

# *Energy Efficiency and Sustainability Accelerator Research and Development*

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Subproject SIS100/SIS18

GSI Task Force Energy  
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# ENERGY EFFICIENCY - TOPICS

1. Energy Saving HTS Magnet
2. KI based Power Grid Monitoring
3. Sensor Based Power Monitoring
4. Watchdog for Accelerator Devices
5. Development of a HTS Nuclotron Cable
6. FAIR Energy Consumption Forecast
7. Cooling Water Flow Control
8. Energy Efficient Design of SIS100 Cooling System
9. Energy Efficient beam Transport by High Current Pulsed Magnets

# CAMPUS STUDIES C. RIPP

Masterthesis C. Ripp

## Analyse des elektrischen Energiebedarfs der GSI

Analysis of the electrical energy requirements of the GSI facility  
 Masterthesis von Christopher Ripp, B.Sc.  
 Matrikelnummer: 132282  
 Darmstadt, den 06.10.2013



GERN-THESIS-2013-114

**EuCARD-2**

Enhanced European Coordination for Accelerator Research & Development

## Academic Dissertation

### ELECTRIC ENERGY CONSUMPTION OF AN ACCELERATOR FACILITY

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**Abstract**—The changes of the German electricity system approaching a high share of renewable electricity production (80% by 2050) lead to a cost increase of electrical energy. This alters the basic conditions for big industrial consumers of electric energy. Fundamental research facilities, especially accelerator facilities (here GSI) have to develop innovative concepts for a more efficient use of electric energy in order to reduce running costs. A major part of the running costs is caused by the electric energy consumption. One of the main aspects of this development is the breakdown of electric energy consumption into consumer groups. To start this process we analyze the load curves of the last three years and identify periodic patterns, average consumption, base load and energy consumption of different operational modes at the accelerator facility. First results point out a high base load, which is equal to about 40% of consumed energy, and a high amount of peak load over a short time period, both could possibly be reduced in the future. The research, analysis and interpretation leads down the large energy consumption, which averages to about 55 GWh per year.

**Index Terms**—accelerator, energy consumption, load curve, load duration curve, base load, energy efficiency, energy management

#### I. INTRODUCTION

Increasing energy prices combined with a high net use of electrical energy makes it worthwhile to analyze the energy consumption of a large research facility like GSI. The EU-financed work package "Energy Efficiency" within the accelerator R&D Framework EuCARD-2 starts in the mid of 2013 [1,2]. Detached Labs, here GSI, have a need of introducing energy management systems or in the first instance an analysis consumption. Even the planning of new to a sustainable energy use, e.g. ESS (renewable energy source) [3].

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The main problem of our analysis was the lack of a monitoring network for each low voltage busbar, which indicates the active power for discrete end devices. We only have the data of one monitoring station at the feeding point. This measured value is the sum of energy consumption of all devices at the GSI site. The pulse power has an extra connection and is not included. Fig. 1 shows the load curve of the year 2011. The accelerator operation mode has of course a large influence on the curve. The period without accelerator operation is called Shutdown and is intentionally that in this time the demand of power is much lower. One can roughly divide the load curve into three sections.

#### II. GENERAL POWER GRID - LOAD CURVES

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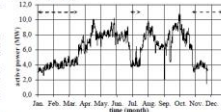


Fig. 1. Load curve of the year 2011 dominated by the accelerator operation periods. In addition the dashed line shows the shutdown periods.



- Multi energy web platform and monitoring at TUD "EnEff Campus Lichtwiese", based on the concept of digital twins.
- Transparent time-dependent, consumption-related CO2 emissions of all of the campus' buildings over all energy forms.

### Modern and Interactive Data Access

Web-based Energy Platform of the Developed Digital Twin



Access to monitoring data based on bird's eye view

Energy heatmap: The energy system at a glance

Further applications

Real-time aggregation at meter or building level

EnEff web platform is in operation - access exclusively via TU Darmstadt VPN

- Platform enables access to the measurement data of all installed meters
- Presentation of variables derived from the data, such as CO2 emissions per building
- Final goal → Live optimization based on machine learning forecast (currently in development)

Optimization Control Panel

Interactive Circuit Diagrams

## Data monitoring - Sensor system approach



# CAMPUS STUDIES

## GSI – LOAD CURVES AND ELECTRICAL POWER

Masterthesis C. Ripp

Energy Consumption: 55 GWh  
 (Electrical) Energy Cost: 7.6 M€ (2012)  
 Max. peak: 12 MW (incl. accel. operation)  
 Min. load: 2.2 MW (e.g. holiday period)

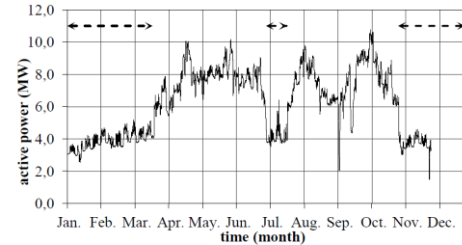
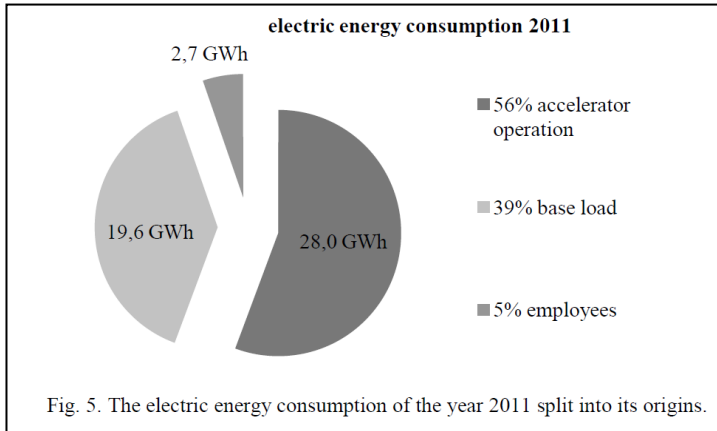


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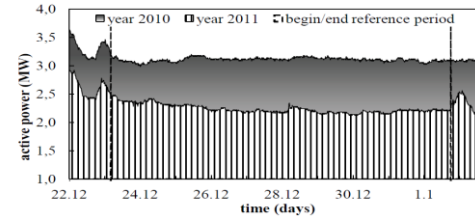


Fig. 4. The load curves illustrates the period between the years winter 2010 (fading grey) and winter 2011 (vertical lines).

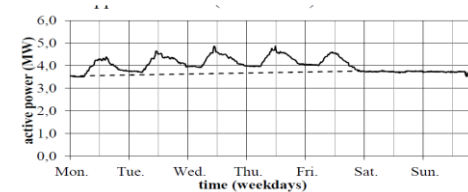
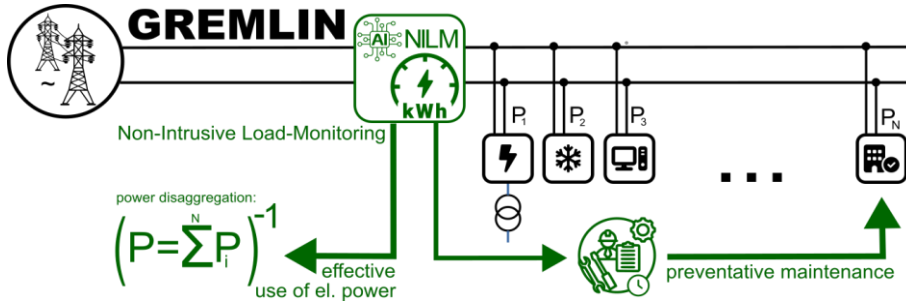


Fig. 2. The "weekend-approximation" (dashed line) simulates a base load for the working days.

# NON-INTRUSIVE LOAD MONITORING AKA. LOAD DISAGGREGATION

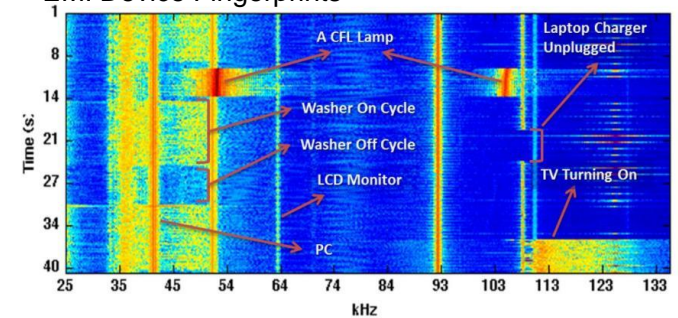


- AI-BASED CLASSIFICATION OF FACILITY'S EFFECTIVE ENERGY CONSUMPTION AT THE DEVICE LEVEL WITHOUT THE NEED FOR DIRECT INSTRUMENTATION OF EACH DEVICE (N.B. "BIG BROTHER" OF DOMESTIC SMART-METERS)
  - N.B. identification via unique electromagnetic interference (EMI) emissions devices generate on the network (aka. 'Van Eck phreaking' or 'TEMPEST')

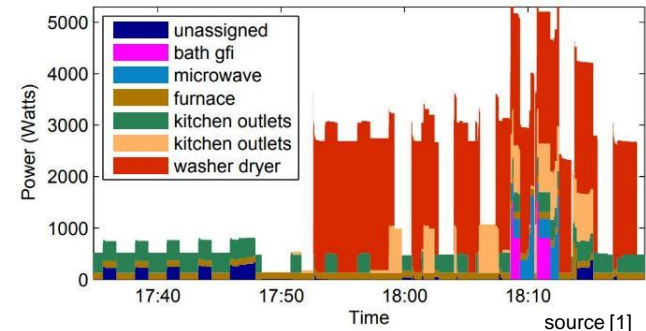
## Opportunities:

- monitor effective energy use on a sub-component level  
→ detect unused or unnecessarily powered devices
- identify malfunctioning, degrading, or inefficient equipment  
→ schedule preventative maintenance or mitigation measures.

EMI Device Fingerprints



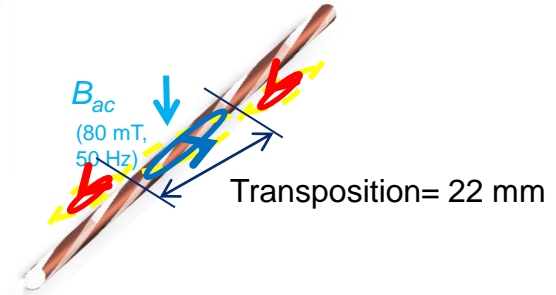
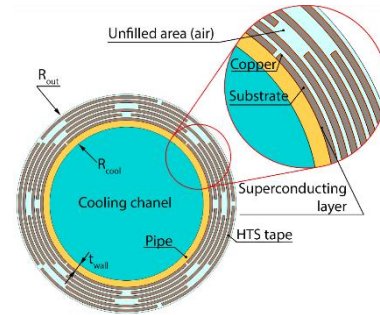
Extended Domestic Application beyond FAIR:



# HTS REBCO CABLE



HTS Nuklotron cable sample



- Design Parameters for a round, high current, low ac loss HTS ReBCO cable defined
- Good direct cooling properties, and windability of FAIR SIS100 cable and apply it to HTS
- Application: fast ramped, high field accelerator magnets
- EU IFAST work packages members:
  - Institute of Electrical Engineering (IEE), Slovak Academy of Sciences, Slovakia
  - ILK Dresden, Germany
  - GSI, Germany
  - EMS Chair, University of Twente (UT), Netherlands

## I.FAST

Innovation Fostering in Accelerator Science and Technology

Horizon 2020 Research Infrastructures GA n° 101004730



# APPLICATIONS OF HTS CABLE IN ENERGY SYSTEM

- Possible Applications of HTS Cables for Fast Ramped Synchrotrons in Energy Systems
- Two studies on Application in Energy Systems performed with IEE Bratislava
- SUPERCONDUCTING FAULT CURRENT LIMITER FROM CORT

- Evaluated cable options

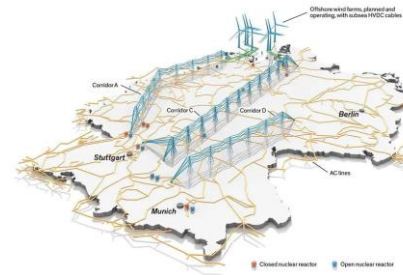
- Stacked tapes cable (ST)
- Roebel cable (Roe)
- CORC/CORT (Conductor on Round Tube) (CR)

- FCL has been studied for CORC/CORT type cable

- Advantages:

- Easily adjustable transport capacity by varying coolant temperature
- Parallel paths in CORT makes tapes requirements less strict
- Round shape gives flexibility for winding

Application	Application field	Cable concepts tested	Cable concept established
Current Leads/Magnet Feeders	Science/Energy	ST, CR	ST
Fault Current Limiters	Energy	Single tape, ST	-
High Field Magnets	Science/Energy	Single tape	Single tape
Fusion	Industry/Energy	ST, CR	-
Induction Billet Heaters/ Magnetic Separation	Industry/Energy	Single tape	-
Magnetic Energy Storage	Energy	Single tape, CR	-
Particle Accelerators/ Particle Therapy	Science, Medicine	ST, Roe, CR	-
Power transmission cables	Energy	CR	CR
Energy, Transport	Energy, Transport	Single tape	-
Transformers	Energy	Single tape, ST, Roe	-
Wireless Energy Transfer	Transport/Energy	Single tape	-
	Science/Medicine	Single tape	-
	Science/Medicine	Single tape	Single tape



# R&D FOR ENERGY EFFICIENT ACCELERATORS



## Workshop „Energy Efficient Beam Transport Technologies“ 26. April 2021 / ZOOM



Workshop "Energy Efficient Beam Transport Technologies"

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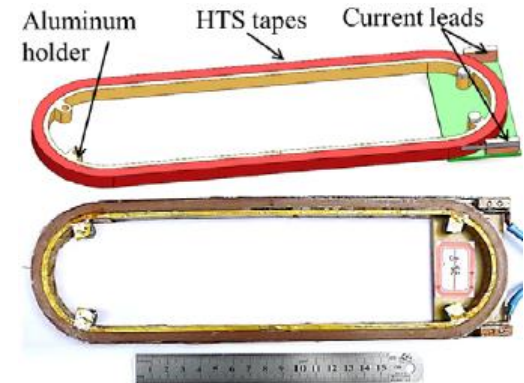
18 of the 22 workshop participants in total on April 26<sup>th</sup>, 2021



# ENERGY SAVING HTS MAGNET

Replacing copper coils in HEST magnets by cryostat containing an HTS Coil

- 56 % of overall GSI energy consumption is made by accelerator operation (assuming 6-7 kh)
- UNILAC: 4,5 MW, SIS: 3 MW, HEST: 1,4 MW, ESR: 2 MW
- Energy dissipation in magnet: 97 % in water 3 % in air
- Maintaining number of windings
- Cold heat cooled 20-40 K (no large infrastructure)
- Potential saving: 10% of overall GSI consumption



HTS pancake coil

Next steps:

- Calculation of AC loss (IEE Bratislava)
- Calculation of hot spot temperature
- Engineering design and prototyping

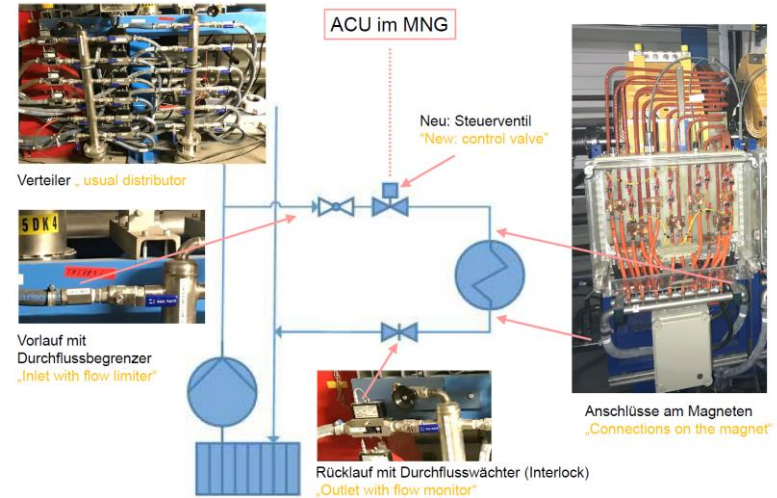


# COOLING WATER FLOW CONTROL FOR MAGNETS

- Controlled cooling water flow rather than constant flow.
- The pumps in these systems consume a lot of electrical energy and generate corresponding costs.
- The total flow rate in the full version of the FAIR cooling system is approx. 3000 m<sup>3</sup>/h.  
Cooling water quantity magnets approx. 1800 m<sup>3</sup>/h at 10bar differential pressure
- The power requirement for pumping this flow rate is approx. 900 kW. If you reduce this flow to 20%, e.g. during shutdown, you only need approx. 180 kW. 720 kW = 17.280 kWh/d = 3110 €/d\*

Two options:

1. On-off (full flow/minimum flow rate) according to magnet usage
2. Controlled flow rate according to magnet power consumption



# OTHER TOPICS

- Provision of controlling power by e.g. operation of cryoplant.
- Provision of controlling power by computing power (green IT cube).

# Energy Efficiency Programs

1. EU IFAST „Sustainable Concepts for Accelerator driven Research Infrastructures“  
( PSI, CERN, ESS, DESY, GSI )
1. Participation in future EU CARAT program „Green Energy Monitoring for Large-scale Infrastructures (GREMLIN)“
2. GSI hosts a Joint Workshop – Industry (Connectus) meets Accelerator in 2023
3. Sustainability INNOVEA in M&T ARD