so-called ICOMAX process was developed at KIT, which is now to be further developed to application maturity within the framework of KaLiAS. In addition to detailed process modelling, this also includes the development and qualification of the associated process equipment.

Another area of the fusion fuel cycle where isotope separation is required is the separation of the unwanted hydrogen isotope protium from the exhaust gas of the fusion reactor. A process called Temperature Swing Absorption (TSA) was developed for this purpose. This process requires the presence of special materials (Figure 1) that absorb the hydrogen isotopes protium, deuterium and tritium to varying degrees. The development of

Fig. 1: Functional materials with different absorption capacities for the three hydrogen isotopes.

these materials and their characterisation was carried out in collaboration with an industrial partner. These materials were produced and measured in 2024 (Figure 2). This forms the basis for the further development and scaling up of the TSA process to the size required for a fusion power plant.

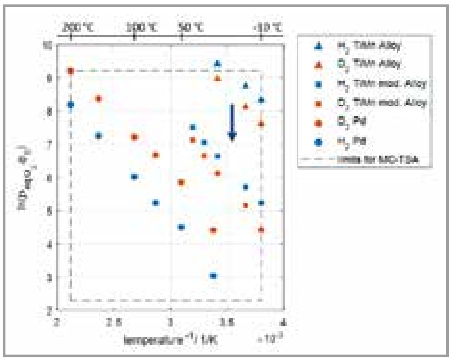


Fig. 2: Equilibrium pressures for different materials as a function of temperature.

VACUUM TECHNOLOGY AND CRYOVACUUM TECHNOLOGY

Continuous separation of the unburnt hydrogen isotopes from fusion products and impurities is essential for the fuel cycle of a fusion power plant. As no technical solution exists for this task to date, we are developing the so-called metal foil pump (MFP). This utilises the principle of superpermeation. With the help of a microwave plasma, hydrogen can pass through a thin niobium foil and thus be separated from all other gases in an ultra-pure manner – even against pressure gradients. On the development path to MFP, the next generation of experimental setups was now re-

Fig. 3: HERMESloom experimental setup in the final assembly stage.

quired – a facility under more DEMO-relevant conditions with regard to lower pressure and unavoidable magnetic fields. The HERMESloom (Figure 3), which was developed for this purpose and built in 2024, contains magnetic coils that were manufactured in an internal ITEP collaboration (Figure 4).

One continous activity outside of fusion is our work on the cryopump concept for the Einstein Telescope (ET) – the planned third-generation European gravitational wave detector.The desired sensitivity requires very low pressures as well as an extreme effort for the proper operation of cryogenic mirrors in the interferometer. This task can only be solved with cryogenic pumps, for which we developed the conceptual design (a section is shown in Figure 5). All pumps in the ET have a pumping surface of around 1500 m² and therefore a correspondingly high re-

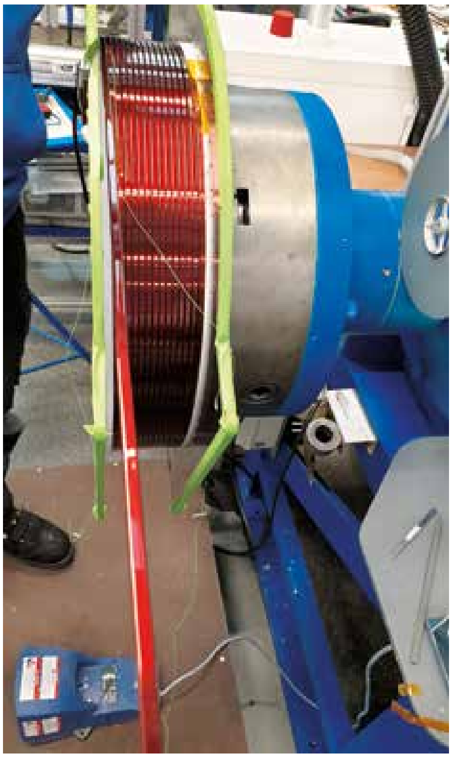


Fig. 4 Production of the magnetic coils for HERMESloom at ITEP.

quirement for the cryogenic supply. The intermediate step that has now been successfully completed was the simulation-based prediction of the heat loads on all these cryogenic pumps, a value that is already required for the rough cost estimate of the ET's cryogenic supply. Here we were able to confirm the significant size of the investment with the results, but also dispel any general doubts about feasibility.

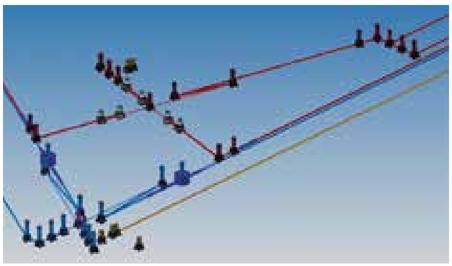


Fig. 5: Corner of the ET triangular interferometer with cryopumps already integrated in the detector layout (beam tubes with blue thickened sections).

The modelling of gas flows through complex vacuum systems, such as those found in the fusion fuel cycle, plays an important role in almost all of the activities carried out. This represents a major challenge in terms of code development and the computing resources required. This complexity arises from the need to model flows across multiple regimes, which requires state-of-the-art kinetic algorithms such as DSMC and DVM methods. To address this, the robust DIVGAS computational process was developed at ITEP, which seamlessly integrates both approaches to deliver accurate results.

In 2024, a numerical study was conducted to investigate the 3D effects – in particular poloidal and toroidal leakage – on the pumping efficiency of the DEMO divertor (see Figure 6). This study utilised large-scale simulations on high performance computers (HPC), including Marconi in Italy and HoreKa in Germany, to investigate these complex phenomena.

The analysis revealed several important findings. The poloidal gaps play a crucial role in the efficiency of the pumps. As shown in Figure 7a, depending on the inlet pressure conditions and pumping scenario (with varying pumping probability ξ), about 7-18 % of the incoming flux Φ returns to the plasma region through the poloidal gaps. In contrast, the effect of the toroidal gaps was found to be weaker, as

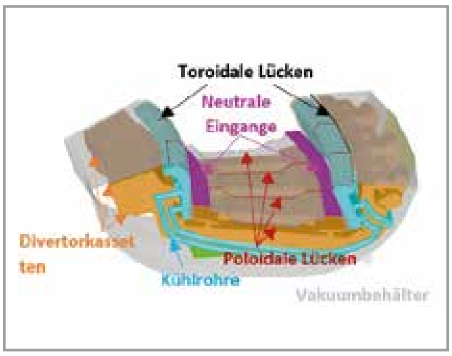


Fig. 6: 3D model of the DEMO subdivertor.

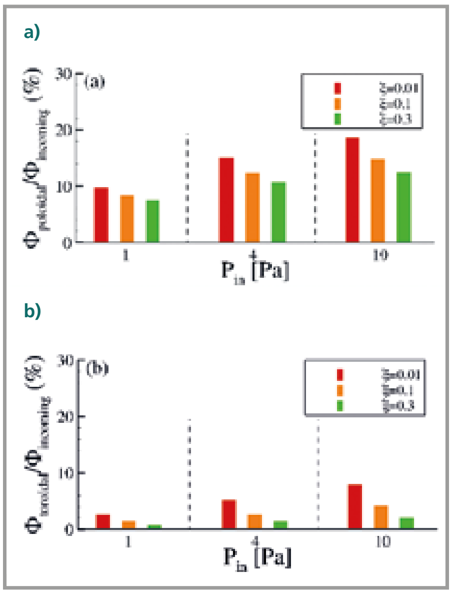


Fig. 7: Percentage of the impinging particle stream that escapes through the poloidal (a) and toroidal (b) openings.

shown in Figure 7b. The analysis revealed that the largest fraction (60-85%) of the incoming flux returns to the plasma vessel through the entrance gaps, which inevitably results in only a small fraction being available for pumping. It is expected that the above numerical results will have a significant impact on the ongoing efforts to improve the DEMO divertor design.

Contact: stefan.hanke@kit.edu and christos.tantos@kit.edu

FUEL CYCLE DEVELOPMENT PLATFORM AND INDUSTRY

DIPAK is an integrated test platform for the validation of new and highly innovative concepts developed by KIT to minimise the tritium inventory in the fuel cycle of a fusion reactor. DIPAK stands for 'DIR Integrated Development Platform Karlsruhe', where DIR is the 'Direct Internal Recycling' concept developed at KIT, which is our reference for the fuel cycle architecture of fusion reactors.

Fig. 8: Exterior view of the planned DIPAK building.

As part of the DIPAK project, components for the fuel cycle are being developed and tested on a prototype or even 1:1 scale. In addition to the new building to be constructed (see Figures 8 and 9), the project also includes a central vacuum vessel for testing the components.

In 2024, a general planner was commissioned for the construction of the DIPAK building. In addition to planning the building, the scope of work for the general planning also includes construction supervision. Construction work is scheduled to begin in the third quarter of 2025.

The production of the central vacuum vessel of DIPAK, which represents the torus or pump duct of the reactor, was already commissioned at the end of 2023. Important manufacturing steps were completed in 2024 (see Figure 10). Production is progressing faster than originally planned. Delivery is therefore expected as early as mid-2025.

The development and production of complex components for the fuel cycle, such as the pellet injector, which produces frozen fuel and injects it into the machine at a speed of around 1 km/s, continued in 2024. For example, the production of the extruder unit required for the pellet injector began. Completion is planned for the first quarter of 2025.

The pellet injector will be tested in the specially constructed JASON facility until

Fig. 9: Section through the DIPAK building; the workshop area is on the left, the test hall on the right.

Fig. 10: Image from the production of the centre section of the central vacuum vessel.

DIPAK is fully available. It is currently being set up in building 630 on KIT's Campus North. In 2024, the infrastructure (electrical installation, gas supply) was expanded or newly built. Completion will take place in parallel with the construction of the test environment for the pellet injector in 2025.

Kontakt: volker.hauer@kit.edu

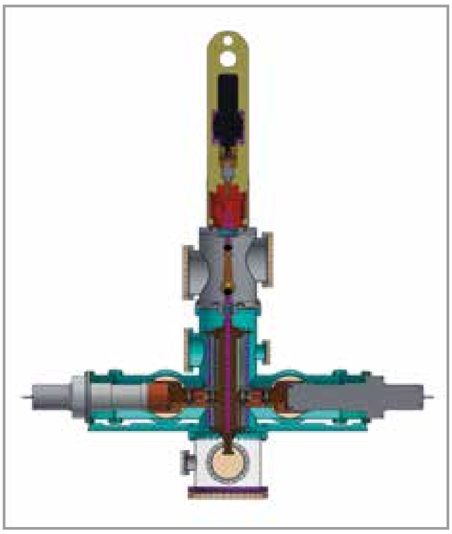


Fig. 11: Design of the extruder unit of the pellet injector.

Highlight

National funding programmes acquired for work on the fusion fuel cycle

In 2024, two projects funded by the Federal Ministry of Education and Research could begin, which will enable the Institute unit Vacuum and Fusion Technology (ITEP-VAK) to significantly advance the research field of "Vacuum and Fusion Technology".

The opportunities that fusion technology can offer as a sustainable way of generating electricity in the future have now also been recognised by politicians. The Federal Ministry of Education and Research (BMBF) has launched several calls for proposals as part of the 'Fusion 2040' funding programme. ITEP-VAK was successful in two applications with a total volume of approx. 5 M€ (Figure 12): KaLiAS (Karlsruhe Lithium-6 Enrichment Strategy) and SyrVBreTT (Synergy Network Fuel Cycle Tritium Technologies). Each of these projects also involves several industrial partners who will work together as part of a public-private partnership (PPP).

The approval and launch of these projects was a significant success for the entire field of research, as it provided the opportunity to build up additional staff and thus, together with additional funding, significantly accelerate development work in the field of fusion research. The additional staff will benefit all research topics, as the work in the new projects is evenly distributed across all three research topics.

KaLiAS involves the further development of the ICOMAX process for lithium isotope separation developed at KIT. This is significant in that no industrial-scale process is yet available for producing lithium that is highly enriched in the lithium isotope 6Li. This is currently a major risk for fusion in general, as the tritium required for the fusion reaction cannot be bred without 6Li. This project is predominantly being worked

Fig. 12: The long-awaited approval notices for the two projects KaLiAS and SyrVBreTT have arrived!

on in the research topic 'Fuel Cycle Development Platform & Industry', as an industrial process is to be developed and a large amount of experimental work must be carried out in the Karlsruhe Mercury Laboratory (HgLab), which is an infrastructure associated with this research topic.

SyrVBreTT includes the development of a fuel cycle for a specific fusion reactor design (the GIGA reactor from Gauss Fusion), as well as components for this. Another part of this project is the development of components of general relevance for fusion reactors, such as the metal foil pump and the pellet injector described above. The developments carried out in SyrVBreTT are performed in the research topics 'Fusion fuel cycle technologies' (e.g. architecture development of the fuel cycle and interface to the plasma), 'Vacuum technology and cryovacuum technology' (e.g. metal foil pump development) and 'Fuel cycle development platform & industry' (e.g. pellet injector development).

All projects began in November (KaLiAS) or December (SyrVBreTT, Figure 13) with a kick-off meeting.

Fig. 13: Kick-off meeting for the SyrVBreTT project in December 2024.

Prizes and awards

In 2024, the following awards, honors and prizes were awarded for work and to ITEP employees.

Fig. 2: Dr. Nadja Bagrets (4th from right) Foto: Milton Arias

Dr. Nadja Bagrets was presented with the IEC 1906 Award for outstanding commitment of German experts in international standardization in Offenbach in September 2024. This is in recognition of Dr. Bagrets' extraordinary commitment to the international standardization committee TC 90 Superconductivity.

This committee is responsible for drawing up standards for superconducting materials and components.

Furthermore, **Dr. Bagrets** was honored by the IEEE Council for Superconductivity at the international conference of applied superconductivity ASC 2024 in Salt Lake City with an award for her outstanding and long-standing service as editor of the journal IEEE Transaction of Applied Superconductivity.

In September 2024, our PhD student **Kai Walter** was awarded the 3rd prize of the "Jan Evetts Award" at the international conference on applied superconductivity ASC 2024 in Salt Lake City, USA. This award is an annual prize for the best publication by a young researcher in the journal Superconductor Science and Technology. It recognizes his publication entitled "Precise determination of oxygen content in $SmBa_2Cu_3O_{7-\delta}$ thin film samples using x-ray diffraction" in the journal Superconductor Science and Technology. In it, Mr. Walter describes a non-destructive method in which X-ray diffraction is used to determine the oxygen content of high-temperature superconducting tapes.

Fig. 1: Kai Walter (right) at the award ceremony

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

Dr. Tim Teichmann

Modeling and Design of a Mercury-driven Vacuum Pump for Fusion Power Plant Exhaust Pumping

Future nuclear fusion power plants will require vacuum pumping systems of unprecedented size and complexity. Presently, the most advanced fusion reactor concept is the pulsed Tokamak. Its pulsed operation poses unique challenges to the vacuum system design, as it has to process high gas loads during the burn phase on the one hand and reach very low pressures between the pulses on the other hand. Further challenging requirements are introduced by the pursued deuterium-tritium reaction, which is currently considered to be the most viable fusion reaction candidate for terrestrial energy production. This reaction involves the hydrogen isotopes deuterium and tritium. While deuterium is stable and abundantly available on earth, tritium is radioactive with a short half-life and thus has to be created artificially. Its limited supply as well as nuclear regulation require that the tritium inventory of fusion power plants is kept as low as possible. For these reasons vacuum pumping technologies have to be developed that feature high pumping speeds, low terminal pressures and minimal tritium inventories. One potential high vacuum pumping technology that fulfills these requirements is the mercury-driven vapor diffusion pump. While diffusion pumps are an established technology, their application in the novel context of a fusion power plant's vacuum systems requires special consideration. The aim of the present work is to develop models of these pumps and to design and optimize them for the application in Tokamak exhaust pumping.

DOI: https://doi.org/10.5445/IR/1000175884

Dr. Jonas Schwenzer

A Process Simulator for the Prediction and Optimisation of the Operation of the Fuel Cycle of a Fusion Power Plant

Future fusion power plants require operation with a closed deuterium-tritium fuel cycle to maintain their operation and safely contain radioactive tritium. The fuel cycle of the European Demonstration Reactor under development (EU-DEMO) implements these functions in a tripartite architecture. The pulsed reactor operation of a tokamak, as planned for EU-DEMO, inevitably propagates to the operation of this fuel cycle, which is characterised by alternating phases with high and low throughputs. The design of the overall system and the integration of the various sub-cycles therefore also requires the consideration of dynamic effects on design criteria, such as the availability and composition of the fuel mixture or tritium emissions.

For this reason, a dynamic process simulation of the entire closed fuel cycle was developed. The simulation achieves a detailed representation of the process by reproducing both the overall architecture of the entire cycle as well asarchitecture of the individual systems on a component basis. The dynamic behaviour of the components is taken into account by a series of balance spaces for which dynamic mass and species balances have been formulated.
Such a closed, all-encompassing simulation of a fuel cycle with physical models is so far unique in its scope and complexity.

The simulation developed was used to analyze the operation of the EU-DEMO fuel cycle for a reference operating point. It was shown that the operating point fulfils all requirements and that dynamic effects do not cause any restrictions in fuel availability and composition. Similarly it could be shown that there are only slight fluctuations in the tritium concentration in the exhaust gas and both average and maximum values exceed all emission requirements.

Link to the thesis: https://publikationen.bibliothek.kit.edu/1000175224

Lectures, Seminars, Workshops

KIT-Fakultät Elektrotechnik und Informationstechnik

Vorlesung

- **Energy Storage and Network Integration**
  (apl. Prof. Dr. Francesco Grilli,
  Prof. Dr.-Ing. Giovanni De Carne)
  WS 24/25
- **Electrical Engineering and Electronics for Mechanical Engineers**
  (Prof. Dr.-Ing. Giovanni De Carne)
  WS 24/25
- **Superconducting Materials Part I**
  (Prof. Dr. Bernhard Holzapfel) WS 24/25
- **Superconductivity for Engineers**
  (Prof. Dr. Sebastian Kempf,
  Prof. Dr. Bernhard Holzapfel) WS 24/25
- **Superconductors for Energy Applications**
  (apl. Prof. Dr. Francesco Grilli) WS 24/25
- **Digital Real Time Simulations for Energy Technologies**
  (TT-Prof. Dr. Giovanni De Carne) SS 2024
- **Superconducting Materials Part II**
  (Prof. Dr. Bernhard Holzapfel) SS 2024

Vorlesung/Übung

- **Superconducting Power Systems**
  (Prof. Dr.-Ing. Mathias Noe) WS 24/25
- **Superconducting Magnet Technology**
  (Prof. Dr. Tabea Arndt) SS 2024

Seminar

- **Anleitung zu selbständigen wissenschaftlichen Arbeiten**
  (Prof. Dr. Bernhard Holzapfel) WS 24/25
- **Seminar Strategieableitung für Ingenieure**
  (Prof. Dr. Tabea Arndt) WS 24/25
- **Advanced Seminar: Accelerators and Detectors – Future Technologies for Research and Medicine**
  (Prof. Dr. Ulrich Husemann,
  Prof. Dr. Bernhard Holzapfel,
  Prof. Dr. Anke-Susanne Müller,
  Prof. Dr. Matthias Fuchs,
  Prof. Dr.-Ing. Maria Francesca Spadea,
  Dr. Axel Bernhard, Markus Schwarz)
  SS 2024
- **Seminar on Applied Superconductivity**
  (Prof. Dr. Sebastian Kempf,
  Prof. Dr. Tabea Arndt, Prof. Dr. Bernhard Holzapfel, Prof. Dr. Mathias Noe)
  SS 2024
- **Projektmanagement für Ingenieure**
  (Prof. Dr. Mathias Noe) SS 2024

Praktikum (P)

- **Supraleitende Materialien**
  (Prof. Dr. Bernhard Holzapfel) WS 24/25
- **Robotische Wickeltechnik für Supraleiterdrähte**
  (Prof. Dr. Tabea Arndt) WS 24/25
- **Supraleitende Materialien**
  (Prof. Dr. Bernhard Holzapfel) SS 2024

KIT-Fakultät für Chemieingenieurwesen und Verfahrenstechnik

Vorlesung

- **Vakuumtechnik**
  (Dr.-Ing. Thomas Giegerich,
  Dr. Christos Tantos) WS 24/25
- **Fuel Cycle Lecture**
  (Politecnico die Torino) Giegerich

- **Vorlesung/Übung**
  Fusionstechnologie A
  (Dr. Klaus-Peter Weiss, Dr. Sara Perez Martin) WS 24/25

KIT-Fakultät Maschinenbau

Vorlesung

- **Magnet-Technologie für Fusionsreaktoren**
  (Dr. Klaus-Peter Weiss, Dr. Michael Wolf)
  SS 2024
- **Angewandte Kryo-Technologie**
  (Dr. Klaus-Peter Weiss, Dr. Holger Neumann) SS 2024
- **Vakuumtechnik und Tritiumbrennstoffkreislauf,**
  (Dr. Thomas Giegerich, Dr. Robin Größle)
  SS 2024

Seminare

Kryo-Seminare

- **22.–23.02.2024:** DKV-Seminar Kühlung von Rechenzentren (Neumann)
- **25.–26.04.2024:** DKV-Seminar Kältemittel (Neumann)
- **11.–13.09.2024:** VDI-Seminar Kryotechnik (Neumann)
- **25.–27.09.2024:** HdT-Seminar Kryostatbau (Neumann)
- **18.–19.10.2023:** DKV-Seminar Grundlagen der Kälte-, Klima- und Wärmepumpentechnik (Neumann)

Duale Hochschule BW – Fachbereich Maschinenbau

- **Kryotechnik** (Neumann) WS 24

Completed PhD Thesis

(* Academic supervisor)

VAKUUM

Jonas Schwenzer
A Process Simulator for the Prediction and Optimization of the Operation of the Fuel Cycle of a Fusion Power Plant
Betreuer: Dr.-Ing. T. Giegerich,
Prof. Dr. M. Kind (CIW)*

Tim Teichmann
Modellierung und Design einer quecksilbergetriebenen Vakuumpumpe zum Pumpen der Abgase eines Fusionskraftwerks
Betreuer: Dr.-Ing. T. Giegerich,
Prof. Dr. M. Kind (CIW)*

Completed Master Thesis

(* Academic supervisor)

MAGNET

Sreekar Gandikota
Theoretical description and experimental verification of a Ne-Heatpipe for electric power equipment
Betreuer: Dr. F. Hornung,
Prof. Dr. T. Arndt*

MATERIAL

André Kurzeja
Konzeption und Aufbau der Station „Wetterextreme" im KIT-Schülerlabor Energie
Betreuer: A. Rimikis, Prof. Dr. B. Holzapfel*

Lennart Leist
Gepulste Laserdeposition von DyBa2Cu3O7-Dünnschichten
Betreuer: Dr. J. Hänisch,
Prof. Dr. B. Holzapfel*

Cheng Ma
Precise determination of the oxygen deficiency in thin film YBCO and GdBCO samples
Betreuer: K. Walter, Prof. Dr. B. Holzapfel*

Kerstin Märkle
Messung der Polarisationsrichtung ferroelektrischer Domänen in Methylammoniumbleiiodid
Betreuer: Prof. Dr.-Ing. A. Colsmann (LTI),
Prof. Dr. B. Holzapfel*

Fabienne Müller
Entwicklung des Moduls „Quantenobjekte und ihre mathematische Beschreibung" für einen Seminarkurs am KIT-Schülerlabor Energie
Betreuer: A. Rimikis, Prof. Dr. B. Holzapfel*

Yassin Rahman
From Raw data to Insights: Revealing Correlations between REBCO-HTSC Parameters through Automated Data Evaluation; Analysis and Visualization
Betreuer: Dr. M. Erbe,
Prof. Dr. B. Holzapfel*

Ryan Schork
Optimierung von REBCO-Dünnschichten auf LMO-gepuffertem IBAD-Band
Betreuer: Dr. M. Erbe,
Prof. Dr. B. Holzapfel*

Simone Severo
Thermal resistance between metallic surfaces in different configurations for high current HTS Cable-in-Conduit Conductor
Betreuer: Dr. N. Bagrets,
Prof. Dr. R. Dagan (INR)*

Simon Urban
Entwicklung einer Testanlage für mechanische Versuche in einer kryogenen Wasserstoffatmosphäre
Betreuer: Dr. K.-P. Weiss,
Prof. Dr. M. Stripf (MMT KA)*

Thomas Vetter
Gepulste Laserdeposition von Ba(Fe,Co)2As2 auf CeO2-gepufferten Substraten
Betreuer: S. Tokatlidis,
Prof. Dr. B. Holzapfel*

RTSET

Anthony Oluwatos Adefolalu
Optimization and Integration of Green Hydrogen in Energy Systems Planning: a Case Study Approach
Betreuer: Prof. Dr.-Ing. M. Noe,
Prof. Dr.-Ing. G. De Carne*

Thomas Caruyer
Entwicklung eines Betriebskonzepts für das EnBW reallabor H2-Wyhlen
Betreuer: N. Nemsow,
Prof. Dr.-Ing. G. De Carne*

Emilien Kettler
Ammonia Cracking unit performance analysis, including efficiency and stability
Betreuer: Prof. Dr. V. Hagenmeyer (IAI),
Prof. Dr.-Ing. G. De Carne*

Max Leuthaeuser
Implementation and Testing of a Voltage Based SoC-balanced and AC-coupled Control for DC Microgrids
Betreuer: Prof. Dr. V. Hagenmeyer (IAI),
Prof. Dr.-Ing. G. De Carne*

Honeymol Mathew
Comparison of two dual active bridge-based reconfigurable converters for DC fast charging stations of electric vehicles
Betreuer: G. Arena, Prof. Dr.-Ing. De Carne*

Sarah Okumu
Stability Analysis of a multi-port Power Hardware in the Loop setup with impedance-based modeling approach
Betreuer: F. Ashrafidehkordi,
Prof. Dr.-Ing. G. De Carne*

Kishore Perumbilly
Modeling and control of a DC fast charging station for electric vehicles
Betreuer: G. Arena,
Prof. Dr.-Ing. G. De Carne*

Completed Bachelor Thesis

(* Academic supervisor)

ENERGIE

Patrick Deiters
Untersuchung des Kontaktverhaltens von hochtemperatur-supraleitenden Bandleitern
Betreuer: Prof. Dr.-Ing. M. Noe*

Marc Jahn
Numerical Calculation of AC Losses of High-temperature Superconductor Slabs: Influence of n-index and JC (B) Dependence
Betreuer: Prof. Dr.-Ing. G. De Carne, Prof. Dr. F. Grilli*

Daniel Paluda
Optimierung des dynamischen Verhaltens von supraleitenden Schaltern
Betreuer: Q. H. Pham, Prof. Dr.-Ing. M. Noe*

MATERIAL

Felix Kohler
Konstruktion und Aufbau eines Elektromotors in modularer Bauweise für das KIT-Schülerlabor ENERGIE
Betreuer: A. Rimikis, Prof. Dr. B. Holzapfel*

Tobias Kohler
Entwicklung eines Unterrichtskonzepts für die Station „Elektromobilität“ im KIT-Schülerlabor Energie
Betreuer: Dr. J. Hänisch, Prof. Dr. B. Holzapfel*

Paul Kruse
Entwurf der Automatisierung einer katalytischen Heliumreinigung
Betreuer: Steffen Bobien, Dr. G. Thimm (DHBW)*

Paul Walter
Entwicklung einer katalystischen Reinigungseinheit zur Entfernung von Wasserstoffverunreinigungen aus Heliumgas
Betreuer: Steffen Bobien, Prof. Dr. K. Schäfer (DHBW)*

RTSET

Daniel Knodel
Entwicklung und Implementierung der Ansteuerung der Ladeinfrastruktur in den Musterhäusern des Energy Lab 2.0
Betreuer: Prof. Dr. V. Hagemeyer (IAI), Prof. Dr.-Ing. G. De Carne*

Completed Technical Thesis

(* Academic supervisor)

MAGNET

Marvin Schmid
Erstellen der Konstruktion und Fertigungszeichnungen einer supraleitenden/ kapazitiven Füllstandssonde für LH2
Betreuer: Dr. R. Lietzow*

MATERIAL

Maximilian Häfele
Entwicklung einer Kalibriereinrichtung für Extensometer
Betreuer: S. Eckerle, Dr. K. P. Weiss*

Lukas Kunz
Entwicklung einer Montagevorrichtung für Flachzugproben
Betreuer: S. Eckerle, Dr. K.P. Weiss*

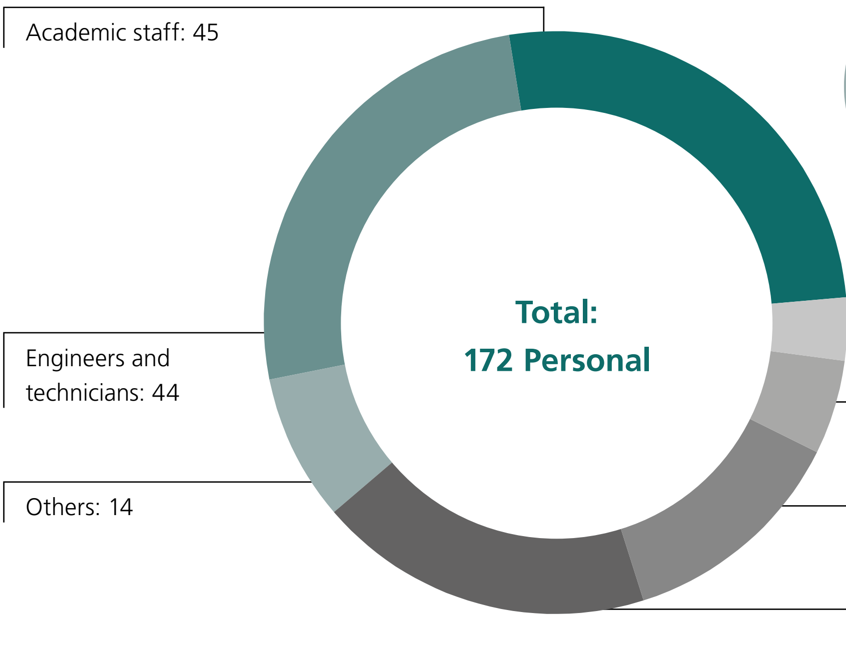
Figures, data, facts

Research Fields and Topics

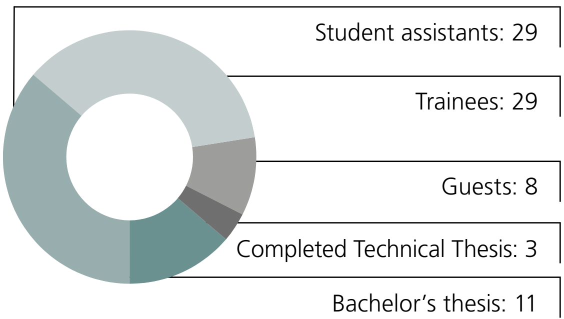
Superconducting and Cryomaterials (Holzapfel)	Energy Applications (Noe)	Real Time System for Energy Technologies (De Carne)	Superconducting Magnet Technology (Arndt)	Vacuum and fusion technology (Giegerich)
	Electro Energy Systems			
Superconducting Materials (Hänisch)	Superconducting Power System Components (Noe)	Grid Modelling (De Sousa)	Coil and Magnet Technology (Hornung)	Technologies of the Fusion Fuel Cycle (Giegerich)
		Hydrogen Integration Platform		
Conductor Concepts and Technologies (Holzapfel)	Modelling of Superconductors and Components (Grilli)	H2 in the Energy System (De Carne)	High Current Components (Wolf)	Vacuum Technology and Cryovacuum Technology (Hanke)
Materials for Cryogenic Applications (Weiss)		Dynamic Energy Storage Systems (De Carne)	Rotating Machines (Arndt)	Fuel Cycle Development Platform & Industry (Hauer)

Personnel Status (m/f/d)

(December 31, 2024)



Additional staff in 2024:



Guest Researcher

Z. Huang
13.04.23–28.03.24
Southwest Jiaotong University, China

Ye Hong
13.04.23–28.03.24
Southwest Jiaotong University, China

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

X. Wang
01.01.24–07.07.24
Mc Gill University, Kanada

S. Okumura
11.04.24–23.07.24
University of Tokyo, Japan

F. Abusaif
14.11.22–31.12.26
Laboratorium für Applikationen der Synchrotronstrahlung, KIT

F. Hattab
01.10.24–31.03.24
Sapienza University of Rome & Eni S.p.A., Italien

S. Banavath
01.11.24–31.12.24
Indian Institute of Technology, India

Memberships

of relevant technical and scientific organisations

Tabea Arndt

- 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
- Mitglied des Kuratoriums der „EnBW Stiftung"

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)
- Editor bei IEEE Transaction on Applied Superconductivity

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"

Giovanni De Carne

- IEEE PELS AdCom Member at Large
- IEEE PELS eGrid Workshop series steering committee chair
- Vice-chair vom IEEE PELS Roadmap auf "High-Power Electronics for Decarbonizing Energy Grids -- ITRG"
- Konferenz Co-chair und Technical Program Chair vom IEEE PES gesponsert "IEEE PowerTech 2025" Konferenz, Kiel, Juni 2025
- 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 Transactions on Power Delivery"
- Assoziierter 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)
- Mitglied der DIN Normungsroadmap Wasserstoff
- Mitglied DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE Referat K184 „Supraleitung“

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
- Mitglied bei CIGRE

Sonja Schlachter

- Mitglied des „International Cryogenic Material Conference (ICMC) Board of Directors“
- 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 SuperConductivity for AcceLerating the Energy“
- Experte in der CIGRE Arbeitsgruppe B4/A3.86 - Strombegrenzungstechnologien für DC-Netze
- Vorsitzender des „Large Scale Track“ des Internationalen Wissenschaftlichen Programm Komitees für die EUCAS 2025.
- 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
- Experte im EUROfusion Scientific & Technical Adivisory Committee (STAC)

Publications

Fusion

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Scientific Reports

Luo, Xueli; Kathage, Yannick; Teichmann, Tim; et al.
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Shirai, Hiroshi; Takahashi, Koji; Pietro, Enrico Di
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Gethmann, Julian; Mueller, Anke-Susanne; Blomley, Edmund; et al.
First year of data taking with the electricity meter network for sustainable operation of the KIT accelerator facilities for the KITTEN project
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Krasch, Bennet; Abusaif, Falastine; Grau, Andreas; et al.
Design study of a compact superconducting undulator based on laser-structured HTS tapes
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Presentation

Boehm, Friederike; Batista de Sousa, Wescley; Grohmann, Steffen
Optimization of cryogenic mixed-refrigerant cascades for intermediate cooling stations of the long-distance superconducting power cable SuperLink
29th International Cryogenic Engineering Conference and International Cryogenic Materials Conference (ICEC/ICMC 2024), Genf, Schweiz, 22.07.2024 – 26.07.2024

Posters

Abusaif, Falastine; Bründermann, Erik; De Carne, Giovanni; et al.
Optimization studies on accelerator sample components for energy management purposes
15th International Particle Accelerator Conference (IPAC 2024), Nashville, TN, USA, 19.05.2024 – 24.05.2024

Gethmann, Julian; Mohammad Zadeh, Mahshid; Bründermann, Erik; et al.
First Year of Data Taking with the Electricity Meter Network for Sustainable Operation of the KIT Accelerator Facilities for the KITTEN Project
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HTS Undulator Design Study and First Results
Applied Superconductivity Conference (ASC 2024), Salt Lake City, UT, USA, 01.09.2024 – 06.09.2024

Krasch, Bennet; Abusaif, Falastine; Glamann, Nicole; et al.
Design Study of a Compact Superconducting Undulator Based on Laser-structured HTS Tapes
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Invited Conference Contributions

Tabea Arndt

- 18.04.2024, T. Arndt, "The circle of innovation", CERN70y, Gateway of Science, CERN, Geneva CH
- 07.10.2024, T. Arndt, Speedy_HTS – A promising approach to high-power density HTS wind power generators, University of Twente, Twente, NL
- 08.11.2024, T. Arndt, M. Noe, M. Wolf, R. Oliveira, S. Palacios, O. Taalibi, TransHyDE and AppLHy!: Transport & Applications of Liquid Hydrogen (LH2), Hydrogène sans frontiers, sommet européen de l'hydrogène, Siège Région Grand Est, Strasbourg, F
- 02.12.2024, T. Arndt, M. Dam, Superconducting Muon Shield Magnet, CEA Saclay Paris-Saclay, F
- 05.12.2024, T. Arndt, Unique selling points of (high-temperature) superconducting magnets and novel trends., MPI Stuttgart, IMPRS-CPQM & MPI UBS & University of Tokyo Center, Winterschool Stuttgart, D

Mathias Noe

- Steffen Grohmann, Mathias Noe, HTS power applications and cooling system developments in Europe 4th IWC-HTS, 23-25 October 2024, Matsue, Japan
- Grohmann, Steffen; Noe, Mathias HTS power applications and cooling system developments in Europe 4th International Workshop on Cooling Systems for High-temperature Superconductor Applications (IWC-HTS 2024), Matsue, Japan, 23.10.2024 – 25.10.2024
- Mathias Noe, Quoc Hung Pham Experiments with a superconducting full-bridge inverter ASC Conference, 1.-9. September 2024, Salt Lake City, USA

Patents Held

- Vorrichtung zur Strombegrenzung mit einer veränderbaren Spulenimpedanz
  Noe, Mathias; Schacherer, Christian
  DE 2532016
  FR 2532016
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- Verfahren und Vorrichtung zur kontinuierlichen Wiederaufbereitung von Abgas eines Fusionsreaktors
  Day, Christian; Giegerich, Thomas
  CN 105706175
  DE 3061098
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  KR 1020167007345

- Design of Superconducting Devices By Optimization Of The Superconductor's Local Criticial Current
  Holzapfel, Bernhard; Rodriguez Zermeno, Victor
  DE 2983218
  US 10153071

- Schienengebundene Magnetschwebebahn
  Holzapfel, Bernhard; Noe, Mathias
  CN 2016800101353
  DE 3256359
  FR 3256359

- Transformator, Wickelkörper dafür und Verfahren zur Herstellung eines Wickelkörpers
  Hellmann, Sebastian
  DE 3341945
  FR 3341945
  GB 3341945

- Supraleitfähiger Leiter und Verwendung des supraleitfähigen Leiters
  Fietz, Walter; Heller, Reinhard; Weiss, Klaus-Peter; Wolf, Michael J.
  CH 3335228
  CN 10814458
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  IE 3335228
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- Verbinder für supraleitfähige Leiter und Verwendung des Verbinders
  Fietz, Walter; Heller, Reinhard; Weiss, Klaus-Peter; Wolf, Michael J.
  CH 3335280
  CN 10814961
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- Verfahren und Vorrichtung zur Herstellung eines supraleitfähigen Leiters
  EM15013 Fietz, Walter; Heller, Reinhard; Weiss, Klaus-Peter; Wolf, Michael J.
  CH 3317903
  CN 10814715
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  US 11328841

- Design of contacts for superconducting busbars and cables
  Rodriguez Zermeno, Victor
  DE 3352303
  FR 3352303
  GB 3352303

- Verfahren und Vorrichtung zur Anreicherung oder Abreicherung mindestens eines Wasserstoffisotops in einem Gasstrom
  Day, Christian; Giegerich, Thomas; Hörstensmeyer, Yannik; Müller, Ralf; Peters, Benedikt
  DE 3441129
  GB 3441129

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

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

- Bitterprinzipbasierte Magnetvorrichtung und Verwendung einer bitterprinzipbasierten Magnetvorrichtung
  Arndt, Tabea
  DE 102020124852.0
  EP 21766121.4-1212
  US 12191073

- Bandleitervorrichtung und Kabel, das die Bandleitervorrichtung aufweist
  Arndt, Tabea
  DE 102020128417.9
  EP 21794557.5-1212
  US 18/250,223

- Hochtemperatur supraleitende Schaltvorrichtung
  Martz, Simon; Noe, Mathias; Pham, Quoc Hung
  EP 23180956.7
  LU LU502329

- Hochtemperatur supraleitender Schalter
  Noe, Mathias
  LU LU502334

- Pumpe
  Arndt, Tabea
  DE 102023115683.7
  WO PCT/EP2024/066166

- Method for determining load parameters
  Courcelle, Maeva; De Carne, Giovanni; Tao, Qiucen
  EP 23195368.8
  WO PCT/EP2024/074149

- Verfahren zum Betrieb eines elektrischen Energieversorgungsnetzes, Computerprogramm, Leistungselektronikeinrichtung
  De Carne, Giovanni
  DE 102016119422.0
  EP 17783483.5

- Kühlsystem für einen Rotor, Rotor und elektrische Maschine
  Arndt, Tabea; Eisele, Matthias
  DE 102024212129.0

Contact

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

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

www.itep.kit.edu

Head
Prof. Dr.-Ing. Mathias Noe (-23500)
Prof. Dr. Bernhard Holzapfel (-26000)
Prof. Dr. Tabea Arndt (-23515)
Prof. Dr. Giovanni De Carne (-25924)

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Prof. Dr. Giovanni De Carne (-25924)

Contact

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

Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen

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Published by

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

July 2025

www.kit.edu