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OPAC – OPTIMIZING ACCELERATORS THROUGH INTERNATIONAL COLLABORATION

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Abstract

The optimization of the performance of any particle accelerator critically depends on an in-depth understanding of the beam dynamics in the machine and the availability of simulation tools to study and continuously improve all accelerator components. It also requires a complete set of beam diagnostics methods to monitor all important machine and beam parameters with high precision and a powerful control and data acquisition system. Within the oPAC project all these aspects will be closely linked with the aim to optimize the performance of present and future accelerators that lie at the heart of many research infrastructures. The project brings together 22 institutions from around the world. With a project budget of 6 M€, it is one of the largest research and training networks ever funded by the EC. This contribution gives an overview of the network's broad research program and summarizes the training events that will be organized by the consortium within the next 4 years.

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 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. This paper gives some examples from the project's 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 researchers who will be trained within oPAC with a broad skill set that will give them an excellent base for a future career in both the academic and industry sectors.

The network presently comprises 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.

RESEARCH

The aim of oPAC is to train researchers in interdisciplinary and intersectoral research fields, where the latest knowledge in simulation tools, control and data acquisition systems, beam physics and instrumentation are all combined to optimize the performance of existing and future accelerator facilities. The following paragraphs give a few examples from the wide range of research projects that will be realized by the network partners.

Beam Physics

A detailed understanding of the motion of charged particle beams in complex electromagnetic field distributions, the impact of beam-beam effects on experiment performance, as well as of collective effects and their potential to drive machine instabilities, and of beam halo formation and propagation processes is very important to optimize the performance of essentially any accelerator. The oPAC partners will develop beam handling techniques and carry out detailed studies into the beam dynamics of some of the most advanced particle beams.

An early stage researcher (ESR) at ALBA, Spain will work on advanced beam physics problems at light sources. (S)he will start with investigations into pinger magnet measurement and analysis. From turn by turn data, schemes for improved tune measurement, resonance analysis, and frequency map measurement will be developed. Based on measurements of the sextupolar Hamiltonian, differences to theoretical models will be studied and effects on the beam lifetime analyzed. Opportunities for contributing to the design and installation of the pinger magnet will be given. In addition, the trainee will participate to measurements using spin depolarization, including the determination of the momentum compaction factor and precision measurements of beam energy. Further work will include investigations into the possibility of single turn injection using a pulsed multipole, different methods to generate ultra-short light pulses, low alpha lattices and laser slicing for the generating of short pulses of the order of 100 fs. CERN has launched a new LHC luminosity upgrade project. This study is very important to further optimize LHC performance and pave the way for an even more advanced experimental program in the future. An ESR will perform optics and lattice design studies for the interaction region design of the HL-LHC experimental insertions. (S)he will study novel design options, such as options for integrating machine magnets in the experiments, lattice and optics configurations for the installation of Crab Cavities in the LHC and investigate their impact on the LHC Machine Protection System, investigate into options for novel compensation schemes for beam-beam interaction in the LHC, as well as for luminosity leveling. Finally, opportunities will be given to look into shielding and radiation effects in the experimental insertions and contribute to the design of a collimation system in the experimental insertions.

Beam Diagnostics

There are several projects around the world that include MW-class proton drivers. Most of these projects use H^- ions which are required to inject the beam into a subsequent ring using charge exchange injection and thereby increasing the beam current whilst maintaining the beam emittance. The European Spallation Source (ESS), however, will use protons, since no accumulator ring is planned. This poses a particular challenge when it comes to measuring the beam size. In a SC linac, there is significant concern about using physical wires due to the losses they generate and due to the possibility of wire fragments contaminating the SC surfaces in the case of a wire breakage. Therefore, most H^- projects are aiming at using laser wires, based on the principle of photo-neutralization. At ESS, however, this method will not work and alternatives will have to be found to be able to monitor the beam size. An ESR will evaluate and develop alternative methods for measuring the beam profile in high intensity beams, including electron/ion beam scanners, ionization profile monitors, quadrupole pick-ups, Compton scattering and luminescence. Once the optimum method has been identified, a prototype will be designed, built up and tested.

Laser-wire systems employ laser beams to scan accelerated particle beams to determine their transverse profile. 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 (RHUL), 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, similar to a project currently ongoing at Rutherford Appleton Lab (RAL); the trainee will collaborate with the ongoing work at RAL to gain early experience. The trainee will design a laser-wire system for monitoring the beam towards the end of the Linac4 beam-line. 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.

Simulation Tools

An ESR at ULIV will apply the latest techniques in computational electromagnetic codes to optimize accelerator performance. Calculations for accelerators often rely on the Finite Difference Time Domain method or the Finite Element Method. These codes require a discretization of the 3D space, which means a very large number of unknowns for complex structures. This results in the need for large memories and processor speeds that often exceed the performance of even the best computers. The multilevel fast multipole method might greatly speed up the computation, reduce memory requirements and thereby be more efficient than commonly used codes for particle accelerators. The trainee will lead the development of a simulation suite based on the multilevel fast multipole method, which will be tested against analytical results. The code will be used to calculate the fields for guiding and accelerating structures in existing and future accelerators, such as the LHC and CLIC, and will be benchmarked against other, more conventional codes.

The software package CST PARTICLE STUDIO is capable of simulating charged particle dynamics in 3D electromagnetic fields. For the design of particle accelerator components this is a commonly used software tool. In general a self-consistent particle in cell simulation (PIC) requires a huge amount of memory- and computational resources. By using Graphics Processing Units (GPUs) and the Message Passing Interface (MPI) for PIC simulations, one might increase both the simulation speed and maximum size of a problem in terms of the number of unknowns. An ESR at CST will support the PARTICLE STUDIO development team in the development of a GPU-based PIC solver. In a first stage, this will require the adaptation, including in many cases, the re-writing of existing and internationally established codes for a GPU environment. In a later stage of the project, this implementation will be extended for the use on systems with multiple GPUs or even computer clusters. The particular challenge is to develop interpolation- and load balancing-schemes which take full benefit from modern GPU architectures.

Control and Data Acquisition Systems

The goal of an ESR project at COSYLAB is the adaptation of existing open-source control systems, used for compact particle accelerators, to large scale, several orders of magnitude more complex and demanding, accelerator facilities, such as FAIR and ESS. These large scale research infrastructures have significantly more stringent performance requirements than allowed by off-the-shelf industrial automation and control systems. In this project, novel concepts will be pioneered and developed into industrial strength tools and platforms. The R&D addresses improved redundancy management, the analysis of existing protocols to define/adopt suitable candidate protocols and measure/analyze performance and scalability improvements.

A second ESR within this work package be employed at Instrumentation Technologies and involved in the improvement of the process to identify the needs for accelerator instrumentation and develop a clear definition of future requirements. Optimization of the performance of any accelerator depends significantly on close collaboration between research institutes and industry. This involves common work on problem definition, requirements setting, prototype and algorithm design, followed by a commonly agreed project plan. This plan determines the steps required for implementation, installation, integration and training of usage and commissioning. The research work of the ESR requires secondments to the participating research institutes, such as for example GSI, CERN, and ALBA to better understand the procedures carried out in their labs. Close collaboration with all other oPAC partners will be key to reaching the goals of this project and in developing long term interdisciplinary collaboration.

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. This training concept is based on the successful ideas developed within the DITANET project [1].

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.

An oPAC school on Accelerator Science and Technology will then be organized by the consortium and 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 ever 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. All events will be announced via the oPAC web page [2] 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 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.

REFERENCES

[1] http://www.liv.ac.uk/ditanet

[2] http://www.liv.ac.uk/opac