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# ENERGY EFFICIENCY OF PARTICLE ACCELERATORS - A NETWORKING EFFORT WITHIN THE EuCARD<sup>2</sup> PROGRAM\*

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## Abstract

EuCARD<sup>2</sup> is an Integrating Activity Project for coordinated Research and Development on Particle Accelerators, co-funded by the European Commission under the FP7 Capacities Programme. Within the network EnEfficient [1] we address topics around energy efficiency of research accelerators. The ambitious scientific research goals of modern accelerator facilities lead to high requirements in beam power and beam quality for those research accelerators. In conjunction with the users' needs the power consumption and environmental impact of the research facilities becomes a major factor in the perception of both funding agencies and the general public. In this network we combine and focus the R&D done individually at different research centers into a series of workshops. We cover the topics "Energy recovery from cooling circuits", "Higher electronic efficiency RF power generation", "Short term energy storage systems", "Virtual power plants" and "Beam transfer channels with low power consumption". Our network activities are naturally open to external participants. With this work we will introduce our energy efficiency topics to interested participants and contributors from the whole community.

## ACCELERATORS AND POWER CONSUMPTION

Regarding the development of accelerator facilities two contradicting trends can be observed that lead to an increasing significance of energy efficiency. The worldwide scarcity of resources and the attempt of several countries to de-emphasize nuclear and coal-fire power production, the classical base load power production schemes, leads to economical and political pressure to limit power consumption in large facilities. On the other hand proposed next generation facilities utilize advanced technologies and provide a new quality of research opportunities, but often connected with significantly higher power consumption. An outstanding example of this development is the CLIC project, an electron/positron linear collider. The new two-beam accelerator concept allows to achieve very high accelerating gradients, which make even highest center of mass energies of 3 TeV accessible for particle physics. However, requirements of high luminosity at these energies result also in an enormous

power consumption, which is estimated around 500 MW [2]. Also for other new accelerator projects energy consumption is an issue and consequently more effort should be invested in efficient technical solutions. Within the network EnEfficient we aim to support and intensify these efforts, especially in view of the new projects.

## STRUCTURE OF THE NETWORK

This network is formed by institutions operating or building large scale research facilities. The scientific goals and thus the layout of the accelerator facilities are different but the need to increase the efficiency of energy use during operation for cost and sustainability reasons is common in all accelerator facilities in research and industry. Within this network we try to combine efforts from the participating partners in several subtasks.

### Energy Recovery from Cooling Circuits

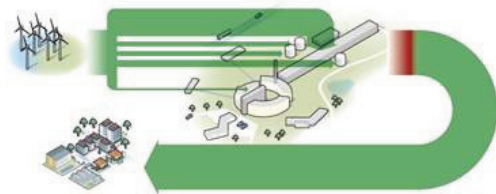


Figure 1: Heat recovery scheme for the European Spallation Source, Lund, Sweden. (Picture ESS).

Modern high power accelerators usually dissipate a lot of their consumed energy in cooling circuits of electronics, magnets and RF. Using the generated waste heat improves the overall efficiency and helps in reducing operation costs. Within this subtask state-of-the-art methods for making use of heat are to be evaluated. Cost versus revenue scenarios are investigated. A collection of heat inventory data in all participating labs has already been conducted. A workshop on heat recovery was held at Lund [3].

### Higher Electronic Efficiency RF Power Generation

One of the main power consumers in accelerators is the RF. At a recent workshop in the Cockcroft Institute in Daresbury [4], 44 international experts were discussing new ideas of how better RF systems could be conceived and built. It

\* EuCARD<sup>2</sup> is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

should be noted that high efficiency in RF power conversion not only reduces the power consumption and thus running cost, but also reduces the power lost as heat and the carbon footprint. The power and cooling installations become smaller as well. Klystrons reach efficiencies of up to 65% today – revolutionary new ideas implying “core oscillations” and the “BAC method” (bunch – align – collect) make the 90% efficiency range appear reachable. Industrial development of multi-beam IOT’s is now just starting for 704 MHz, 1.2 MW peak – success of this R&D could lead to a significant power savings for ESS. Magnetrons appear to be an alternative with high efficiency, but phase-stable synchronization remains to be demonstrated. Very interesting is also the development of solid-state power amplifiers, which have made significant progress over the last 10 years, not only in peak performance but also in efficiency, which is now competitive with vacuum electronic power-RF.

*Short Term Energy Storage Systems*

Electrical energy storage on time scales of seconds up to around a minute can substantially contribute to the safe and efficient operation of accelerators: Short interruptions of the grid, often only below 1 second, can already lead to unwanted beam aborts, and for large facilities like the LHC it can take many hours to restore the beams and to recover luminosity operation. During the long recovery time often the full grid power is needed, and thus the short interruptions lead to inefficiency. A solution to this problem could be realized by introducing energy storage devices to back up the grid on a short time scale.

Energy storage at accelerators is even more important for the pulsed operation of high power klystrons or ramped magnets. The negative feedback of a strongly fluctuating high power load on the electricity grid can be avoided by a fast and efficient short-term storage device which continuously takes up an essentially constant power from the grid, stores it on a second time scale and delivers high power pulses e.g. to pulsed magnet systems.

The following devices address especially the short-term energy storage:

- Super- or Ultra-Capacitors
- Superconducting Magnetic Energy Storage (SMES)
- Rechargeable Batteries (e.g. Lead or Lithium Ion Batteries)
- Flywheel Energy Storage

The most cost-effective solution will, of course, depend on the application-specific requirements, but a fast and efficient power conversion and control unit plays a key role in all cases. The general availability of infrastructure like cryogenics on research sites can foster new technical developments.

Such problems are common to many accelerator facilities. The aim of this task is to exchange information and experience gained at different labs with regard to the mentioned

problems and to develop potential solutions, for example by utilizing the mentioned SMES.

*Virtual Power Plants*

Modern research accelerator facilities are dedicated to deliver high power high brightness beams to their scientific users. The ambitious beam parameters requested lead to accelerator designs which consume a considerable amount of electrical energy. Beside the accelerator itself a large scale research facilities has to provide infrastructure for its users. This leads to an overall high energy consumption suggesting to use the accelerator labs for energy network stabilizing measures.

Instead of increasing the energy production in times of high demand it is as effective to reduce the overall power consumption. This is standard procedure on a long term basis. The scheduled winter shut down at CERN being an example.

If a facility identifies enough power consumers which can be switched off on short notice, ideally without impact to the facility’s routine operation, they can form a virtual power plant. A typical example would be a refrigerator which has to cool its inventory below a fixed temperature. During normal operation it will be cooled lower than that maximum temperature. The grid operating company can switch the cooling off for short periods of time as long as the maximum temperature is not exceeded.

For identification of power using devices which are possible candidates to be part of a virtual power plant the power consumption of the entire facility has to be analyzed. A survey of the electrical energy use of the present GSI accelerator complex and science campus has been done. The project started before the beginning of EnEfficient. It has been completed and published as master thesis [5].

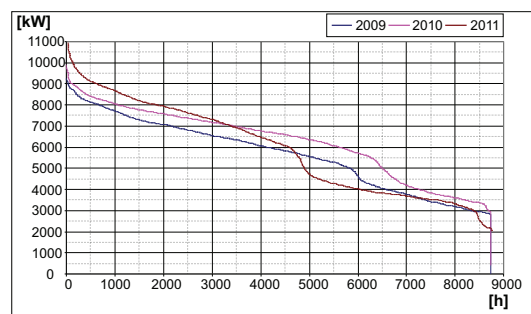


Figure 2: Distribution of power loads in a 15 minute average caused by GSI campus and accelerator facility. Note the difference in load from 5000 h to 6500 h due to different operation times of the accelerator (taken from [5]).

The power consumption of the future FAIR facility, which has already been estimated for operating cost determination, could be topic of a workshop within this network.

Beside the accelerator itself main power consumers are cryo plants for superconducting magnets and the water cooling circuits for electronics. Finding modes of operation

together with cryo and cooling experts which use less energy temporarily is of high interest for forming virtual power plants at research labs.

### *Beam Transfer Channels with Low Power Consumption*

Focusing systems are important parts of all kind of accelerator facilities. High energy accelerators provide beams for fixed target experiments or for the production of secondary beams. The transport of high energy beams requires quadrupole lenses with rather strong magnetic fields. After a

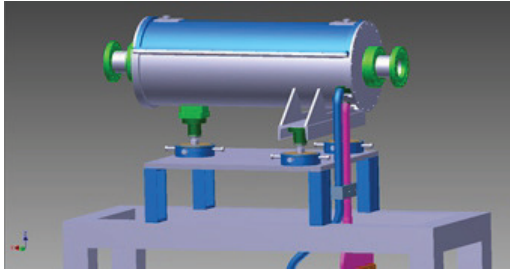


Figure 3: Quadrupole lens with ceramic tub and supply conductors mounted on the frame.(Picture: GSI).

few previous tests our novel type of quadrupole lens is characterized by its iron free magnetic core in which one single conductor is wound four times along the beam pipe. This arrangement creates the desired magnetic quadrupolar field for beam focusing. The special feature of such lenses is their low inductance which enables a short pulsed operation. The short operation time and the low resistance of the conductor reduces the average energy dissipation in comparison with a long pulse or c.w. operation of conventional magnets.

The design drafts developed at GSI will now be used as basis for the manufacturing design and construction by an industrial partner. With his help we found a compromise for the bending of the conductor and its cranks being in the optimal shape for the desired magnetic field but still producible.

The design of the lens, which will be operated in a short pulsed mode, has to consider transient effects induced by the fast current variation. Therefore, special technical solutions

had to be developed for the connector and the conductors. The overall design has also to cover the large Lorentz forces caused by the high current pulses of several hundreds of kilo amperes, which may reach values of up to 64 tons per meter.

The energy efficiency of such lenses may be significantly improved at operation in a resonant electrical circuit. A conceptual study on technical issues of such an energy recovery is planned. Furthermore, a comparing study of different types of beam transport technologies with respect to their energy efficiency has been started. The usability of pulsed focusing systems or in general pulsed beam lines will be the topic of a future workshop within this network.

## SUMMARY

The scientific goals of research facilities are reached by using state-of-the art technologies. The efficient and cost effective use of electrical power is getting increasingly into focus of general public and funding agencies. EnEfficient aims to combine the efforts to reduce environmental impact and costs carried out at different sites. The network is open for contributions. Please do not hesitate contact us if you are hosting workshops on energy efficiency in science or related topics.

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