BEAM DIAGNOSTICS RESEARCH WITHIN OPAC

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Abstract

The optimization of the performance of existing and future accelerator facilities is the goal of the oPAC project, recently selected for funding by the EU. This shall be realized by closely linking beam dynamics studies with beam instrumentation developments, advancements in numerical simulation codes and more powerful control systems. With a project budget of 6 M€, oPAC is one of the largest Marie Curie ITNs ever funded by the EU and will allow training 22 early stage researchers (ESRs) within its four year project duration. The consortium brings together universities, research centers and industry partners that will closely collaborate and also organize a number of training events open to the international accelerator community. In this contribution, the beam diagnostics R&D program across the network is presented, together with upcoming events.

INTRODUCTION

Many of the today's most advanced research infrastructures rely on the use of particle accelerators. This includes for example synchrotron-based light sources and FELs, high energy accelerators for particle physics experiments, high intensity hadron accelerators for the generation of exotic beams and spallation sources, as well as much smaller accelerator facilities where cooled beams of specific (exotic) particles are provided for precision experiments and fundamental studies. Moreover, particle accelerators are very important for many commercial applications, such as for example medical applications, where they are used for the provision of radioactive isotopes, x-ray or particle beam therapy. Furthermore, they are widely used for material studies and treatment, lithography, or security applications, such as scanners at airports or cargo stations.

The full potential of any particle 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 for benchmarking modeling codes against experimental results, 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, and if the state-of-the-art in control and data acquisition systems is pushed further by the international research community to link all the above.

This requires constant progress in these fields and, most importantly, continuous exchange of knowledge and researchers, critical review and discussion of the state-of-the-art by leading experts, and an agreement between international partners on future standards for all important machine components. The oPAC consortium will combine 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 network will carry out a very broad and closely interconnected experimental program that combines many different scientific disciplines, such as for example physics, electronics, IT, material sciences, and even medical applications. 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 ESRs 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.

The network consists of 12 beneficiary partners (three from industry, three universities and six research centers), as well as of 13 associated and adjunct partners, 6 of which are from industry.

BEAM DIAGNOSTICS R&D

A versatile beam diagnostics system is crucial for the successful operation and continuous optimization of any particle accelerator or light source. A few years ago, the DITANET consortium [2] set out to define improved training standards in this research area. This involved close collaboration between international partners, continuous exchange of knowledge and researchers and the organization of training events that were open to the international science community. The development of cutting edge beam diagnostics devices is also a key aspect in the oPAC project and this section gives some examples.

Beam Profile Monitoring

There are still a number of open challenges in monitoring the profile of particle beams: This is caused either by the limited dynamic range of many monitors, a lack of sensitivity for low energy, low intensity beams or an inability to monitor profiles of high intensity or high energy beams. Within oPAC several project aim at pushing this technology beyond present limits.

An understanding and possible control of beam halo is important for all accelerators. It is crucial for the operation of high energy accelerators, where beam loss can cause critical damage to machine components and

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deteriorate the quality of the experimental data. Many different effects leading to halo formation have been analyzed, but a comprehensive study of halo generation processes and transport through different accelerator structures is missing. An ESR at the Cockcroft Institute (CI)/University of Liverpool will develop a beam monitor for halo propagation mechanisms. This work will be based on a micro mirror-based halo monitor that was developed by groups at CERN, the CI and the University of Maryland over the past few years. It uses Texas Instruments' DMD technology and has already demonstrated that it is suitable to measure beam profiles with a dynamic range of better than 10^5 [3,4].

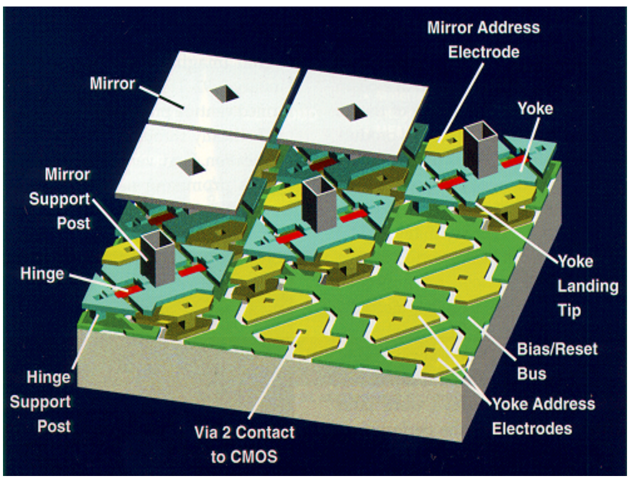

Fig. 1: Illustration of the DMD technology.

Within the oPAC project this monitor will be substantially improved by using the latest high definition mirror matrix, providing even higher frame rates and better spatial resolution, and by combining, for the first time, several such monitors in the same accelerator to investigate halo propagation directly and to benchmark numerical predictions.

In addition to these beam halo studies, another project focuses on the monitoring of the transverse beam profile in high power beams: Laser-wire systems employ laser beams to scan accelerated particle beams to determine their transverse profile [5]. They are well suited to operation at high power or low emittance machines because they are relatively non-invasive devices and they cannot be destroyed by the beam they are measuring. In the frame of an ESR project at Royal Holloway University of London, a laser-wire beam profile monitor for measuring the transverse beam profile of an H^- beam will be developed. The project will initially develop a laser-wire system to measure the emittance at the exit of the ion source of Linac4 at CERN. Particular challenges include the novel use of fiber lasers and the use of fibers for light transport. The ESR will explore the technique of emittance measurement by measuring the profile of the neutralized beam downstream of the laser-wire location where an efficient extraction of the signal in a difficult to access area needs to be developed; this project will also involve significant design effort in collaboration with the Linac4 machine physicists at CERN.

SQUID-based Beam Current Monitor

Standard beam intensity measurement methods rely on capacitive or inductive coupling to the magnetic field produced by the beam. When approaching low beam intensities, the limiting factor for the measurement accuracy is the noise - either in the processing electronics, or acquired by the coupling of the measurement device to the vacuum chamber.

It has already been shown that High Temperature (HT) Superconducting Quantum Interference Devices (SQUIDS) can overcome some of these limits [6,7]. These devices can provide a measurement dynamic range exceeding 80 dB and have enough resolution to measure beams down to the sub-micro-ampere level. The ability to achieve the superconducting state at high temperatures (typically 60 - 90 K) substantially reduces the complexity of the cooling required, leading to devices that can be fairly easily integrated into any accelerator.

An ESR at CERN will carry out studies into an HT-SQUID based beam current monitor for the ELENA storage ring [8] at the AD. This work includes designing, implementing and measuring the performance of such a system.

Beam Loss Monitoring

The limitation of beam losses will be especially important for future applications of particle accelerators in high-energy physics, medicine and nuclear energy technologies. Within an ESR project at CIVIDEC, Austria the development of a versatile beam loss monitor which can resolve different particle species such as charged particles, neutrons, and photons, single-particles, will be realized. The monitor is expected to have a high dynamic range of $1:10^4$, very good timing resolution on the sub-nanosecond scale, and an excellent radiation tolerance to ensure a long life time. This monitor shall serve as a general purpose beam instrument for monitoring the particles in beam halos to optimize accelerator performance. It will be based on CVD diamond detectors, a conversion unit for neutrons and photons, ultra-fast low-noise readout electronics with a bandwidth of 1 GHz, a fast digitizer with 5 GS/s, and a dedicated readout system with on-line dead-time free data manipulations for zero suppression and 100 MB memory for data recording.

In addition, another ESR at CERN will carry out an R&D program into Beam Loss Monitors for use in Cryogenic Environments aimed at protecting and optimizing high luminosity insertions using superconducting magnets. It is expected that the luminosity of the LHC will, in the future, be limited by the beam loss limits of the superconducting magnets. To allow an optimal detection of the energy deposition in the magnet coils by the beam particles, the detector needs to be placed near to the particle impact location. This condition implies that the particle dose detectors are

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installed in the cold mass of the magnet, which has not yet been demonstrated.

IMRT Image Reconstruction

An ESR will be embedded into the basic nuclear physics group at CNA/University of Seville in collaboration with the department of atomic, molecular and nuclear physics and the hospital "Virgen de Macarena". The aim is to design a detection system for verifying a 3D method of image reconstruction for Intensity Modulated Radiotherapy Treatment (IMRT). The experimental setup will be based firstly on commercial silicon strip detectors, coupled to home-made purpose-built electronics and acquisition system that will be setup around phantoms made of water-equivalent material. A Geant4 application to simulate the energy deposited in the detector, irradiated by 6MV beams from a Siemens PRIMUS linac dual energy machine, will be developed. The goal of these studies is to estimate the sensitivity of Si-detectors in different situations, according to the energy deposited in each electrode. Experimental measurements to evaluate the performance of the detection system, test Geant4 calculations and validate the 3D reconstruction method will be performed. Secondly, new detection technologies will be considered for improving IMRT. Whilst the project targets IMRT, the detection technique and the corresponding simulation, are very relevant for many other applications.

TRAINING EVENTS

All oPAC trainees will be embedded into a structured course program at their host university or, in case their work contract is with an industry partner or a research center, with a collaborating university. In addition, the network will organize a large number of training events that will also be open for participants from outside the network.

International Schools

All oPAC trainees will participate in two schools on the 'Optimization of Particle Accelerators'. This will allow them to liaise with external participants and thus ensures knowledge exchange within a wider community and is an ideal opportunity for establishing links to other researchers working on similar topics. It was decided to send all trainees to the well established CAS and JUAS schools, depending on their start within the project.

A second school will be organized by the consortium and will be held in 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 even further.

Topical Workshops

As part of the network's long term strategy to create lasting structures for the wider scientific community, even beyond the time frame of this project, the network will initiate a series of Topical Workshops. These will cover topics such as 'Beam Physics' (ALBA, Spain), 'Beam Diagnostics' (CIVIDEC, Austria), 'Simulation Tools' (CST, Germany) or 'Libera Technology' (Instrumentation Technologies, Slovenia). These workshops will bring together 25-30 experts and will typically last 2 days. Institutes for organizing these events were already identified and all presentations given will be made available via the CERN indico system.

In addition, the oPAC trainees will be given the necessary resources to organize a 2-day workshop themselves during their 2nd year within the project.

Conference on Accelerator Optimization

In the final year of oPAC, a 3-day international conference on the optimization of particle accelerators will be organized, with a focus on the methods developed within the network. It will be organized for the international accelerator community. A focus will be set on contributions from early stage researchers.

SUMMARY

An overview of the beam diagnostics R&D program within the recently approved oPAC project was given. The network is one of the largest initial training networks ever funded by the European Union and will train 22 early stage researchers over the next four years. The consortium consists of universities, research centers and industry partners and will also organize a rather large number of training events. This includes Schools, Topical Workshops and an international conference which will all be open also for participants from outside the project.

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