ACCELERATOR OPTIMIZATION WITHIN THE OPAC PROJECT

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Abstract

Many of today's most advanced research infrastructures rely on the use of particle accelerators. This includes for example synchrotron light sources and free electron lasers (FELs), high intensity hadron accelerators for the generation of exotic beams and spallation sources, as well as much smaller accelerator facilities for precision experiments and fundamental studies. Moreover, accelerators are very important for many commercial applications, such as in medicine, for studying and treatment of materials, lithography and security, for exmaple scanners at airports or cargo stations. The full potential of any accelerator can only be exploited if the performance of all its parts are continuously optimized, if numerical tools are made available that allow for developing and improving advanced machine designs and if methods are developed in partnership between the academic and industry sectors to monitor beams with ever higher intensities and brightness, shorter pulse lengths or smaller dimensions. This contribution presents the R&D and training program of the oPAC project.

INTRODUCTION

oPAC was selected by the European Commission for funding within the FP7 Marie Curie Actions. With a total budget of up to 6 M€ it is one of the largest Initial Training Networks (ITNs) ever funded by the EU and will train 22 early stage researchers in accelerator science and technology over the project's four year life time.

oPAC currently brings together more than 30 universities, research centers and industry partners from all over the world and continues to expand through new adjunct partners. Following an international recruitment campaign, all positions have been filled and research into the project's work packages on beam physics, beam diagnostics, simulation tools and control and data acquisition systems has started.

RESEARCH

oPAC combines studies into the physics and dynamics of particle beams, with an improvement of existing accelerator and field simulations tools, the development of innovative beam instrumentation techniques and an intense R&D program into accelerator control and data acquisition systems. The strong presence of the industry sector in the consortium ensures that spin-off developments are actively sought and that the training program provides all fellows with a broad skill set that will give them an excellent base for a future career in both the academic and industry sectors. All developments are closely linked to the much wider experimental programs at the different oPAC research infrastructures, which ensures that the foundations of oPAC are laid in a truly interdisciplinary way The following paragraphs outline recent progress in some selected projects.

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Large Hadron electron Collider

In preparation for a future Large Hadron electron Collider (LHeC) at CERN, an energy recovery linac (ERL) test facility is foreseen as a test bed for superconducting radiofrequency (SRF) development, cryogenics and advanced beam instrumentation, as well as for studies of ERL-specific beam dynamics. A CERN ERL test facility would comprise two linacs, each ultimately consisting of four superconducting (SC) five-cell cavities at ~802 MHz and two return arcs on either side. In such a scheme, a final electron energy of about 300 MeV will be reached. This machine should feature an average beam current above 6 mA to explore the relevant parameter range of the future LHeC. oPAC fellow Alessandra Valloni is contributing to the initial design of this facility [1].

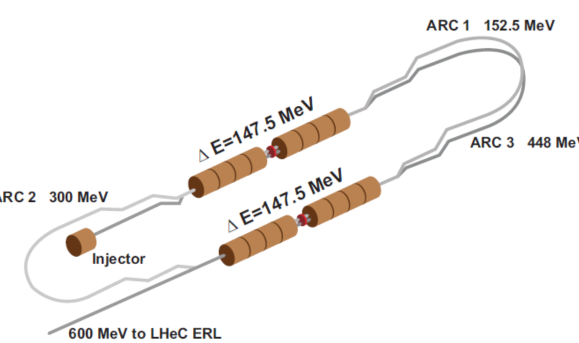

Figure 1: Illustration of an upgrade to the LHeC pre-accelerator. By modifying the machine backleg to include a second full cryomodule, the recirculator can deliver a higher beam energy of 600 MeV.

The accelerator consists of the following elements:

- 5 MeV injector with injection chicane;
- superconducting linacs;
- transport lines including spreader regions at the exit of each linac to separate and direct the beams via vertical bending and recombiner sections to merge beams and to match them for acceleration through the next linac;
- beam dump at 5 MeV.

A two-pass recirculating linac will enable operation in energy recovery mode. Flexibility in the design will eventually permit additional passes to be supported to increase the final beam energy. The prototype architecture will produce 300 MeV beams with a target current of about 6 mA. Different candidate RF frequencies for the SC linac have been examined, and the final choice of ~802 MHz is mainly dictated by a compromise of cost considerations and beam dynamics issues, along with functional synergies with other existing systems.

A possible upgrade design following the installation of an additional cryomodule to raise the beam energy up to 600 MeV is shown in Figure 1. In this new configuration the facility could represent a smaller clone of the final LHeC project and be adopted as a pre-accelerator/injector to the final 60 GeV machine. Preliminary lattice designs and other features are discussed in [1].

Cryogenic Beam Loss Monitors

At the LHC triplet magnets, close to the machine's interaction regions, the current Beam Loss Monitoring (BLM) system is sensitive to particle showers resulting from the collision of the two beams. With beams of higher energy and intensity resulting in higher luminosity, distinguishing between these interaction products and possible quench-provoking beam losses from the primary proton beams will be very challenging in the future. Therefore, investigations are underway to optimize the system by locating the beam loss detectors as close as possible to the superconducting coils of the triplet magnets. This means putting detectors inside the cold mass in superfluid helium at 1.9 K.

Previous tests have shown that solid state single crystal chemical vapour deposition (scCVD) diamond and p+-n-n+ silicon detectors, as well as liquid helium ionization chambers are promising candidates. oPAC fellow Marcin Ryszard Bartosik at CERN is contributing to studies investigating the question of the detectors' radiation resistance during 20 years of nominal LHC operation, by reporting on results from high irradiation beam tests carried out at CERN in a liquid helium environment.

Different Si detectors at cryogenic temperatures were tested for their radiation hardness, see e.g. Figure 2. In these measurements a total integrated fluence of $1.22 \cdot 10^{16}$ protons/cm^2 was reached, corresponding to an integrated dose of about 3.26 MGy for silicon.

An irradiation effect on detector sensitivity was observed, see Figure 3. The forward bias modus leads to high signals at the beginning of the irradiation, but unfortunately the decrease in signal at higher fluence is faster compared to reverse bias modus. Further observations are that the forward bias for low resistivity silicon is less stable than for high resistivity silicon. In liquid helium, the major downside of silicon compared to diamond disappears: the leakage current for silicon is below 100 pA at 400 V, even under forward bias for an irradiated diode. The performed experiments allowed the observation of how radiation affects the detector sensitivity for silicon and single crystal diamond.

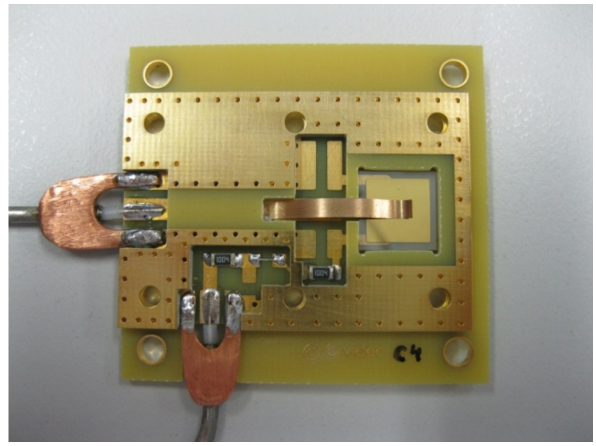

Figure 2: Holder for direct current readout from Cividec.

For BLM application as a safety critical system, long term stability of the detectors is a high priority criterion. The data therefore requires more time for treatment to allow further application relevant conclusions and physical results. Silicon and diamond detectors have recently been installed on the cold mass of an LHC magnet. This location will enable to gain further experience with the detectors' long term performance and will bring an unprecedented insight to LHC beam losses. More experiments with current pulse response measurements using TCT with a pulse laser at cryogenic temperatures during irradiation are foreseen.

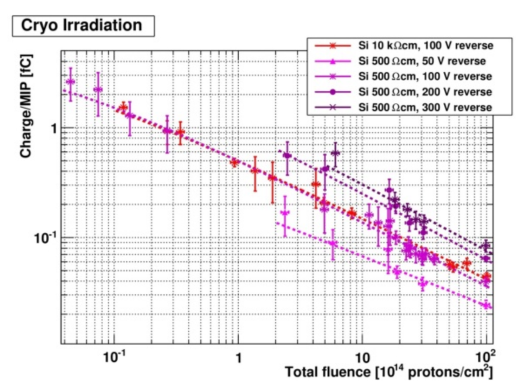

Figure 3: Dependence of the charge collected in Si detectors with a resistivity 500 Ωcm on fluence.

TRAINING EVENTS

Training within oPAC is provided locally at the respective host institute, primarily provided through cutting edge research, local lecture and seminar series, as well as network-wide training offered by the whole consortium. During the four year project life time, the network will also organize a series of Topical Workshops and international schools to which all trainees will be invited. Whilst most events will focus on specific aspects of accelerator R&D, two schools will wholly concentrate on the provision of complementary skills training. The following paragraphs give an overview of upcoming events. This holistic training concept is based on the ideas developed within the DITANET project [4, 5].

International Schools

At the start of their training all oPAC fellows participated in either the CERN Accelerator School or the Joint Universities Accelerator School. This provided them a sound training basis as they take on their projects within the Network. Both schools included lectures and tutorials covering accelerator physics, relativity and electro magnetism, particle optics, longitudinal and transverse beam dynamics, synchrotron radiation, linear accelerators, cyclotrons and general accelerator design.

An oPAC School on Accelerator Optimization will be organized by the consortium in summer 2014 at Royal Holloway University of London, UK. It will cover advanced techniques for the optimization of particle accelerator performance - in particular the combination of different fundamental techniques to push the limits of accelerators ever further.

All trainees will also meet for a dedicated researcher skills school in Liverpool, UK in June 2013. During the week-long school they will be provided with subject-specific training in addition to the usual generic topics, including project management, scientific writing, problem solving techniques and building bridges between academia and industry. The fellows will be asked to present a short summary of their projects as part of presentation skills training and also to develop a detailed project plan of their oPAC projects. A second complementary skills school in the project's final year will allow the fellows to build on project management with an advanced course in addition to covering topics relevant to their future employment, such as CV writing and job applications, as well as an introduction to the careers market and writing competitive grant applications.

Topical Workshops

oPAC will also organize a series of international workshops which will be open to the wider scientific community. Starting with expert trainings on 'Simulation Tools' (CST, Germany) and 'Beam Diagnostics' (Bergoz, France) which will be held on June 25/26 the consortium will organize a two day Topical Workshop on the Grand Challenges in Accelerator Optimization at CERN, Switzerland on June 27/28th 2013 [6]. This two-day international event will provide an overview of the current state of the art in beam physics, numerical simulations and beam instrumentation and highlight existing limitations. It will discuss research and development being undertaken and ambitions to further improve the performance of existing and future facilities. In addition to invited talks, there will be industry displays and a special seminar covering recent LHC discoveries. All participants will have an opportunity to contribute a poster. All oPAC Fellows shall attend this event which will provide them with a very broad training and an excellent opportunity to network with their other fellows and senior scientists.

Topical workshops on beam physics, control systems, industry applications and technology transfer will follow and will typically bring together 30-50 experts and last 2 days. Institutes for hosting these events have already been identified and all presentations given will be made available via the CERN indico system. All events will be announced via the oPAC web page [7] and in the project's quarterly newsletter (subscription can be registered via the oPAC web page).

Conference on Accelerator Optimization

In the final year of oPAC, a 3-day international conference on accelerator optimization will be organized, with a focus on the methods developed within the network. This event will also serve as a career platform for the network's trainees who will get the opportunity to present the outcomes of their research projects. In addition, a symposium open to the general public will be held at the Cockcroft Institute/University of Liverpool to promote the research outcomes beyond the scientific community.

SUMMARY AND OUTLOOK

This paper has given a brief introduction to the oPAC project – one of the largest EU funded training networks for early career researchers. Providing a holistic approach to accelerator optimization an international consortium carries out 22 R&D projects and organizes a wide range of training events over the network's four year duration. Progress in some selected research projects was described and preview of upcoming training events was given.

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