

Status of PACMAN project at CERN

N. Catalan-Lasheras, H. Mainaud-Durand, M. Modena,
CERN, Switzerland
michele.modena@cern.ch

Abstract

Though the Large Hadron Collider (LHC) at CERN is just at the start of a program expected to run for 20 additional years, CERN is studying the next generation of colliders, like the Compact Linear Collider (CLIC). This project proposes an electron-positron collider with a length close to 50 km and with a centre of mass energy of 3 TeV at the collision point. One of the main challenges is the sub-micrometric size of the beams, down to a few nanometres at the interaction point. As a consequence, the accelerator will require unprecedented nanometric tolerances of beam alignment. A series of several thousands components will have to be assembled, aligned at the micrometre level and most critically, stabilized actively at the nanometre level. PACMAN, a study on Particle Accelerator Components Metrology and Alignment to the Nanometre scale, is a Marie Curie Program supported by the European Commission (FP7 Program), creating a network of 16 Academic and Industrial Partners. The project is hosted at CERN and it offers training and PhD studentship to 10 students selected worldwide. Specialties are covering: beam instrumentation, metrology, micrometric alignment, magnetic measurements, nano-positioning and high precision engineering. The technical goal of PACMAN is to push the limits of the alignment of accelerator components by combining multi-disciplinary measurements and techniques, in the same bench.

1. Objectives of the research

CLIC will allow physicists to explore a new energy region in the multi TeV range beyond the capabilities of today's lepton colliders. It will provide significant fundamental physics information complementary to the LHC. The passive and active alignment of components shall reach unprecedentedly small values at the micrometre and even nanometre level. In practise, the alignment of the three fundamental components must be included within a cylinder with a radius of a few micrometres along a sliding window of several hundreds of meters. These components are quadrupole magnets acting as lenses that keep the beam focalized, accelerating

structures that boost the beam energy and beam position monitors which provide a non-invasive monitoring of the beam position. Some of these magnets are heavy objects weighing more than a hundred kilograms and measuring up to 1800 mm. Still, their reference axis must be aligned within a few micrometres.

1.1 Component alignment strategies

The current alignment strategy consists of three steps: first to measure, for each component, the position of its reference axis w.r.t external targets named fiducials (fiducialisation process), then to align the components on a common support, and finally to align this support in the accelerator tunnel using alignment sensors. First tests have shown that the precision and accuracy of 10 micrometres, required for linear colliders and other future accelerators, cannot be reached with his strategy. The scientific objective of the PACMAN is thus to propose and develop an alternative solution integrating all the alignment steps and a large number of technologies at the same time and location, in order to meet the required tolerances. As an example, a unique stretched wire will be used to determine the reference axes of quadrupole magnets (magnetic axis) and beam position monitors (electromagnetic centre) with respect to the mechanical interfaces of alignment sensors using a 3D Coordinate Measuring Machine (CMM).

1.2 The modular structure

Accelerators are composed of modular elements built as mechanical supports on which the components are assembled. These modules sometimes constitute the backbone of several kilometres of accelerator and are industrially produced in large numbers (order of thousands of units). The requirement of tighter tolerances of alignment will thus be fulfilled at the manufacturing stage.

A number of issues need to be solved to reach this goal. They define the research goals and sub-objectives of the PACMAN network, some of them being listed as follows:

- Optimize the manufacturing and assembly of the quadrupole iron quadrants and their monitors, by applying high precision engineering and very accurate machining.
- Integrate the nano-positioning system to the assembled quadrupoles.

- Refine methods of magnetic measurements of magnets with very small aperture, within an absolute accuracy of a few micrometres by using vibrating wire techniques and printed circuit boards rotating search coils.
- Develop and refine methods of measurements for finding the electromagnetic centre of microwave cavities.
- Develop portable methods of absolute alignment based on new techniques like Micro Triangulation and Frequency Scanning Interferometry (FSI) as an alternative to 3D CMM measurements.
- Upgrade the existing seismic sensors to work in the presence of magnetic fields.
- Build a prototype alignment bench integrating all the mentioned metrology, electromagnetic measurements and nano-positioning systems, keeping in mind the automatization of the process needed for series productions.

2. The Partner consortium structure:

	<i>Partner name</i>	<i>Country</i>	<i>Role</i>	<i>Main field of activity / department</i>
1	CERN	CH	Leader	Fundamental research
2	Cranfield University	UK	Academic	Precision & microsystems engineering
3	Desarrollos Mecanicos de Precision (DMP)	ES	Industrial	High precision manufacturing
4	Eltos	IT	Industrial	Printed Circuit Boards
5	Etalon AG	DE	Industrial	Opto-electronic measurement equipment
6	Swiss Federal Institute of Technology Zürich (ETHZ)	CH	Academic	Geodesy and Geodynamics lab
7	Hexagon Metrology GmnH	DE	Industrial	Industrial metrology applications
8	Instituto de fisica Corpuscular (IFIC)	ES	Academic	Experimental physics
9	Laboratoire d'Annecy-le-vieux de Physique des Particules (LAPP)	FR	Academic	Mechanics
10	Metrolab	CH	Industrial	Advanced magnetic field measurements
11	National Instruments (NI)	HU	Industrial	Control, measurement and automation applications
12	Universita degli studi del Sannio	IT	Academic	Engineering department
13	SigmaPhi	FR	Industrial	Resistive, superconductive and permanent magnets
14	Lab. for Materials and Mechatronics (SYMME)	FR	Academic	Mechatronics
15	Nederlandse Organisatie voor toegepastnatuurwetens - chappelijkonderzoek (TNO)	NL	Industrial	High tech systems and materials
16	Delft University of Technology	NL	Academic	Precision and micro-system engineering

3. Originality innovative aspects

Transverse alignment on a nanometre scale, for objects in the metre range does not exist yet. Standard alignment is done with sequential steps adding up errors. Attempts to reduce systematic and random errors are ongoing, and the eventual solution must be compatible with an electromagnetic environment. The PACMAN project is the first attempt to combine simultaneously measurement and active alignment of mechanical and electromagnetic structures. Nano-positioning is available today for applications from integrated circuits to high precision microscopy, interferometry, and disk drive testing. The level of accuracy required for future accelerators can be achieved with commercially available nano-positioning systems but the required combination of high loads, magnetic field and vibration stabilization is presently out of reach. In metrology, no methods are available yet for portable absolute measurements in the micrometre range. This is another objective of the project, not only to be used in the particle accelerator, but also in other domains such as aerospace, automotive industry, etc. Despite using the latest technologies available, existing sensors are not yet adapted to the harsh accelerator environment. Magnetic fields, ionizing radiation and high electrical and mechanical noise are conditions for which manufacturers do not always have a solution.

4. Conclusion

PACMAN will be an opportunity to develop contacts and knowledge between the private sector and research institutes. PACMAN partners have been selected on the basis of their experience and expertise, and for their potential synergies which will be exploited during and after completion of the project.

The PACMAN project was approved in March 2013 and started on the 1st of September the same year, for a duration of 4 years. 10 PhD students will arrive at CERN between February and May 2014, to work on this important project.

References:

- [1] <http://pacman.web.cern.ch/pacman/>