European Cryogenics Days 2017
and
2nd International Workshop on Cooling Systems of HTS-Applications

September 13 – 15, 2017 | Bldg. 11.40

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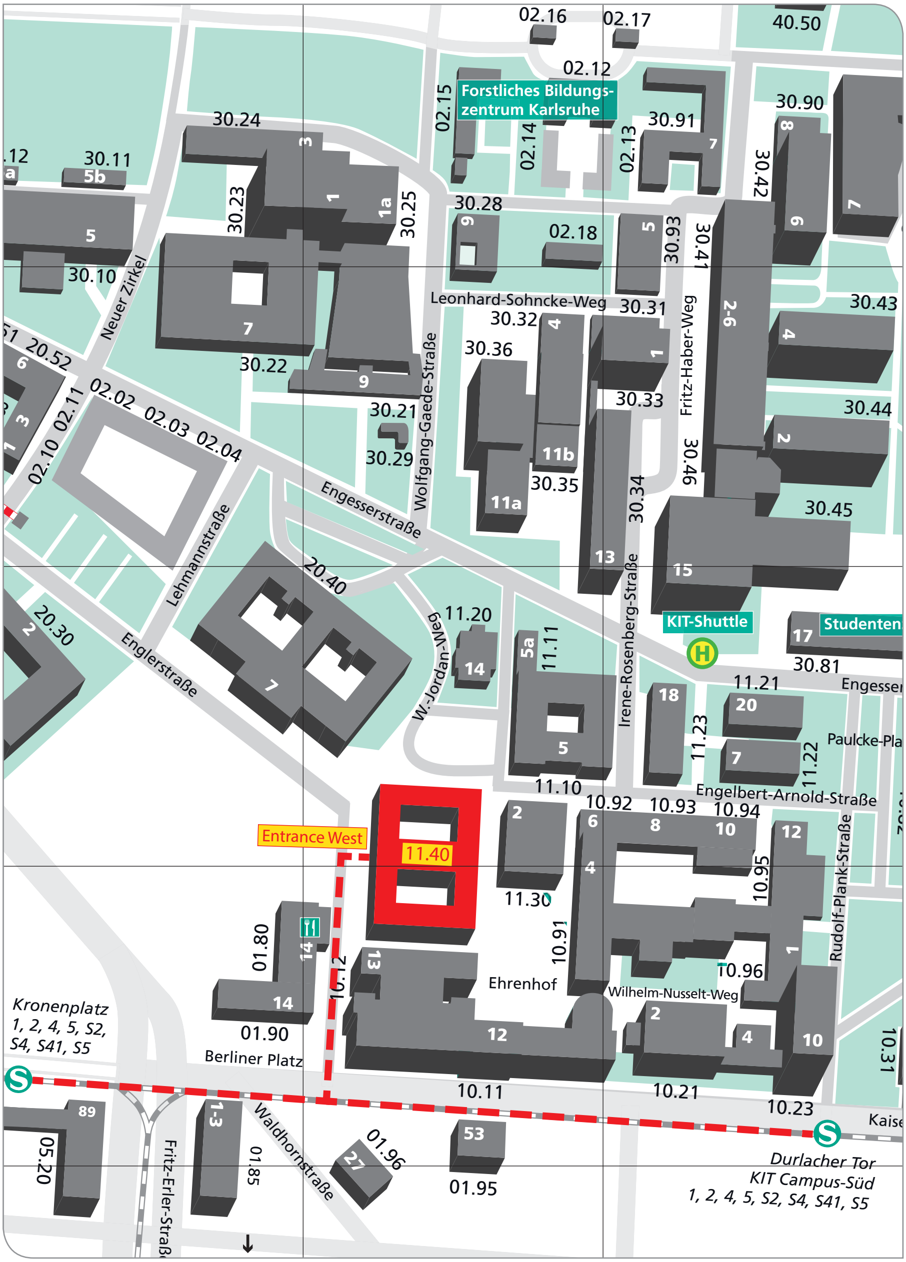
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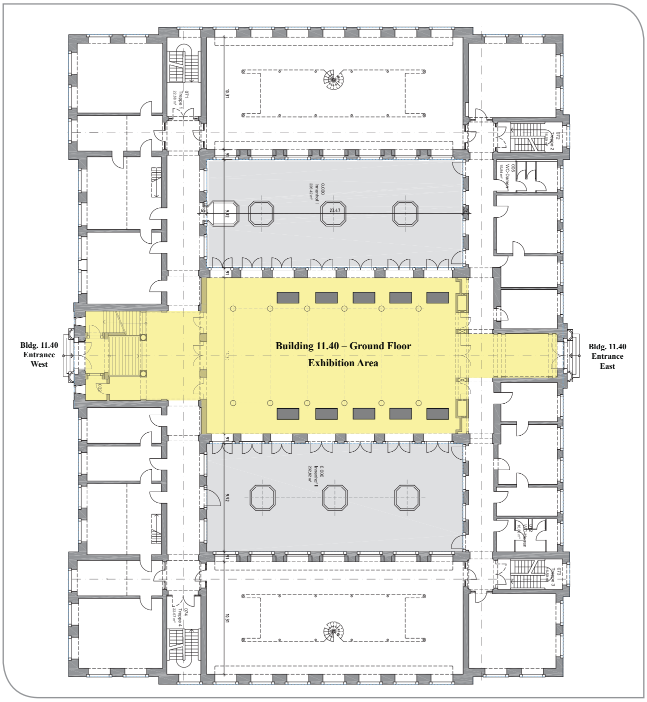
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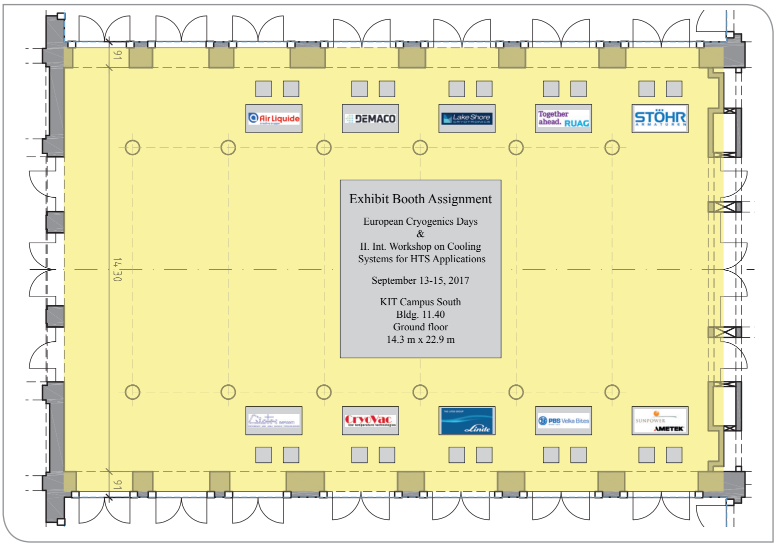
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European Cryogenics Days
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II. Int. Workshop on Cooling
Systems for HTS Applications
September 13-15, 2017
KIT Campus South
Bldg. 11.40
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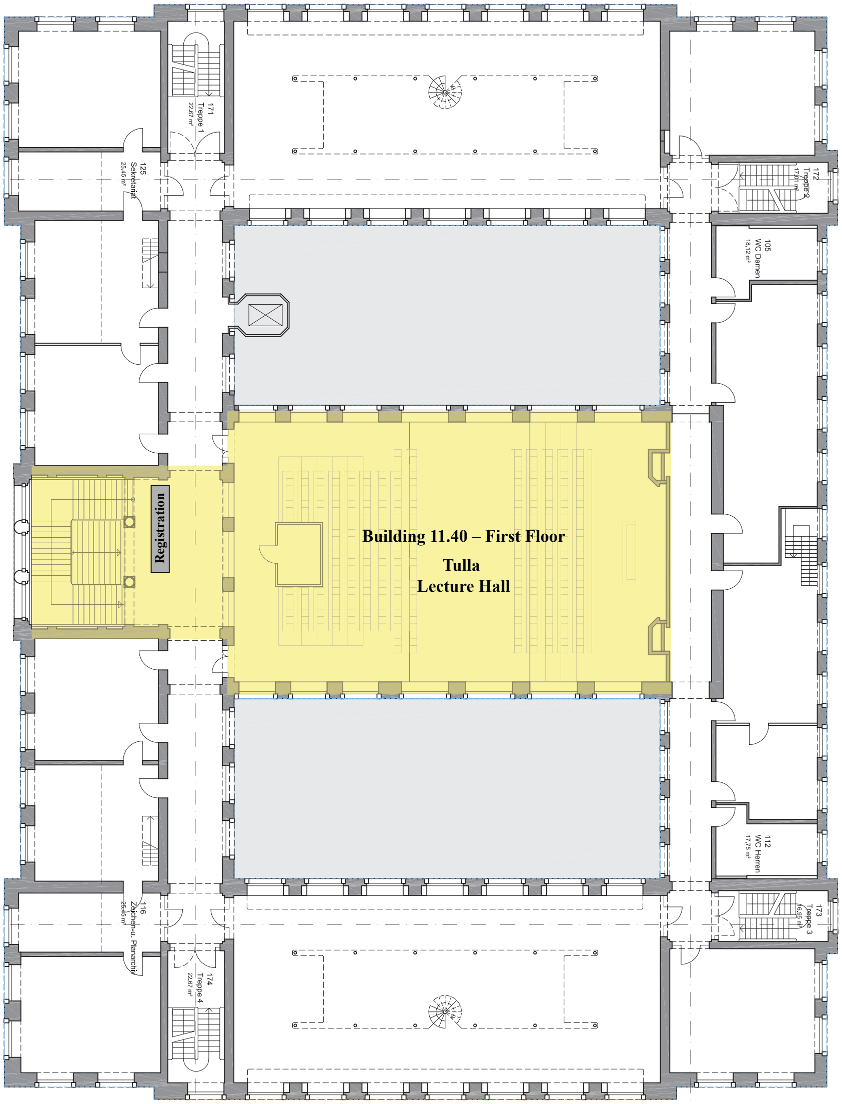
Registration
Building 11.40 – First Floor
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Lecture Hall


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OVERALL SESSION TABLE

EUROPEAN CRYOGENICS DAYS

WEDNESDAY, 13 SEPTEMBER 2017

Time	Activity	Length
08:00	Registration	
09:00	Opening	15m
09:15	Cryogenics Society of Europe General Meeting	1h 40m
10:55	Coffee Break	30m
11:25	OR1-1	25m
11:50	OR1-2	25m
12:15	Q/A Session 1	15m
12:30	Lunch	90m
14:00	OR2-1	25m
14:25	OR2-2	25m
14:50	OR2-3	25m
15:15	OR2-4	25m
15:40	Q/A Session 2	20m
16:00	Interaction Break	1h
17:00	OR3-1	25m
17:25	OR3-2	25m
17:50	OR3-3	25m
18:15	OR3-4	25m
18:40	Q/A Session 3	20m
19:00	Exhibitors Welcome Reception	1h 30m
20:30	End of Day 1	

II. INT. WORKSHOP ON COOLING SYSTEMS FOR HTS APPLICATIONS

THURSDAY, 14 SEPTEMBER 2017

Time	Activity	Length
08:00	Registration	
08:45	Welcome to IWC-HTS	15m
09:00	OR4-1	30m
09:30	OR4-2	15m
09:45	OR4-3	15m
10:00	OR4-4	15m
10:15	OR4-5	15m
10:30	Coffee Break	30m
11:00	OR5-1	30m
11:30	OR5-2	15m
11:45	OR5-3	15m
12:00	OR5-4	15m
12:15	OR5-5	15m
12:30	Lunch	90m
14:00	OR6-1	30m
14:30	OR6-2	15m
14:45	OR6-3	15m
15:00	OR6-4	15m
15:15	OR6-5	15m
15:30	Coffee & Poster Session	2h
17:30	Break	30m
18:00	Bus Transfer	30m
18:30	Conference Dinner	3h
21:30	Bus Transfer	30m
22:00	End of Day 2	

FRIDAY, 15 SEPTEMBER 2017

Time	Activity	Length
09:00	OR7-1	30m
09:30	OR7-2	15m
09:45	OR7-3	15m
10:00	OR7-4	15m
10:15	OR7-5	15m
10:30	OR7-6	15m
10:45	Coffee Break	30m
11:15	OR8-1	30m
11:45	OR8-2	15m
12:00	OR8-3	15m
12:15	OR8-4	15m
12:30	OR8-5	15m
12:45	Discussion	30m
13:15	Lunch	1h 15m
14:30	Bus Transfer (KIT Campus North)	30m
15:00	Technical Excursion Karlsruhe Tritium Neutrino Experiment KATRIN KIT Campus North	2h 30m
17:30	Bus Transfer	30m
18:00	End of Workshop	

WEDNESDAY, 13 SEPTEMBER 2017

08:00		**Registration**
09:00		**Opening**
09:15		Cryogenics Society of Europe – General Meeting Open to all, voting by CSE members only
10:55 – 11:25		**Coffee Break**

Session 1 – Cryogenics in Astrophysics

11:25 – 12:30
Session Chair: Steffen Grohmann (KIT, Germany)

11:25	OR1-1	Gerd Jakob (ESO, Germany) Cryogenics at the Extremely Large Telescope (ELT)
11:50	OR1-2	Lionel Duband (CEA, France) Sub-K cooling for space and ground-based telescopes
12:15	Q/A	Plenary discussion on Session 1

12:30 – 14:00	**Lunch**

Session 2 – Cryogenics in Particle Physics and Computing

14:00 – 16:00
Session Chair: Dimitri Delikaris (CERN, Switzerland)

14:00	OR2-1	Laurent Tavian (CERN, Switzerland) The FCC project and its cryogenic challenges
14:25	OR2-2	David Montanari (Fermilab, United States) Long-baseline neutrino facility (LBNF)
14:50	OR2-3	Adrian Zenklusen (Linde Kryotechnik, Switzerland) ESS target moderator cryogenic plant process design
15:15	OR2-4	Hans Hilgenkamp (University of Twente, Netherlands) Superconducting supercomputers and quantum computing
15:40	Q/A	Plenary discussion on Session 2

16:00 – 17:00	**Interaction Break**

Session 3 – Cryogenics in Transportation, Air Separation and Power Applications

17:00 – 19:00
Session Chair: Pascale Dauguet (AirLiquide, France)

17:00	OR3-1	Hiroyuki Ohsaki (University of Tokyo, Japan) Review and update on MAGLEV
17:25	OR3-2	Mykhaylo Filipenko (Siemens, Germany) Towards hybrid electric aircraft – killer application for HTS technology?
17:50	OR3-3	Limin Qiu (Zhejiang University, China) Development of large-scale cryogenic air separation systems
18:15	OR3-4	Mathias Noe (KIT, Germany) Cooling requirements for superconducting power cables
18:40	Q/A	Plenary discussion on Session 3
19:00		**Exhibitors Welcome Reception**
20:30		**End of Day 1**

THURSDAY, 14 SEPTEMBER 2017

08:00	**Registration**
08:45	Welcome to IWC-HTS

Session 4 – Power Grid Applications

09:00 – 10:30
Session Chair: Mathias Noe (KIT, Germany)

09:00	OR4-1	Friedhelm Herzog et al. (Messer, Germany) Liquid nitrogen operated cooling systems for superconducting power lines (invited)
09:30	OR4-2	Naoko Nakamura et al. (Mayekawa MFG, Japan) Turbo-Brayton refrigerator of Yokohama HTS cable project
09:45	OR4-3	Steffen Kloeppel et al. (TU Dresden, Germany) – Cooling Considerations for the Long Length HVDC Cables Cryostat within BEST PATHS Project
10:00	OR4-4	H.J.M. ter Brake et al. (University of Twente, Netherlands) SupernetNL program: 3.4 km 110 kV AC underground superconducting cable in the Dutch grid
10:15	OR4-5	Mike Staines et al. (Robinson Research Institute, New Zealand) Cooling systems for HTS transformers: Impact of cost, overload, and fault current performance expectations

10:30 – 11:00 **Coffee Break**

Session 5 – Novel Machinery

11:00 – 12:30
Session Chair: Fons de Waele (TU Eindhoven em, Netherlands)

11:00	OR5-1	Thomas Reis et al. (Oswald, Germany) Cryogenic challenges for different superconductive motor topologies (invited)
11:30	OR5-2	Jan Wiezoreck et al. (ECO5, Germany) Cryogenic design of the EcoSwing 3.6 MW superconducting wind generator
11:45	OR5-3	Jiuce Sun et al. (KIT, Germany) Compact cryogen-free modular cooling system for large scale offshore superconducting wind turbines
12:00	OR5-4	Mingyao Xu et al. (SHI, Japan) Development of High-capacity Single-stage GM Cryocoolers at SHI
12:15	OR5-5	Claus Hanebeck et al. (Vision Electric Super Conductors, Germany) Cryogenics in high-current busbars and multistage cooled current leads

12:30 – 14:00 **Lunch**

Session 6 – Small-scale Applications

14:00 – 15:30
Session Chair: Marcel ter Brake (University of Twente, Netherlands)

14:00	OR6-1	Cathy Foley et al. (CSIRO, Australia) HTS SQUID systems for mineral prospecting (invited)
14:30	OR6-2	Alexei Kalaboukhov et al. (Chalmers University, Sweden) Operation of a high-Tc SQUID gradiometer with a two-stage MEMS-based Joule-Thomson micro-cooler
14:45	OR6-3	Christoph Pfeiffer et al. (Chalmers University, Sweden) A liquid nitrogen-cooled cryostat for multichannel HTS magnetoencephalography
15:00	OR6-4	Tonny Benschop et al. (Thales Cryogenics, Netherlands) Recent development in compact and reliable cryocoolers at Thales Cryogenics
15:15	OR6-5	Tetsuo Oka et al. (Niigata University, Japan) Attempt to generate uniform magnetic field by face-to-face magnet system containing HTS bulk magnets

15:30 – 17:30 **Coffee & Poster Session**

Poster Session

15:30 – 17:30

Session Chair: Steffen Grohmann (KIT, Germany)

P-01	Qian Bao et al. (SHI, Japan) Development of a pneumatic GM cryocooler with dual-displacer
P-02	Lin Bian et al. (Chinese Academy of Sciences, China) Cryogenic system of the 3W1 superconducting wiggler magnet
P-03	Guido Consogno et al. (WEKA, Switzerland) Flow regulation of cryogenic fluids: Design of a high-rangeability control valve
P-04	Lucas B S da Silva et al. (Universidade de São Paulo, Brazil) MgB2 superconducting bulks with AlB2 doping
P-05	Vladimir Datskov et al. (GSI, Germany) 2G HTS tape reliable protection in 250 A current leads
P-06	Fridolin Holdener et al. (Shirokuma, Switzerland) Valve actuated by electric stepper motor-based linear drive
P-07	Minaru Kawamura et al. (Okayama University of Science, Japan) Cooling and ac-losses in the superconducting super motor
P-08	Shane T. Keenan et al. (CSIRO Manufacturing, Australia) Large voltage modulation HTS 2D SQIF arrays operated on a single stage cryocooler
P-09	Yuzhe Lin et al. (KIT, Germany) CFD analysis of the regenerator performance of cryocooler under different accele-rations
P-10	Alexey Pan et al. (University of Wollongong, Australia) Enhancement of critical current density by large antidots in inhomogeneous arrays in YBa2Cu3O7 thin films
P-11	Jens Tamson et al. (KIT, Germany) Cryogenic PHAse EQuilibria Test Stand (CryoPHAEQTS)
P-12	Yanan Wang et al. (Chinese Academy of Sciences, China) The effect of impedance on VM type thermal compressor output characteristics for obtaining liquid helium temperature
P-13	Chao Zhou et al. (University of Twente, Netherlands) The design and analysis of a superconducting magnet system for magnetic density separation
P-14	Xiaotao Wang et al. (TIPC, CAS, China) Numerical and experimental studies of a two-stage pulse tube cryocooler working around 20K

P-15	Sonja Schlachter et al. (KIT, Germany) Design and performance of a conduction-cooled´HTS magnet in the radio-blackout experiment COMBIT
P-16	Mohammad Yazdani-Asrami et al. (Robinson Research Institute, New Zealand) Heat transfer in HTS transformer and current limiter windings
P-17	Chao Wang (Cryomech Inc., United States) Large capacity cryocoolers and cold helium circulation systems for HTS applications
P-18	Michal Vojenčiak et al. (IEE SAS Bratislava, Slovakia) Forced flow cooling of HTS CORC cable used in superconducting coil
P-19	Moritz Kuhn et al. (ILK Dresden, Germany) Cooling system for a superconducting DC-rail

17:30	**Break**
18:00	**Bus Transfer**
18:30	**Workshop Dinner**
21:30	**Bus Transfer**
22:00	**End of Day 2**

FRIDAY, 15 SEPTEMBER 2017

08:00 **Registration**

Session 7 – Systems and Solutions

09:00 – 10:45
Session Chair: Krzysztof Brodzinski (CERN, Switzerland)

09:00	OR7-1	Christopher Boyle et al. (Fabrum Solutions, New Zealand) Commercial cryocoolers for use in HTS applications (invited)
09:30	OR7-2	Sastry V. Pamidi et al. (Florida State University, United States) Opportunities and challenges for cooling HTS power applications with gaseous helium circulation
09:45	OR7-3	Marc, Dhallé et al. (University of Twente, Netherlands) Superconducting magnetic density separation
10:00	OR7-4	Jérôme Pellé (GTT, France) Membrane cryostats
10:15	OR7-5	Rainer Soika et al. (Linde Kryotechnik, Switzerland) Cryogenic relief device sizing based on existing norms
10:30	OR7-6	Chandra Sarkar Swapan et al. (Jadavpur University, India) Performance studies of an indigenously built condenser for a reverse Stirling cycle based cryocooler

10:45 – 11:15 **Coffee Break**

Session 8 – Heat Transfer and Modelling

11:15 – 13:15
Session Chair: Christoph Haberstroh (TU Dresden, Germany)

11:15	OR8-1	John M. Pfotenhauer (University of Wisconsin, United States) Recent advances in cryogenic pulsating heat pipes (invited)
11:45	OR8-2	A.T.A.M. de Waele et al. (TU Eindhoven, Netherlands / Oswald, Germany) Capillary cooling of AC superconducting coils
12:00	OR8-3	Romain Bruce et al. (CEA, France) Thermal performances of a meter-scale cryogenic pulsating heat pipe
12:15	OR8-4	Eugen Shabagin et al. (KIT, Germany) Calculation of temperature profiles and pressure drop in concentric three-phase HTS power cables
12:30	OR8-5	David Gomse et al. (KIT, Germany) Numerical model of a micro-structured heat exchanger for cryogenic mixed refrigerant cycles
12:45	Q/A	Discussion and Closing

13:15 – 14:30	**Lunch**
14:30	**Bus Transfer**
15:00	**Technical Excursion** Karlsruhe Tritium Neutrino Experiment KATRIN (KIT Campus North)
17:30	**Bus Transfer**
18:00	**End of Workshop**

OR1-1 | Cryogenics at the Extremely Large Telescope (ELT)

Gerd Jakob

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The European Southern Observatory (ESO) is building the Extremely Large Telescope (ELT), a 40-m class telescope to be installed on top of the 3046 m high mountain Cerro Armazones in the central part of Chile's Atacama Desert. Once being operational around 2025, the ELT will be the largest optical/near-infrared telescope in the world, gathering 13 times more light than the largest optical telescopes existing today. "The world's biggest eye on the sky" will vastly advance astrophysical knowledge by enabling detailed studies of planets around other stars, the first galaxies in the Universe, super-massive black holes, and the nature and distribution of dark matter and energy which dominate the Universe.

Powerful facility instruments are under development that can deliver the science cases for the ELT. The first instrument roadmap is listing more than six scientific instruments, each of them in the 10-20 tons class. Three selected first-light instruments are currently in detailed design phase, a diffraction-limited near-infrared imager, a single-field near-infrared wide-band integral field spectrograph, and a mid-infrared imager and spectrometer. While the telescope optics operates at ambient temperature, the instrument optics and in particular the detectors will be cooled to cryogenic temperatures down to 4 Kelvin. ESO is aiming to implement proven technology and commercial off-the-shelf components to build the cryogenic infrastructure for the ELT instruments. A combination of Liquid Nitrogen cooling and low-vibration cryo-coolers will be installed to provide the required temperature levels and cooling capacities.

I will present a brief status of the ELT construction and the planned instruments, and will give an overview of the cryogenic concept.

OR1-2 | Sub-kelvin cooling for space and ground-based telescopes

Lionel Duband

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The quest for knowledge and the initiative to solve the mysteries around us entail to develop instruments at the state of the art in many technological domains. This is particularly true in the field of astrophysics, where the signals from faint galaxies and other dim sources require to use high sensitivity leading experiments. In that respect cryogenics and the use of low temperature detectors are often essential for the accomplishment of the scientific objectives, offering unique advantages and unmatched performance. Therefore there is an increasing demand for coolers able to provide temperature below 1 K. Cooling for space implies specific requirements such as operation in microgravity, limited energy and mass budgets, reliability and long lifetime. These last two requirements also apply for systems dedicated to ground-based telescopes, usually set in remote and harsh environment such as the high altitude Atacama site in Chile or south pole, for which maintenance must be limited to a strict minimum. Various solutions have been successfully developed and flown, or are currently in operation in ground based telescopes. New developments are underway. Several cooling techniques and projects will be presented and discussed.

OR2-1 | The FCC project and its cryogenic challenges

Laurent Tavian

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Following the update of the European strategy in particle physics, CERN has undertaken an international study of possible future circular colliders beyond the LHC. The study considers several options for very high-energy hadron-hadron, electron-positron and hadron-electron colliders. From the cryogenics point of view, the most challenging option is the hadron-hadron collider (FCC-hh). The FCC-hh cryogenic system will have to produce up to 120 kW at 1.8 K for the superconducting magnet cooling, 6 MW between 40 and 60 K for the beam-screen and thermal-shield cooling as well as 850 g/s between 40 and 290 K for the HTS current-lead cooling. The corresponding total entropic load represents about 1 MW equivalent at 4.5 K and this cryogenic system will be by far the largest ever designed. In addition, the total mass to be cooled down is about 250’000 t and an innovative cool-down process must be proposed.

This talk will present the proposed cryogenic layout and architecture, the cooling principles of the main components, the corresponding cooling schemes, as well as the cryogenic plant arrangement and proposed process cycles with emphasis to the main cryogenic challenges.

OR2-2 | The Long-Baseline Neutrino Facility

David Montanari, Mark Adamowski, Johan Bremer, Michael Delaney, Aurelien Diaz, Kevin Haaf, Erik Voirin

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David Montanari, dmontana@fnal.gov, Fermi National Accelerator Laboratory, USA

The Deep Underground Neutrino Experiment (DUNE) collaboration is developing an international multi-kiloton Long-Baseline Neutrino experiment to be located about a mile underground at the Sanford Underground Research Facility (SURF), in Lead, SD, USA. In the current configuration four cryostats will contain a modular detector and a total of 68,400 ton of ultra pure liquid argon, with a level of impurities lower than 100 parts per trillion (ppt) of oxygen equivalent contamination. The Long-Baseline Neutrino Facility (LBNF) provides the conventional facilities and the cryogenic infrastructure (including the cryostats housing the detector) to support DUNE. This contribution presents the modes of operations, layout and main features of the LBNF cryogenic system.

The system is comprised of three sub-systems: External/Infrastructure (or LN2), Proximity (or LAr) and Internal cryogenics. The External/Infrastructure provides the infrastructure and equipment to store, produce and distribute the cryogenic fluids needed for the operation of the Proximity Cryogenics, which delivers them to the Internal at the pressure, temperature, mass flow rate, quality and purity required by the detector inside the cryostat. The External/Infrastructure cryogenics includes the LN2 refrigeration system and the surface facilities, with the receiving stations, the LN2 and LAr storage tanks and the vaporizers. The Proximity Cryogenics includes the LAr and GAr purification systems, the phase separators, the condensers, and the piping connecting the various parts. The Internal Cryogenics consists of all the cryogenic equipment located inside the cryostat, namely the GAr and LAr distribution systems and the systems to cool down the cryostats and the detectors.

An international engineering team will design, manufacture, commission, and qualify the LBNF cryogenic system. The expected performance, the functional requirements and the status of the design are presented in this contribution.

OR2-3 | ESS Target Moderator Cryogenic Plant Process Design

A. Zenklusen, J. Jurns, P. Arnold and H. Quack

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The European Spallation Source (ESS) project is a neutron spallation source facility currently under construction outside Lund, Sweden. The ESS accelerator will deliver a 5 MW proton beam to a spallation target at 2.0 GeV with a nominal current of 62.5 mA to generate fast neutrons. The cooling of the spallation target with liquid hydrogen circulating in the cryogenic moderator system (CMS) transforms these fast neutrons to slow neutrons which compose the useful radiation. The liquid hydrogen itself is cooled by a helium refrigeration cycle, the target moderator cryogenic plant (TMCP) providing cooling capacity in a wide range of 2.3-31.8 kW at 15-20 K. TMCP's maximum cooling capacity of 31.8 kW will make it the world's largest plant of its kind. The TMCP project is challenging in many ways. The heat load of the CMS has to be removed precisely all the time by the TMCP. In addition the TMCP has to meet highly dynamic requirements as the heat load ceases quickly in case the proton beam trips off. Furthermore transitions within the wide cooling capacity range have to be achieved seamlessly. In this talk the progress of the TMCP engineering is summarized. Process design, control strategies, machine concept and layout are presented.

OR2-4 | Superconducting supercomputers and quantum computing

Hans Hilgenkamp

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Information technologies have been developing at a formidable pace. While miniaturization has been the driver for this in the past decades (Moore's law), the attention is now focusing to the energy consumption. Already a considerable fraction of the worlds' energy use is in information technologies. Also, the on-chip energy dissipation and concomittant high temperatures form a bottleneck in further speeding up processors. For these reasons a great interest exist in the exploration of new computing paradigms.

In my presentation, I will introduce two of such paradigms and discuss their current progress and prospects, namely superconducting ‚RSQF' circuitry and quantum-computation. Both technologies require (ultra)-low temperatures, providing interesting challenges for cryogenic engineering.

OR3-1 | Review and update on MAGLEV

Hiroyuki Ohsaki

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Since April 1997 the running tests of the superconducting maglev system have been carried out at Yamanashi maglev test line, which is located about 100 km west from the center of Tokyo, aiming at its practical application. Construction of a commercial line has already started between Tokyo and Nagoya. The distance is about 290 km and the commercial service is plan to start in 2027. The extension of the line to Osaka is also planned and its commercial service will start in 2045 or earlier. The commercial line between Tokyo and Osaka is called "Chuo Shinkansen," which will be the Tokaido Shinkansen Bypass connecting three major metropolitan areas in Japan.

The superconducting maglev vehicles have superconducting magnets for the electrodynamic suspension and linear synchronous motor propulsion, and these technologies enable a super high-speed operation at 500 km/h with a lower noise and a higher efficiency. The magnets use NbTi superconducting wires cooled with liquid helium and 4 K GM-JT cryocoolers for the closed-loop cooling system. The superconducting racetrack coils are about 1.0 m long and 0.5 m high. Its magnetomotive force is 700 - 750 kA. A 16-car maglev train will have 34 superconducting magnets and 136 superconducting coils in total.

It has been approved that NbTi superconducting magnets have sufficiently good performance for revenue service. However, high-temperature superconducting magnets using Bi2223 or REBCO wires are highly expected to be introduced. They would have better stability and simpler cryostat structure, and need simpler cooling systems.

OR3-2 | Towards Electric Aircraft - An Opportunity for High Temperature Superconductivity?

Dr. Mykhaylo Filipenko

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The world of transportation is in a transition: From combustion engines to electric machines. This change is getting more and more momentum on the land, on the sea and in recent years also in the air. On the one hand, electric aircraft is supposed to open absolutely new opportunities for urban mobility with such concepts as prosed and currently heaviliy investigated by Uber, Vahana, CityAirbus or Lilium. On the other hand electric aircraft and in particular hybrid electric aircraft will allow to reduce the COx, NOx and noise emissions as required by the ACARE 2050 goals. Although demonstrated by several proof-of-concepts maiden flights by Siemens in close collaboration with Diamond Aircraft, Magnus and EXTRA that hybrid electric flight is possible, there are many technical challenges on the road to the entry into service of hybrid electric regional jet. Siemens and Airbus have a started collaboration in June 2016 to adress jointly this challanges and make a large step towards this ambitious goal.

The challenges relate mainly to the weight and efficiency of electric propulsion components. Motors and generators at the multi-MW scale have been available for industrial applications for a large time - however at such weights that render flying with them impossible. With a power-to-weight ratio of around 0.5 kW/kg traction drives for motors or ships are significantly heavier than gas turbines which have a typical power-to-weight ratio of about 5 kW/kg to 9 kW/kg. With the SP260D Siemens Aircraft developed a electric propulsion direct drive motor with power of 260 kW and a weight of roughly 50 kg, therefore a power-to-weight ratio of about 5.2 kW/kg which is the currently world record.

For doing so we went to the edge of magnetic, mechanical, thermal and electric properties of materials and involved numerical optimization to be as lightweight as possible. Nonetheless we need to take an additional big step. How to go even further with lightweight electric machines?
An immense opportunity could offer high tempereratur superconductors as they allow far higher airgap magnetic fields than the best NeFeB magnets and much higher current densities in the stator. In this talk I would like to adress in how far superconductivity could allow to significatly increase the power-to-weight ratio of hybrid electric propulsion systems and therefore be a key technology for hybrid electric aircraft.

OR3-3 | Development of large-scale cryogenic air separation systems in China

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Industrial gases such as oxygen (O2), nitrogen (N2) and argon (Ar) can be regarded as the „blood" of modern industries such as in steelmaking and chemical product industries, which act as the primary users of the products of air separation unit (ASU) in the world. In the present, the production of large quantities of high-purity industrial gases still mainly depends on a large-scale cryogenic air separation method. Here, the terminology „large-scale" means that the O2 production of a single ASU is beyond 60,000 Nm3/h. With the rapid growth in demand for industrial gases in steel and chemical industries, there has been significant emphasis placed on the development of China's large-scale air separation technologies. Currently, the maximum capacity of a single unit has been able to attain 120,000 Nm3/h (oxygen), and the specific power consumption of 0.38 kWh/m3. This paper reviews the current state-of-the-art for large-scale cryogenic air separation systems being deployed in China. The technological parameters and features of the involved key equipment, including a molecular sieve adsorber, air compressor unit, plate-fin heat exchanger, turbo-expander and distillation column are described in detail. The developing 80,000-120,000 Nm3/h air separation processes and equipment are introduced. A summary of the existing problems and future developments of these systems in China are discussed.

OR3-4 | Cooling requirements of superconducting power cables

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Superconducting cables have been built and tested for voltages larger than 100 kV, currents up to 5 kA and a length of up to 1 km. Within long term field tests, superconducting power cables have shown that they can fulfill all technical and operational requirements. This resulted in an increased interest for more applications and in contrast to the voltage and current design parameters, the cooling design parameters of a superconducting cable depend mainly on the length of the cable and the heat input. These parameters have to be adapted to each cable to fulfil the specification. This presentation gives an overview on cable specifications and requirements and points out specific cooling requirements. For two different examples of a medium and high voltage cable, design options are presented and discussed. It can be seen that the different loss contributions differ very much between medium and high voltage cables and that for example the interconnection between specification and maximum length before re-cooling needs a careful investigation. Finally, a design procedure is proposed that considers main specification and cooling requirements.

OR4-1 | Liquid Nitrogen operated Cooling Systems for Superconducting Power Lines

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HTS power cables or high current bus bar systems can be cooled by circulating subcooled liquid nitrogen through the cryostats in which they are integrated. The heat impact which has to be removed is mainly caused by heat transfer through thermal insulations and by the circulation pumps. To minimize the required cooling energy it is necessary to optimize pressure drop and surface area of cable cryostats and operate the circulation pumps with low dissipation.

The circulating liquid nitrogen is cooled in a vacuum subcooler which uses liquid nitrogen as refrigerant. Vacuum pumps allow an operation pressure of 150 mbar to achieve a vaporisation temperature of 64 K (13 K below the atmospheric boiling point of nitrogen). This is advantageous because the ampacity of superconductors is dependant on the difference between their transition- and operation temperature. Lower temperatures are not practical, because at 63 K nitrogen becomes solid.

Messer has developed a cooling system with an adequate vacuum subcooler, a liquid nitrogen circulation system and a storage vessel for the German AmpaCity project of Innogy SE (formerly RWE Deutschland AG), Nexans and KIT (Karlsruhe Institute of Technology). Within this project in 2014 the worldwide longest superconducting power cable was installed in the city of Essen, Germany. After more than three years of practical operation many important figures from cable and cooling unit are available.

The system can easily be adapted for the operation of high current bus bars. These installations are normally much shorter than power cables, so pressure drop through the cryostat and heat impact of the circulation pumps are comparatively low. On the other hand the heat impact of the current leads is quite high and an efficient cooling system affords a combination of mechanical refrigeration and liquid nitrogen cooling.

OR4-2 | Turbo-Brayton refrigerator of Yokohama HTS cable project

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The operational stability and long term reliability of a High Temperature Superconducting (HTS) cable system combined with a liquid nitrogen cooling system was verified in the demonstration test performed in a real grid. The test was successfully implemented from October 29, 2012 till December 25, 2013. The HTS cable system reliability has been verified in the test, but some problems related to the refrigerators have also been revealed. To handle some problems we develop a refrigerator with a high efficiency and a long maintenance interval. Target characteristics we set are a maintenance interval of 30,000 hours, a COP of 0.1 and a cooling capacity of 5 kW. These target values were achieved using a reverse Brayton cycle and high performance turbo compressor and turbo expander units. Our cooling system utilizing this refrigerator has proved to be stable for long operation.

This Turbo-Brayton refrigerator Neon gas was chosen as coolant based on its density and speed of sound. This refrigerator includes a three stage turbo compressor and a turbo expander. The heat of compression is removed by water through a heat exchanger. The heat exchanger for regeneration is set at the front of the turbo expander, while the heat exchanger for heat exchanging between neon gas and liquid nitrogen is located at the back of the expander. The mass flow rate of neon gas is controlled via a buffer tank to maintain the pressure of the system at the rated value especially when system operation is started or stopped.

In second phase of Yokohama project, we installed the cooling system including Turbo-Brayton refrigerator in TEPCO's network, Asahi S/S, and its demonstration test have started from March 31, 2017. The demonstration test will be continued for one year. Progress of the demonstration test is possible to review the web site of SEI, http://www.sei.co.jp/super/cable/jissho.html.

The Turbo-Brayton refiregetaror we developed and project progress of which are discussed in detail in this presentation.

OR4-3 | Cooling Considerations for the Long Length HVDC Cables Cryostat within BEST PATHS Project

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HVDC cables have been identified as the preferred solution for future pan-European grids for the transmission over long distances of the large power produced by renewable energy farms which are generally located far for the consumption places.

The European project Best Paths has been launched to identify the remaining barriers and propose some innovative solutions to achieve such envisioned grids. As superconductivity offers very attractive and efficient solutions vision studies for long-distance superconducting power transmission lines are conducted.

The superconducting technology under study is based on the MgB2 conductor cooled with one-phase liquid hydrogen. A flexible cryostat with 15 to 25 K core cooling and with additional shield cooling using liquid nitrogen or hydrogen gas is required.

For long length cables the limiting parameters are the cryostat heat load and the pressure drop. The calculation results show the interdependencies of the maximum length between neighboring cooling sections with the heat load on shield and core, mass flows and pressure drop, enthalpy change, viscosity, friction factors and cryostat geometry. The calculations are carried out for different fluid options and diameters, and the corresponding results are presented and discussed.

OR4-4 | SupernetNL program: 3.4 km 110 kV AC underground superconducting cable in the Dutch grid

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TenneT, a leading European electricity transmission system operator (TSO) is planning to install a 3.4 km long underground superconducting 110 kV cable as part of the Dutch electricity grid, in the city of Enschede. HTS cables have already been demonstrated on a relatively small scale in other countries, but they are usually not part of the meshed high-voltage grid and the length of the relevant cable section generally does not exceed 1 km. In 2009, a 600-meter section of HTS cable was installed in New York, and in 2014 a 1-km long section was taken in operation in Essen, Germany to replace a 10 kV AC medium-voltage line.

In the Supernet NL program, TenneT is working together with several leading knowledge institutes including University of Twente, Delft University of Technology, the Institute of Science and Sustainable Development (IWO), HAN University of Applied Sciences and RH Marine. These institutes have been investigating control engineering aspects and the requirements the cable must meet.

In the meantime, the tender process has been started which consists of two phases. In the first phase (summer 2017) appropriate candidates are selected directly followed by a call for tender in August. Receipt of the best and final offer is scheduled for the end of November.

In the presentation, the project will be introduced and requirements will be discussed, specifically focusing on the cryogenic aspects.

OR4-5 | Cooling systems for HTS transformers: impact of cost, overload, and fault current performance expectations

Mike Staines, Mohammad Yazdani Asrami, Neil Glasson, Nathan Allpress, Liam Jolliffe, Enric Pardo

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In a future commercial marketplace HTS transformers will compete with oil-immersed copper transformers - highly developed, efficient and reliable. Although HTS can offer reduced weight, lower load losses, and perhaps current limiting capability, to have any chance of commercial competitiveness the total cost of ownership (TCO) taking into account purchase price, installation and lifetime operating costs, must be lower than the conventional alternative. In addition the HTS transformer in operation must meet regulatory and network operator expectations not easy to satisfy with high current density HTS wire and cryogenic operation.

The cooling system for e.g. a 40 MVA 3-phase HTS transformer needs to provide for a total thermal load at 66 K of around 3 kW, dominated by current lead and AC loss. The TCO perspective shows that one of the commercially available cryocoolers options is clearly best for closed-circuit cooling systems in this application. A 3-phase vacuum-insulated glass-epoxy composite cryostat for an HTS transformer with warm iron core is perhaps the single most expensive component of the cryogenic system. A hybrid cryostat, with vacuum insulation around the cores and foam insulation around the transformer tank can provide adequate thermal performance at a fraction of the cost.

Overload capability without loss of lifetime is often counted an advantage of HTS transformers. However AC loss increases non-linearly with current, typically increasing by a factor of 10 for a doubling of current. Providing this amount of reserve capacity in a cryocooler can be prohibitively expensive. This, and the need for back-up cooling capacity during cryocooler maintenance or malfunction, has important consequences for system design and cost.

For most grid applications HTS transformers will need to match the fault current and recovery performance of conventional transformers: to withstand the fault current drawn by a zero impedance short for 2 seconds to allow time for the grid protection system to isolate the fault, and then to recover to normal operation while carrying rated current. For HTS transformer windings immersed in subcooled liquid nitrogen the withstand time will be largely determined by the mass of the conductor. Recovery after the fault will depend on the boiling heat transfer characteristics of the winding, which can be seen as an important facet of cryogenic system design for transformers. Solid conductor insulation, rather than paper wrap, and subcooled operation provide for maximal heat transfer during recovery.

OR5-1 | Cryogenic challenges for different superconductive motor topologies

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Numerous studies and prototypes have proven the potential benefit of supercon- ducting material being used in motors and generators. The electromagnetic system used in the motor or generator offers already for normal conductive systems a large variety of topologies, with the superconductor being introduced completely new compositions can be realized. This presentation will give an overview of selected rotor and stator topologies being suitable for integrating superconducting material to improve the performance. The specific requirements of each system will be discussed, focusing on the potential application range. Besides the electromagnetic layout it is also important to completely integrate necessary cryogenic components into the motor or generator. Depending on the topology the specifications for the cryogenic components will be listed and characteristical constraints are mentioned. Complementary to the theoretical discussion of the topologies some representative demonstrators of the past will be selected and presented.

OR5-2 | Cryogenic design of the EcoSwing 3.6 MW superconducting wind generator

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We report about the cryogenic design of the EcoSwing 3.6 MW superconducting wind generator. The wind generator is currently under manufacturing. While the stator of the wind generator is made up by rather conventional copper windings, the rotor is equipped with superconducting coils.

The chosen cooling approach using GM coolers with rotating cold heads is described.
The thermal budget is calculated as balance between main heat sources at cryogenic temperature and cooling capacity of the cold heads.

The heat transfer inside of the cryogenic system is done by heat conduction. Two modelling approaches used for calculation of the heat flows and temperature distribution are presented for the EcoSwing rotor. Material properties for thermal connections and challenges occurring from the operation on a wind turbine are discussed.

OR5-3 | Compact cryogen-free modular cooling system for large scale offshore superconducting wind turbines

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High temperature superconducting (HTS) generators are expected to pave the way to scale up offshore wind turbines to 10 MW and beyond. Although study of HTS wind generators has been of great interest and several designs have been proposed, the commercialization has not yet come. Despite the demonstrated feasibility and realized technical advantages, cryogenic cooling is still the key barrier to make the use of HTS technology in the field of offshore wind applications more transparent.

In order to fulfill the requirements of handling, transportation, maintenance and reliability of long-term offshore operation, we have proposed a compact cryogen-free modular cryogenic cooling system for large scale HTS wind generators. The HTS generator usually contains many identical superconducting coils and each coil is allocated one identical modular cryostat in order to achieve the working temperature of 20-40 K. The modular cryostat enveloping the HTS coil adopts rectangular shape and consists of a vacuum vessel, a thermal shield with multi-layer insulation and corresponding supporting structures. Rods made of titanium alloy are selected as support structures to reduce the heat load. A small scale two-stage Stirling or pulse tube cryocooler driven by oil-free linear compressor will be implemented in each modular cryostat to deliver the required cooling power.

OR5-4 | Development of High-capacity Single-stage GM Cryocoolers at SHI

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Applications including HTS superconducting motor, power transmission line and power generator are usually considered to consume 102 W to 104 W cooling power. Most of those applications are currently using direct liquid nitrogen cooling or Turbo-Brayton cryocoolers. Though having the potential to significantly reduce the cost and space requirement, current commercial GM cryocoolers lack the suitable cooling power which is crucial in HTS applications.

Since 2013, Sumitomo Heavy Industries, Ltd. (SHI) has been developing high capacity single stage GM cryocoolers for HTS applications around 80 K. With a conventional scotch-yoke-driven single-displacer GM cryocooler, a cooling capacity of 650 W was achieved with an input power of about 13 kW.

To further improve the efficiency, a novel concept, called dual-displacer GM cryocooler has been developed since 2015. In a dual-displacer GM cryocooler, displacers are connected to both ends of the Scotch yoke. Two expansion spaces are constructed by the displacers and cylinders. Helium gas is supplied to and discharged from the upper and the lower expansion spaces with a phase shift of about 180°. In principle, the pressure oscillation amplitude at the compressor side is reduced and thus the overall efficiency of the cryocooler is improved. With a dual-displacer concept, a cooling capacity of 725 W at 80 K was achieved with an input power of 13.8 kW.

In a Scotch yoke type GM cryocooler, the driving mechanism becomes heavier and more complicated as the required cooling capacity increases. Recently, SHI has been developing pneumatic GM cryocoolers. As preliminary results, a cooling capacity of 700 W at 80 K was achieved with an input power of 18.0 kW.

A summary of the development status of such cryocoolers will be reported in this presentation.

OR5-5 | Cryogenics in high-current busbars and multistage cooled current leads

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The use of high-temperature superconductors (HTS) has big advantages especially in high direct current applications. Relevant industrial applications can be found in chlorine, zinc or copper electrolysis and aluminum plants.

We developed a superconducting busbar for 20 kA based on YBCO tapes including two novel multistage cooled current leads at the ends. The special characteristic of the system is the closed-loop operation evaporating no cryogens after initial cool down. This feature is advantageous particularly with regard to industrial application. A 25 m long demonstrator will be installed in a chlorine plant at BASF in Ludwigshafen under real industrial conditions within the scope of government-granted 3S project.
In high current busbars the major cooling demand is generated in the current leads. To minimize these current lead losses we increased the efficiency by installing common cooling machines for three different temperature stages.

To reduce the required quantity of high temperature superconductors, the superconductors inside the busbar are cooled by sub-cooled liquid nitrogen at a temperature between 65 and 70 K. The need of superconductor is further minimized by increasing the distance between the single HTS tapes. Both technical measures create high demands on the supporting structure plus the pipe cryostat elements and their cooling system.

Test results of the current lead and busbar sections will be presented.

OR6-1 | Making Practical HTS SQUID Systems for Mineral Exploration

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High temperature superconductivity (HTS) was discovered 30 years ago. At the time of discovery, the research community gave many great promises of disruptive applications, especially in superconducting electronics. Over the last three decades HTS devices have been developed using a range of Josephson junction technologies. DC and RF Superconducting Quantum Interference Devices (SQUIDs) have been developed where several research groups have demonstrated devices with a white noise of 5 $\mu\varphi 0/\sqrt{Hz}$.

The application of SQUIDs have been most impactful in their use in mineral exploration. To achieve commercial application, it was necessary to develop a new approach to the cryogenic housing to make the system robust, light and compact. Also, other novel device concepts and systems were developed with the aim to provide tensor gradiometers and spinning rock magnetometers.

This talk will provide an overview of the development of HTS SQUIDs at CSIRO and review a number of different devices including magnetometers, gradiometers and the more recently developed SQUID arrays. The talk will also review the development of the commercial system called LANDTEM which is a magnetometer. This talk will review the system development, the system integration and other applications using gradiometers and SQUID arrays. I will conclude with the issues that need to be overcome to create greater market penetration and wider impact.

OR6-2 | Operation of a high-Tc SQUID gradiometer with a two-stage MEMS-based Joule-Thomson micro-cooler

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Practical applications of high-TC SQUIDs require cheap, simple in operation, and cryogen-free cooling. Mechanical cryo-coolers are generally not suitable for operation with SQUIDs due to their inherent magnetic and vibrational noise. In this work, we utilized a Joule-Thomson microfluidic cooling system to operate our high-TC SQUIDs [1]. The micro-cooler system is based on a commercial desktop CryoLab unit from DEMCON kryoz [2]. It contains a two-stage MEMS micro-cooler with a base temperature of 75 K, gross cooling power of 75 mW@80 K, and temperature stability ± 50 mK.

Our high-TC dc SQUID gradiometers were fabricated from YBa2Cu3O7-x thin films grown by pulsed laser deposition on 10 mm × 10 mm SrTiO3 bicrystal substrates with 24° misorientation angle. The SQUID chip was glued onto a 0.3 mm thick silicon wafer chip carrier that was attached to the second stage of the cold head. The vacuum housing of the cold stage was made from non-magnetic material (polyethylene terephthalate, PET) and evacuated to a base pressure below 2x10-3 mbar. The vacuum chamber features a 0.3 mm thick sapphire window that is placed above the sensor/cold stage. We demonstrated that the equivalent magnetic flux noise of the high-TC SQUID gradiometer is largely unaffected by the micro-cooler setup. The cut-off frequency of the 1/f noise in our SQUID measured on the micro-cooler was around 10 Hz. This indicates that the micro-cooler does not introduce significant magnetic fields in the vicinity of the cold stage. We thus demonstrate that such a microfluidic cooling system is a promising technology for cooling of high-TC SQUIDs in practical applications.

We also used the micro-cooler system to build a prototype a magnetic ac susceptibility (ACS) system for detection of specific binding reactions between DNA target molecules and functionalized magnetic nanoparticles (fMNP) in liquid solution. The detection principle relies on changes in Brownian rotation dynamics of fMNPs. We present the results of experiments with various concentrations of magnetic nanoparticles and discuss further development of the portable magnetic bioassay system for detection of influenza virus using oligonucleotide-tagged magnetic nanoparticles with sub-picomolar sensitivity.

[1] A. Kalabukhov et al., Supercond. Sci. Technol. 29 095014 (2016).
[2] http://kryoz.nl/portfolio-item/cryolab-msg/

OR6-3 | A liquid nitrogen-cooled cryostat for multichannel HTS magnetoencephalography

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Magnetoencephalography (MEG) is a functional neuroimaging technology used in neuroscience as well as in the diagnosis and treatment of brain disorders like epilepsy and for surgical planning. In MEG neural activity is measured by sensing the weak magnetic fields (~10s to 100s of femto-tesla) that are generated by neural currents in the brain. Highly sensitive magnetic field sensors are required for MEG. Today's commercial systems therefore employ liquid helium-cooled low-Tc SQUIDs. With advances in high-temperature superconducting (HTS) technology high-Tc SQUIDs have become a serious alternative. Due to the higher operating temperature they can be placed closer to the head and therefore measure higher magnitude signals than low-Tc SQUIDs that must record from further away – thus enabling them to overcome the typically higher noise compared to their commercial counterparts [1].

We have developed a liquid nitrogen-cooled cryostat for a 7-channel HTS MEG system. The cryostat is designed for minimum distance between the cold (~77 K) SQUIDs and the head of a subject at room temperature. With superinsulation around the nitrogen vessel and a small vacuum space between the sensors and a thin window, we can achieve minimum sensor-to-head distances of less than 3 mm. The magnetometers are arranged in a dense hexagonal pattern for high spatial sampling of a small area of the head ($\approx$ 15 cm^2). The outer sensors are tilted towards the middle to align them to the average adult head's curvature. The sensor tilt combined with a thin, curved window ensures minimal distance to the head for all sensors. The system employs 10 mm × 10 mm bicrystal dc SQUIDs made from YBa2Cu3O7-x with direct injection feedback (to minimize crosstalk [2]). The SQUIDs are thermally connected to liquid nitrogen via a sapphire fixture. To control temperature the nitrogen reservoir can be pumped on. The cryostat achieves high temperature stability (<0.1K) over long measurement times (>18h with a single filling).

We will present the design and performance of the cryostat and show results from measurements on a head phantom.

[1] Schneiderman, J. Neurosci. Methods 222, 42-46 (2014)
[2] Ruffieux, Supercond. Sci. Technol. 30, 054006 (2017)

OR6-4 | Recent development in compact and reliable cryocoolers at Thales Cryogenics

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Cryocoolers are an enabling technology for devices cooling. This could be either the cooling of spectroscopy sensors, cooling of compact HTS devices or to avoid refilling of cryostat filled with liquid Nitrogen.

In the recent years – pushed by market needs – enormous progress has been achieved in compactness and reliability of cryogenic coolers capable of delivering cooling powers between 100mW and 15W at 77K. Utilizing both the Stirling and pulse-tube principles Thales Cryogenics is manufacturing several thousands of coolers per year which are being used from very compact hand held thermal imagers to complex satellite programs such as MeteoSat Third Generation. These coolers could also be ideal for cooling various HTS applications.

In the presentation Thales will present latest developments in compactness with their SWaP coolers, coolers with low exported vibrations and high efficient coolers. Also the latest update on cooler reliability achieved today and expected in the future will be discussed.

Based on its existing product portfolio Thales has also developed a Cryogenic Test Bench as a flexible tool that can be used by universities or research institutes for the characterisation of the performance of devices at programmable cryogenic temperatures between 60 and 150 K. The design philosophy behind this tool and its possible utilisation will also be presented.

OR6-5 | Attempt to Generate Uniform Magnetic Field by Face-to-Face Magnet System Containing HTS Bulk Magnets

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In order to develop small-scale nuclear magnetic resonance devices, the authors have been developing uniform magnetic fields in the space between the face-to-face settled magnetic poles which contain HTS bulk magnets. Since the NMR magnets in general require highly uniform field, it was expected to be difficult to form such homogeneous magnetic-field distribution with use of HTS bulk magnet, because the bulk magnets is characterized by its inhomogeneous magnetic field showing steep gradient. The authors modified the shape of the field distribution from convex to concave by attaching an iron plate on the pole surface. Then, the magnets were then settled face-to-face with various gaps, and the magnetic-field uniformity was estimated in the space. In order to detect the NMR signals, the field uniformity less than 1,500 ppm should be required after the former results on the hollow-type magnets. When we combined the concave and convex field distributions to compensate the uneven field distributions, the best uniformity reached 358 ppm in the 30 mm gaps, which exceeded the target value. In addition, we numerically simulated the feasible performance in this configuration, which resulted in obtaining the best uniformity of 30 ppm at 1.1 T at 7 mm distant from the pole surface in the gap of 30 mm. This result suggested that the concave and convex magnetic field distributions compensate the field uniformity with each other with keeping the magnetic field strength in the gap.

OR7-1 | Commercial Cryocoolers for use in HTS Applications

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The emerging commercial HTS applications place expectations of high reliability, long service intervals, and environmentally robust cryocoolers. Whilst there have been several attempts at developing cryocoolers in the 300W to 2000W (at 77K) for these applications, the market need has yet to be satisfied.

Fabrum Solutions in collaboration with Absolut Systems have formed a joint venture company, AFCryo, that produces a commercially available range of acoustic pulse tube cryocoolers featuring low maintenance, high power output, and cost effective operation.

These cryocoolers utilize diaphragm pressure wave generators that hermetically seal the working fluids of the compressor from the helium working gas, ensuring zero degradation of the pulse tube performance. The efficiency, low servicing, and cost effectiveness of these cryocoolers suit the demands of HTS applications, in turn making the commercial success of HTS devices more achievable.

OR7-2 | Opportunities and Challenges for Cooling HTS Power Applications with Gaseous Helium Circulation

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Most high temperature superconducting (HTS) power system components that have been demonstrated used liquid nitrogen (LN2) as the cryogen. Gaseous helium (GHe) is being explored as an option for cooling HTS power devices for specialized applications. A major advantage of using GHe is the versatility of operating temperature of HTS systems leading to significantly higher power densities compared to LN2 temperature regime. In some naval and aviation applications the broader operating temperature window allows the necessary flexibility in designing superconducting systems to tackle the gravimetric and volumetric power density design requirements. However, challenges do exist in using GHe as the cryogen due its weaker dielectric strength and lower thermal capacity compared to those of liquid nitrogen. This paper presents the research and development efforts at the Florida State University Center for Advanced Power Systems in Gaseous helium cooled HTS devices. The developments include GHe circulation systems with large mass flow rates, AC loss measurements at 20-80 K range, cryogenic dielectric characterization of GHe and HTS components in GHe, and novel designs for gaseous helium cooled power devices. The paper discusses examples of successful demonstrations of HTS devices cooled with gaseous helium and the implemented solutions for the challenges faced.

The work presented is funded by the Office of Naval Research.

OR7-3 | Superconducting Magnetic Density Separation

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We discuss the design challenges and the envisaged solutions that are encountered in the demonstration and implementation of superconducting magnetic density separation (SMDS), a new and potentially wide-spread application area for superconductors.

MDS is a relatively new technique that allows to separate mixed product streams (e.g. shredded waste) based on the mass density of its constituent materials. In contrast to earlier magnetic separation methods, which rely directly on magnetic- or Lorentz-type of forces on the particles, its application is not limited to magnetic or conducting materials. Instead, a product stream is fed in a ferro-fluid that flows through a magnetic field with a high vertical gradient. The balance between the magnetic force that acts on the fluid and gravity that acts on the particles causes the latter to float on a well-defined depth, depending on their density. This technology was pioneered at the University of Delft and is meanwhile commercially available and successfully used with several types of product stream.

State-of-the-art MDS relies on rare-earth-based permanent magnets (PM) to provide the magnetic field gradient. Compared to PM, superconducting electromagnets offer higher flux densities and a more flexible design space, which allow for 5-10 times higher gradients (i.e. separation resolution), smoother field profiles and an about 5 times deeper fluid bed (throughput). Therefore, a consortium of Dutch universities, component manufacturers and end-users is developing a superconducting MDS demonstrator and - in a later stage - prototype system. Key issues in the design of such a SMDS system are economic competitiveness, user-friendliness and reliability. The prototype seeks to meet these requirements with a GM-powered conduction-cooled MgB2-based system of racetrack coils.

The presentation introduces the principles behind MDS; reviews its application areas; discusses the desired magnetic field profile together with its optimal practical implementation; and finally focusses on the ensuing challenges in terms of the thermal and mechanical housekeeping of an SMDS system.

This work is part of the research programme “Perspectief” with project number P14-07, which is partly financed by the Netherlands Organisation for Scientific Research (NWO).

OR7-4 | Membrane cryostats

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GTT, a French Engineering company specialized in the design of cryogenic containment systems works with CERN on developments of specific cryostats dedicated to the CERN activities. Thanks to a design done with components well adapted to cryogenic conditions, GTT proposes solutions fulfilling the project needs.

A perfect tightness of the containment system associated with high thermal characteristics of insulation limit the heat exchanges and participate in the argon purity.

This technology, used in more than 180 Liquid Natural Gas Carriers all around the world and some 30 very large onshore tanks is now well known by CERN. It has been used for the 17m^3 pilot project and for the two 600m^3 cryostats NP02 and NP04 which will be used by CERN to detect interactions between neutrinos and argon atoms.

OR7-5 | Cryogenic relief device sizing based on existing norms

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The sizing of cryogenic relief devices for applications below 75 K is typically based on the scenario for insulation vacuum loss and subsequent air condensation on cold surfaces. Large heat fluxes and density changes that go along with this event must be considered in the sizing of the appropriate relief devices.

DIN EN ISO 21013 adresses these issues from a normative standpoint. However, the sizing of relief devices for complex cryogenic apparatus cannot be performed directly based on the rules given in DIN EN ISO 21013. We highlight these issues and show how safety devices can be sized based on DIN EN ISO 21013, by a suitable extension of the rules given in the norm.

OR7-6 | Performance Studies of an Indigenously Built Condenser for a Reverse Stirling Cycle Based Cryocooler

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The function of a typical cryogenic condenser is to transfer the refrigerating effect produced after expansion of working fluid like hydrogen and helium gas to the incoming ambient gas like nitrogen for its liquefaction. The separate close refrigeration cycle operates on Reverse Stirling Cycle. The efficiency of liquefaction critically depends on the effectiveness of the condenser. We have developed successfully a cryogenic condenser using copper of electrolytic grade for a liquefaction duty of 10 litres of liquid nitrogen per hour. The condenser was tested by exposing it to liquid nitrogen for a considerable period of time followed by the non-destructive testing for identifying the surface defects. Refrigerating effect transfer effectiveness of the condenser is evaluated by assembling it in Cryogenerator model, ZIF-1002 and by measuring the amount of gas liquefied. Both of the results found are satisfactory. Selection of material, fabrication, testing of the condenser developed for a Cryocooler have been described in the paper to assess, its suitability for a Cryocooler based on Reverse Stirling cycle liquefier.

Keywords: Reverse Stirling Cycle; Condenser; Cryogenerator; Cryocooler

OR8-1 | Recent Advances in Cryogenic Pulsating Heat Pipes

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Research activities regarding cryogenic pulsating heat pipes (PHPs) are quickly springing up around the world. The strong interest is motivated in part by the exciting potential of PHPs for many cryogenic applications where effective heat transfer over large distances is required. In this regard the PHP supplies a complimentary functionality to regenerative cryocoolers that produce localized cooling at their cold tip. This report provides an update on recent experimental and modeling activities with cryogenic PHPs, demonstrating effective thermal conductivity values exceeding 50,000 W/m-K, and transferring heat over distances on the order of a meter. In addition, the report highlights the unique features associated with cryogenic PHPs, such as temperature dependent fill ratios, system pressures exceeding multiple bars, and operation up to and beyond the critical point. Preliminary investigations into the ability of a PHP to spread heat from one region to another are also report

OR8-2 | Capillary cooling of AC superconducting coils

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AC superconducting coils have losses which warm up the coil and so limit the performance. Good thermal contact between the coil and the cooling agent is important. Cooling of the coils by heat conduction through solid conductive material is no option since very large eddy-current heating would be generated in the thermal bridge. Previously we analyzed cooling by a cryocooler where the cooling power was distributed by a flow of cold gas over the coils, driven by a fan. Presently we investigate the possibility of cooling the coils with a cryofluid, such as hydrogen or nitrogen, obtained from a reservoir and flowing through capillaries in close thermal contact with the coils. In our contribution the technique will be introduced. We report on recent experiments where the AC losses are simulated by electrically heating capillaries under conditions which are comparable to the conditions in the application. In particular the behavior near the maximum cooling power will be described.

OR8-3 | Thermal performances of a meter-scale cryogenic pulsating heat pipe

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The combination of dry superconducting magnet using cryocooler as a cold source is becoming a standard. As the magnetic field highly decreases the cryocooler performances, the distance between the hot and cold spot is preferable to be higher than 1 m to maintain these performances. Thanks to their operation simplicity, compacity, lightness, and of course thermal performances, Pulsating Heat Pipes (PHP) are good candidates, as long two-phase thermal link, for these kind of systems. PHP can also work without gravity, in multiple orientations, with a small amount of liquid/gas and at a temperature around the saturation state of the working fluid inside. These devices are studied at different temperature to mostly cool down small electronic devices. At cryogenic temperature, PHPs have been studied in vertical and horizontal position filled with nitrogen, helium and neon mixtures. The longest one ever tested at these temperature is about 30 cm long. In this paper, we present the thermal performances of a 1 m long horizontal PHP made of 36 stainless steel parallel tubes. The tube internal diameter is 1.5 mm, close to the critical diameter (~1.7 mm) to maintain capillarity forces necessary to the PHP operation. Both evaporator and condenser section are copper made and are separated by an adiabatic section. Each section is 33 cm long and 40 cm large. This PHP has been studied with nitrogen with the condenser temperature maintained at 75 K. Several pressure and temperature sensors placed in the three different sections allow to monitor the thermodynamic behavior of the PHP. The maximum equivalent thermal conductivity measured is about 150 kW/(m.K) with a liquid ratio of 0,7 inside the PHP. This system can transfer a maximum heat power of 30 W before reaching its operation limit.

OR8-4 | Calculation of temperature profiles and pressure drop in concentric three-phase HTS power cables

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In recent years, many cities have faced an increasing power demand, while the space for urban cable channels is limited. Due to the low transmission losses at large power densities, high temperature superconducting (HTS) cables offer an increasingly attractive alternative to conventional cable solutions. HTS cables allow a simpler grid structure with less space for cable routing and lower overall cost in comparison to conventional cables. They require operation below critical values of temperature, current density and magnetic field strength of the superconductor. Since HTS materials lose their electrical resistance at temperatures close to the normal boiling point of liquid nitrogen, LN2 is a common coolant in many HTS applications.

This work presents a differential equation model for three-phase concentric HTS cables, describing the temperature distribution in the various cable layers and in the liquid nitrogen flow. The model considers the AC losses in the superconducting phases in addition to the external thermal load, as well as pressure losses in the coolant flow. The integrity of the algorithm is verified through energy conservation, yielding negligible numerical solver errors. The final application study shows options for extending the cable length up to factor five, using a second cooling unit in combination with a mixed coolant.

OR8-5 | Numerical model of a micro-structured heat exchanger for cryogenic mixed refrigerant cycles

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Cryogenic mixed refrigerant cycles (CMRCs) offer a cost-efficient method for cooling in the temperature range between 80 and 200 K. The performance of CMRCs is considerably influenced by the entropy production in the main heat exchanger. Therefore, high process efficiencies require small temperature gradients among the fluid streams as well as small pressure drops and limited axial heat conduction. This is best achieved with micro-structured heat exchangers, where large volumetric heat transfer areas can be realized.

The zeotropic refrigerant mixtures applied in CMRCs render the heat exchanger design process challenging, since inconstant fluid properties, two-phase heat transfer and pressure drop have to be considered simultaneously. Furthermore, only few data on the convective boiling/condensation kinetics of zeotropic mixtures is available in literature.

This contribution presents the design process of a micro-structured heat exchanger with a newly developed numerical model. The governing equations and the solution strategy are presented, followed by the final design and first experimental results.

P-01 | Development of a pneumatic GM cryocooler with dual-displacer

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As an alternative to conventional low temperature superconducting (LTS) materials, high temperature superconducting (HTS) materials have the potential to significantly reduce the cooling cost due to their higher critical temperature. Usually proportional to the physical size of the cooling object, cost reduction is especially conspicuous in large scale applications including power transmission cable and power generator. On the other hand, relatively high cooling capacity, roughly around 102 W to 104 W, remains indispensable for most cryocooler consumers in HTS area. In order to fulfill this requirement, a single-stage, dual-displacer, pneumatic type GM cryocooler has been developed at Sumitomo Heavy Industries, Ltd.(SHI).

GM type cryocoolers can be more compact and efficient compared with the currently available large-scale Turbo-Brayton cryocoolers. The main difficulty, however, is that the force needed to drive the displacer increases with the cooling capacity at the same time, which leads to the scale-up of the housing and consequently impairs the reliability of the whole system. To overcome this problem, a pneumatic type design is proposed in which the driving force is substituted by the pressure difference of helium gas. Additionally, a novel concept, called dual-displacer structure, is introduced to further increase the cooling efficiency. Since supply and discharge timing is reversed in the two expansion spaces, the pressure oscillation amplitude at the compressor side is reduced and thus the overall efficiency of the cryocooler is improved.

A prototype unit was designed, built and tested in 2016. As preliminary results, a cooling capacity of 550W at 80K was achieved with an input power of about 13 kW. Detailed design concept and performance results will be presented in this report.

P-02 | Cryogenic system of the 3W1 superconducting wiggler magnet

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Institute of high energy physics, Chinese academy of sciences plans to develop a superconducting wiggler magnet which is going to be installed into the storage ring of Beijing electron-positron collider to replace the 3W1 permanent wiggler magnet. Design of the cryogenic system of 3W1 superconducting wiggler magnet is introduced in this paper, including design of the cryostat and current leads, analysis of heat leak, design of the cooling system, and so on. The superconducting magnet is going to operate in liquid helium bath. Cryocoolers are used for cooling down the cryostat and current leads and also avoiding the liquid helium vaporing. In order to reduce the heat leak, HTS materials are used for the current leads. The design of the cooling scheme of the HTS current leads is also introduced.

P-03 | Flow Regulation of Cryogenic Fluids: Design of a High-Rangeability Control Valve

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To control the mass flow, the pressure or the temperature in a cryogenic plant, often cryogenic control valves are used. These valves regulate thanks to the axial movement of a throttling element with defined geometry, controlled by a pneumatic actuator and an electro-pneumatic positioner.

The electro-pneumatic positioner in combination with a pneumatic actuator drives the valve to the position where the needed opening is being realized. The smoother the relationship of the opening vs. the stroke of the valve is, the more precise the positioner can accomplish its task.

In particular in the case, when the same valve should be able to operate in several working points (for example cool down, warm up and cold operation) or with different loads of the plant, the opening vs. stroke curve becomes challenging. It demands to cover a high range of regulation values (high rangeability). In extreme cases, the plant may have a smaller valve for the control of low mass flows in parallel to a larger valve, because the needed "rangeability" cannot be reached in only one valve.

This contribution shows how a high "rangeability" can be reached in order to cover multiple functions with the same valve and shows the comparison of the calculated values with Kv measurements.

P-04 | MgB_2 superconducting bulks with AlB_2 doping

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Optimization in the intrinsic and extrinsic properties of MgB_2 superconducting material is extremely important for practical application in cables, wires and tapes. Actually, the mechanisms used for it optimization is through the synthesis process as well as the improvement in the grain connectivity, densification, pinning, doping, and MgO control. Many groups around the word use elements as Ti, Zr, Hf, Al, Mn, Li, Si and others, as a dopant. Defects or any other inhomogeneity in superconducting matrix can improve the flux pinning behavior and, as a consequence, the transport properties. In this work MgB_2 superconducting bulks with addition of AlB_2 powders was prepared and analyzed, with an attempt to dope the material with Al and simultaneously introduction artificial pinning centers. Superconducting, microstructural and optical characterization were performed and the results were analyzed together. As a result the superconducting critical parameters could be improved, compared with samples of pure MgB_2 prepared using the same routes.

P-05 | 2G HTS tape reliable protection in 250 A current leads

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The heavy ion synchrotron SIS100 at the FAIR complex requires reliable and economical cryogenic current leads, operating at 1-3 Hz cycling current over 20-30 years of the accelerator life. More than 500 HTS local current leads will supply DC power for 140 corrector magnets. A novel design of these local current leads enables an operation at 0-250 A DC and a cycling current with ramp rates up to 750 A/sec and pulse current up to 300 A. The HTS part of current lead is made of 2G SuperOX tape and it is protected during quenches by use of an optimized brass strip stabilizer with gold plated Cu contacts. The cryo-stability of this protection concept was studied at GSI and the experimental data are presented in this paper.

P-06 | Valve actuated by electric stepper motor-based linear drive

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Actual cryogenic valves are mostly driven by pneumatic actuators. PLC generated electrical analogue or digital signals are guiding control valves via an electro-pneumatic positioner and shut-off valves by switching an electromagnetic pneumatic pilot valve. However, a pneumatic air supply system is complicated and the complexity increases with the number of valves and the geographical expansion. Furthermore, a pneumatic air supply system has a very low energy efficiency, needs continuous servicing and requires space. Thus, operation and capital costs for an electro-pneumatic system to actuate valves are high.

There are new developments in in the refrigeration, natural gas and energy industries which use pneumatic free electric driven control and shut-off valves.

Based on the positive service experiences, innovative cryogenic and warm valves, actuated by an electric stepper motor-based linear actuator were developed. The development includes also the electronic control module with specific algorithms for the full valve functionality. Valve safety function fail open or fail closed as well as many further control advantages are available. Using of electric stepper motor-based linear actuators for cryogenic and warm valves allows a highly-simplified installation for cryogenic systems. These advantages open a high potential to reduce operation and capital costs remarkably.

Examples of such valves will be shown and described. Development perspectives will be discussed.

P-07 | Cooling and ac-losses in the superconducting super motor

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We have been developing a new type of superconducting synchronous rotating machine to achieve very high power-to-weight ratio over jet engines while reducing ac-losses sufficiently.[1] This machine, we call superconducting super motor/generator, whose self-inductions in the armature are cancelled out with iron ring cores, which enables naturally elimination of ac-losses owning to self-magnetic flux. In this work, we demonstrate that the other ac-losses due to alternating external magnetic field caused by rotating permanent magnets also can be reduced significantly by wounding 2G-HTS wires placed between permanent magnet and iron ring core, as their surfaces are perpendicular to the cores. The ac-losses in a prototype with 2G-HTS wire 50 meters in total length are measured by a thermal and a mechanical method. The results shows that the ac-losses are reduced to an eighth or less of ac-losses in wounding parallel to the cores. While the extent of the reduction of the ac-losses ensures development of the practical machine, we are analyzing further the remaining ac-losses in detail and developing a passive or an active method to eliminate them to the utmost limit to allow cooling with a compact cryocooler.

[1] M. Kawamura and J. A. Jones, "Superconducting Super Motor", IEEE trans. appl. supercond., vol. 27 (2017)

P-08 | Large voltage modulation HTS 2D SQIF arrays operated on a single stage cryo-cooler

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We report on the development and operation of an integrated miniature portable RF antenna system using high-temperature Superconducting Quantum Interference Filters (SQIFs) cooled using a single stage Stirling-cycle cryo-cooler. The HTS SQIF antenna's small dimensions (10 mm x 10 mm), high temperature operation (77 K) and low power dissipation (< 100 mW) make them ideally suited for an integrated system using a compact lightweight cooler.

We have previously described the performance of 2D SQIF arrays with 20,000 YBCO step-edge Josephson junctions in liquid nitrogen (LN2) [1]. Here the performance of larger-scale SQIF antennas, with over 100,000 Josephson junctions, operated on a miniature cryocooler is reported. The electrical transport properties of the SQIF arrays, including current -voltage (I -V) and voltage -magnetic-field (V -B) characteristics, are compared with LN2 measurements. We also investigate the electromagnetic and vibrational noise contributions of the cryo-cooler to the system noise of the SQIF array.

V -B measurements show SQIF array sensitivities of more than 20 kV/T and voltage modulation depths of ~ 20 mV for 100,200 junctions at 77 K, with good agreement between results obtained with both cooling methods. Improvements in SQIF sensitivity are observed by adjusting the temperature of the cryo-cooler to optimise the array critical current.

[1] E.E. Mitchell et al., Supercond. Sci. Technol. 29, 06LT01 (2016).

P-09 | CFD analysis of the regenerator performance of cryocooler under different accelerations

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High temperature superconducting (HTS) technology is a promising enabling technology to allow the offshore wind turbines (WT) scaling up to 10 MW and beyond by radical reduction of the head mass. In order to provide adequate magnetic field, the HTS coils are supposed to work at a low temperature of 20-40 K, thus a cryogenic cooling system is required. Comparing with cooling by means of cryogenic liquids, the cryogen-free method which adopts conduction cooling with regenerative cryocoolers leads to certain advantages such as smaller size, simple structure and elimination of safety issues related with cryogens. These advantages are particularly valuable in superconducting WT operating in offshore condition, and thus the cryogen-free cooling system attracts more and more attention in demonstrating HTS WT projects.

The cold head of the cryocooler linking to the superconducting filed coil rotates together with the rotor. The resulting centripetal acceleration and oriental variation may introduce streaming inside the regenerator and lead to performance degradation. However, up to now the influence of acceleration on the oscillating flow and heat transfer inside the regenerator has not yet been investigated.

As a response to the demands of performance stable cryocooler system, in this paper we will study the impact of the gravity and centripetal acceleration on the regenerator performance. Two dimensional numerical model of the regenerator will be established by Ansys Fluent. The temperature and pressure distribution of the regenerator will be illustrated and the dependence of operating frequency, acceleration and regenerative material will also be discussed.

P-10 | Enhancement of critical current density by large antidots in inhomogeneous arrays in YBa2Cu3O7 thin films

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The current-carrying ability of type II superconductors can be effectively enhanced by introducing certain intelligent defects within the material. Antidots are a type of intelligent defect where the superconductor is removed in a controlled manner. Engineering antidots in arrays throughout the superconductor leads to interesting and scientifically appealing effects such as an increase to the current carrying ability, rectification of the current, flux filtering and inhomogeneous magnetic field response. We investigated various arrays with different shapes of antidots possessing dimensions larger than magnetic penetration depth in YBa2Cu3O7 (YBCO) superconducting thin films. YBCO thin films of high quality were produced by pulsed laser deposition with Tc = 90.0 ± 0.5 K, and JC ≈ 3.5 × 1010 Am-2 at T = 77 K. Through photolithography and ion beam etching uniform, graded and spaced arrays were then created in the thin film. Comparing the difference in JC between the patterned and as deposited films between temperatures of 4.2K-85K and fields of 0-±5T provides an understanding of the effectiveness of the antidot configuration. Non uniform pinning arrays of micron sized triangular antidots enhanced JC over a broad temperature and field range, whereas the uniform array counterpart systematically degraded JC [1]. Furthermore, the asymmetric pinning potential of the triangular antidot causes an anisotropic flux trapping, the basis of the ratchet effect.

[1] George, J., Jones, A., Al-Qurainy, M., Fedoseev, S.A., Rosenfeld, A. and Pan, A.V., 2017. Tunable pinning effects produced by non-uniform antidot arrays in YBCO thin films. Annalen der Physik. 1600283 (2017), DOI 10.1002/andp.201600283.

P-11 | Cryogenic PHAse EQuilibria Test Stand (CryoPHAEQTS)

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Cryocoolers and cryoplants can provide efficient cooling for high-temperature superconductor (HTS) applications in the range of small and large cooling capacities, respectively. At some kW cooling power and temperatures below 77 K, which is typical for HTS power applications, both technologies have their limitations, however. The technology gap may be closed with cryogenic mixed refrigerant cycles (CMRCs). Such development requires fluid property data of cryogenic fluid mixtures, which are unavailable today. Therefore, the Cryogenic Phase Equilibria Test Stand is being built at KIT. CryoPHAEQTS will provide physical property data of binary, ternary or quaternary mixtures of cryogenic fluids. The test stand is operated between 15–300 K and at pressures up to 15 MPa. Operation with hydrogen and deuterium is considered through compliance with relevant explosion protection regulations. The cooling is provided by a pulse-tube cryocooler and the cell temperature is adjusted by electrical compensation heating. Vapour-liquid (VLE) and vapour-liquid-liquid equilibrium (VLLE) measurements are conducted by dynamic gas-phase circulation; solid-liquid equilibrium (SLE) measurements by a calorimetric method. The measurement cell has optical access, allowing dynamic light scattering (DLS) and surface light scattering (SLS) experiments . These techniques are used to determine the bulk transport properties of the investigated systems, such as thermal diffusivity, mutual diffusivity, kinematic viscosity and surface tension. With this experimental set-up, both fluid state and transport properties of cryogenic fluid mixtures can be measured simultaneously in equilibrium, yielding consistent and reliable thermodynamic data.

P-12 | The Effect of Impedance on VM Type Thermal Compressor Output Characteristics for Obtaining Liquid Helium Temperature

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The Vuilleumier cryocooler is driven by a classical thermal compressor, which utilizes temperature difference between the ambient and the lower temperature to generate an oscillating pressure wave. This type thermal compressor is called as VM type thermal compressor spontaneously, normally working at low frequency, and can be used to drive low temperature stage pulse tube cold head. VM type pulse tube cryocooler has the potential advantages of compactness and high efficiency, which is attracting more and more attentions to achieve liquid helium temperature, and can be applied in HTS, MRI, et al. Based upon thermoacoustic theory, the impedance matching between thermal compressor and low temperature stage pulse tube cryocooler is of great significance to achieve higher efficiency. The output characteristics of VM type thermal compressor for driving pulse tube cryocooler with numerical simulation was studied in this paper. For the thermal compressor, dependency of the pressure ratio and acoustic power on the load impedance changing with certain scopes have been presented and discussed. The amplitude of impedance ranges from 5E8 to 5E9 Pa·s/m3 , and phase angle of impedance varies from -70° to 70°. The output pressure ratio is found to mainly depend on the phase angle of impedance while acoustic power is dependent on amplitude of impedance chiefly. To achieve the highest efficiency for the whole system, the option for the load impedance is a trade-off between above two factors. The study lays the foundation for designing a VM type pulse tube cryocooler working at liquid helium temperature as well as improving system performance.

P-13 | The design and analysis of a superconducting magnet system for magnetic density separation

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A superconducting magnet system has been designed, analyzed and optimized, serving as demonstrator for a Magnetic Density Separation (MDS) system. MDS, as a novel recycling technology, allow the selective magneto-hydrostatic separation of materials in a waste stream based on their different mass densities. Regarding the present MDS with permanent magnets, superconducting magnet offers higher flux densities and a more flexible design space, which allows for 5-10 times higher gradients (i.e. separating power), smoother field profiles and a ~ 5 times deeper fluid bed for material separation.

This work focuses on the design and optimization of superconducting magnet, cryogenic cooling and cryostat systems. The NbTi magnet design has been optimized by balancing magnet performance, stability and offered field quality, against materialand cooling cost. The zero boil-off liquid He-cooled and conduction cooling system operated at 4.2 K, are both designed, analyzed and compared. For the cryostat, the space from top magnet to the fluid should be kept narrow (< 5 cm) to maintain optimal field amplitude in the ferrofluid. This leads to the challenge of reconciling the mechanical constraints imposed by the planar coil geometry with the thermal insulation requirements. A straightforward pillar-type structural elements is designed but with a high heat in-leak, while a local reinforced structure on the top flange is also proposed and analyzed to achieve same space with less heat leak but with some manufacture difficulties. Here, the analysis and optimized design of the magnet are presented. Construction of the magnet system is planned to commence in the second half of 2017.

The work is part of the research programme "Innovative Magnetic Density Separation for the optimal use of resources and energy" with project number P14-07, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

P-14 | Numerical and Experimental Studies of a Two-Stage Pulse Tube Cryocooler Working Around 20K

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The absence of cold moving parts in pulse tube cryocoolers has allowed it to has advantages of low vibration, high reliability, and low cost, which can meet requirements of many high-temperature superconducting applications. However, Stirling type pulse tube cryocoolers working around 20 K are still not commerally aviable due to low efficiency and low power density. With Comprehensive consideration of higher specific power of whole system and performance in relative lower working temperature of 20K, this paper proposes a thermally coupled two stage co-axial pulse tube cryocooler to pursue several watts cooling power around 20K.At the first stage, an ultrahigh frequency operation of 100 Hz is utilized to precoo the second stage for seeking a higher power density. At the second stage, a relative lower frequency of around 30Hz is used for improving system efficiency. Firstly, a quasi-one-dimensional numeric model based on the thermoacoustic theory is used to optimize the operating and structure parameters and some simulation results are briefly introduced. The influences of different phase shifters such as doule-inlet and room temperature displacers are also also investigated numerically. Then, in the experiments, typically a lowest no-load temperature of 13 K has been obtained and the cooling power at 20K was 2 W with an input electric power of 500 W, which mean an efficiency of 5.6% of Carnot. The influences of different operating and structure parameters such as frequency, mean pressure and precooling temperature were also investigated numerically and experimentally.

P-15 | Design and Performance of a Conduction-Cooled HTS Magnet in the Radio-Blackout Experiment COMBIT

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In the framework of the Helmholtz-Russia Joint Research Group (HRJRG) „COMBIT" we developed a conduction-cooled HTS magnet to provide a high magnetic field for a radio blackout mitigation experiment in the arc-heated wind tunnel L2K at the German Aerospace Center in Cologne. The radio blackout phenomenon is well-known since the early days of space exploration. During hyper-sonic flights or during reentry in a planet's atmosphere a dense plasma layer can form at the surface of the space vehicle leading to mitigation or reflection of radio waves. As a consequence voice communication with ground stations and GPS data telemetry can be disturbed. The goal of "COMBIT" was to demonstrate that the radio blackout can be mitigated by a local reduction of the plasma density in the vicinity of senders and antennas by magneto-hydrodynamic effects using crossed electric and magnetic fields. In order to generate a high magnetic field in the plasma we developed a conduction-cooled HTS magnet and a cryogenic system that is able to withstand the high temperatures in the plasma. The HTS magnet was made with RE-Ba-Cu-O coated conductors and has an outer diameter of only 70 mm. Despite the small size which is a consequence of the experimental boundary conditions the magnet was able to generate a high and variable magnetic field outside the cryostat in the plasma. In several measurement campaigns, the magnetic field reached up to 2 T in the plasma, corresponding to a maximum magnetic field of 5.16 T at the conductor. Mitigation of the radio blackout could be demonstrated successfully.

After an introduction to the radio blackout phenomenon we present the design of the conduction-cooled HTS magnet and the cryogenic system and discuss their performance during the experimental campaigns.

P-16 | Heat transfer in HTS transformer and current limiter windings

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Design of cryogenic systems for HTS transformers and fault current limiters (FCL) must provide for fault conditions as well as normal operation. In the course of a fault the HTS windings may be heated rapidly to a temperature of 300 K or higher. The ability of the device to return to normal operation after a fault current depends critically on the efficiency of heat transfer from the hot windings to the cooling system. The engineering of the interface of the winding with the cryogen, generally liquid nitrogen in the case of HTS transformers and FCL, can properly be considered a crucial component of cooling system design.

We report measurements of heat transfer from short metal and superconductor tape samples immersed in liquid nitrogen in conditions which approximate those in an HTS transformer winding. Samples were subjected to current pulses of several hundred A/mm2 for time intervals up to 2 seconds. The average sample temperature was estimated from the resistance. The current density during cool down was varied over the range corresponding to HTS transformer operation. Heat transfer was measured on samples with UV-cured polymer coatings as well as on bare samples. Somewhat paradoxically, by thermally insulating the metal surface from the liquid nitrogen the coating can drastically improve heat transfer. It does this by avoiding film boiling - the formation of a gas sheath on the surface - and extending the range of efficient cooling by nucleate boiling where the liquid is able to continuously wet the hot surface.

We find that heat transfer during conductor cool down

- Is highest in subcooled operation e.g. at 65 K at atmospheric pressure compared to operation at the boiling point e.g. 77.3 K at atmospheric pressure
- Is significantly increased by a thermally insulating coating of optimised thickness applied to the conductor compared to bare conductor, and reduced by wrapped-paper electrical insulation

P-17 | Large Capacity Cryocoolers and Cold Helium Circulation Systems for HTS Applications

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We have developed large capacity single stage GM cryocoolers with cooling temperatures from 11 K to 80 K. They have been used for HTS applications, such as FCLs, SMES, motor/generator, HTS cable and HTS magnets, etc. A Model AL325 is designed for 25 K operation, which can provide a cooling capacity of 110 W at 25 K. The current development of the AL325 is to replace lead in the regenerator for RoHs compliance. The model AL600 GM cryocooler was improved to have a cooling capacity of 700 W at 80 K, with the highest relative Carnot efficiency of 15.3%. This cold head vibration has been analyzed and reduced significantly.

Two types of cold helium circulation system using AL300 GM cryocoolers (300 W at 80 K) have been developed recently to circulate cold helium for remote cooling. A new compact, low cost cold helium circulation system could provide >180 W at 80 K at a remote location. In this system, a set of check valves connects to the cold head expansion chamber to convert a small portion of AC oscillating flow in the cold head to DC gas flow for circulating cold helium in the remote loop. Another cold circulation system with a cryogenic fan has been developed for other applications. The system with AL300 GM cryocooler and 3 meters long transfer line has 84 W at 40 K, 183 W at 60 K and 260 W at 80 K at remote cooling heat exchanger. Cooling Capacities of these cold helium circulation systems could be doubled with AL600 GM cryocooler.

P-18 | Forced flow cooling of HTS CORC cable used in superconducting coil

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Coils for AC applications or for applications with rapid change of the magnetic field have to be produced with low inductance. This usually requires using a cable instead of a single conductor. One of the concepts applicable for coated conductors is Conductor on Round Core cable (CORC). In this solution coated conductors are helically wound on round former. The former can be braid conductor, solid wire or tube. Last written option offers possibility of partial or full cooling by forced flow of coolant inside the tube former.

We tested forced flow cooling method on 4 m long HTS CORC cable wound to form of small coil with non-vacuum thermal insulation made of aerogel and polyurethane foam. Critical current of the coil cooled by forced flow of liquid nitrogen was about 16 % lower than critical current of the same coil cooled by liquid nitrogen bath. From this result we deduced that temperature of superconductor was elevated about 1 K above liquid nitrogen temperature.

In next experiment we have used forced flow cold helium gas. In this way we succeed in reduction of the coil temperature below liquid nitrogen temperatures and thus enhancing the coil performance.

P-19 | Cooling System for a Superconducting DC-Rail

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DC-rails are used in a wide field of industrial applications, for example in aluminum smelters and chlorine electrolysis plants. Up to now usually large sized DC-rails made out of copper or aluminum transport currents up to a few hundred kA. The development of compact, efficient and innovative superconductor components is forced mainly due to the high density of energy flux and requires a suitable cooling system. Replacing conventional high power rails to superconducting DC-rails allows a reduction in size, installation area and prize. Last but not least it will increase the electrical efficiency of the whole process.

Within the framework of the government founded research project “3S-SupraStromSchiene”, project no. 03ET129C, a superconducting DC-rail was designed and is currently under construction. The ILK Dresden is responsible for the cooling system of this superconducting DC-rail. This novel cooling system that consists amongst others of a high power cryocooler and a special “cold” cryogenic pump will be presented for the use of a superconducting DC-rail system for a chloralkali process. The presentation describes the concept, design and experimental results of these key components.

The high power cryocooler is based on the principle of a pulse tube cooler and provides a cooling power of 400 W at a temperature of 65 K. In ordinary pulse tube coolers the acoustic power at the warm end of the pulse tube is transformed to useless heat. Using two commercial reciprocating compressors, where one is acting as a compressor and the other one as expander, it is possible to recover a certain part of these acoustic power. In this way the theoretical efficiency exceeds 11% at 65 K. The cold cryogenic pump works fully submerged inside the subcooled liquid nitrogen reservoir and consists of a double acting piston pump which is powered by a linear drive. It provides a mass flow up to 0.5 kg/s at a pressure difference of up to 2 bar. Other parameters are possible depending on the design requirements.

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Lam	Simon	Enhancement of critical current density by large antidots in inhomogeneous arrays in YBa2Cu3O7 thin films	
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Lewis	Chris J.	Large voltage modulation HTS 2D SQIF arrays operated on a single stage cryo-cooler	
Lin	Yuzhe	CFD analysis of the regenerator performance of cryocooler under different accelerations	Karlsruhe Institute of Technology, Germany
Luo	Ercang	Numerical and Experimental Studies of a Two-Stage Pulse Tube Cryocooler Working Around 20K	
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Mierau	A.	2G HTS tape reliable protection in 250 A current leads	
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Neumann	Holger	CFD analysis of the regenerator performance of cryocooler under different accelerations	
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Pan	Alexey	Enhancement of critical current density by large antidots in inhomogeneous arrays in YBa2Cu3O7 thin films	University of Wollongong, Australia
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Rem	P.C.	The design and analysis of a superconducting magnet system for magnetic density separation	
Ringsdorf	Bernd	Design and Performance of a Conduction-Cooled HTS Magnet in the Radio-Blackout Experiment COMBIT	
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Schlachter	Sonja	Design and Performance of a Conduction-Cooled HTS Magnet in the Radio-Blackout Experiment COMBIT	Karlsruhe Institute of Technology, Germany
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Walschburger	Uwe	Design and Performance of a Conduction-Cooled HTS Magnet in the Radio-Blackout Experiment COMBIT	
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Wang	Chao	Large Capacity Cryocoolers and Cold Helium Circulation Systems for HTS Applications	Cryomech Inc., USA
Wang	Yanan	The Effect of Impedance on VM Type Thermal Compressor Output Characteristics for Obtaining Liquid Helium Temperature	Chinese Academy of Sciences, China
Wang	Xiaotao	Numerical and Experimental Studies of a Two-Stage Pulse Tube Cryocooler Working Around 20K	TIPC, CAS, China
Weber	D.	Flow Regulation of Cryogenic Fluids: Design of a High-Rangeability Control Valve	
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