1st PACMAN Workshop

Monday, 2 February 2015 - Wednesday, 4 February 2015

CERN

Book of Abstracts

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Welcome

Corresponding Author: steinar.stapnes@cern.ch

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Introduction to PACMAN from the chairman of PACMAN Supervisory Board

Corresponding Author: paul.shore@cranfield.ac.uk

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PACMAN: technical details

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Summary:

PACMAN is a study on Particle Accelerator Components Metrology and Alignment to the Nanometre scale. This is an Innovative Training Network program, with 10 students working towards a PhD thesis, in multi-disciplinary fields as metrology, survey and alignment, magnetic measurements, high accuracy mechanical engineering, nano-positioning, beam instrumentation, RF measurements. An exceptional academic and industrial network has been put in place around the students. This talk will present the scientific and technical goal of the program and will detail the 4 work-packages and 10 subjects of research and development associated.

Introduction / **4**

State of the art of very high precision measurements in metrology

Corresponding Author: p.morantz@cranfield.ac.uk

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Broad band seismic instrumentation

Summary:

To comprehensively monitor seismic ground motion seismic sensors with a very wide frequency response, high dynamic range and low intrinsic noise are required. To achieve meaningful measurement of the complete seismic band multiple sensors are needed. These are collocated and typically recorded simultaneously. The design principles of very low frequency and low noise broad band velocity seismic sensors and low noise accelerometers will be discussed. Results will be provided characterizing in detail the performance of such instruments.

Introduction / **6**

Support and actuation of the segmented primary mirror of the E-ELT

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Summary:

The next "big thing"in ground-based astronomy is the design and construction of the European Extremely Large Telescope (E-ELT), a 39.3 m segmented primary mirror telescope for the optical and near-infrared range. TNO aims to contribute to this prestigious project via the design and realization of support structures for the primary mirror segments and actuators for piston-tip-tilt control of the segments, which must perform with nanometers of accuracy. This talk will give an overview of these technological developments, discuss the realized hardware and present some recently obtained results.

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Group picture

WP 4 / **8**

Stretched wire techniques for a 15 GHz RF-BPM

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Summary:

A precise, reproducible pre-alignment of beam position monitors (BPM) and quadrupole magnets is a critical prerequisite to achieve a low emittance beam transport along the main linacs of the Compact Linear Collider CLIC, currently under study at CERN.
Within the PACMAN Marie Curie training network we present first ideas of a dedicated stretched wire test bench, to analyse the electrical center of the high resolution CLIC/CTF3 cavity BPM, operating at a dipole mode frequency of 15 GHz. Fundamentals of the resonant cavity BPM, concepts and general design are discussed.

WP 4 / 9

Experience on design, prototyping and testing of the cavity BPM for the European-XFEL

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Summary:

New linear accelerators need high precision beam offset measurements at dedicated position along the beamline. Resolutions below 1 µm are achievable by using Cavity Beam Position Monitor (CBPM) pick-ups for most of the used charge ranges. Since the beam distance at the European-XFEL will be at least 222 ns low-Q CBPMs are chosen to enable single bunch detection. The CBPMs for the European-XFEL are produced in the industry and tested at the FLASH facility with electronic prototypes. The principle of the design of the CBPM will be described followed by tests in laboratory and beam based.

WP 4 / 10

RF and digital signal processing of HOM and cavity BPM signals

Summary:

A system for processing high frequency (multi-GHz) signals from HOM couplers and cavity bpms will be discussed. The system uses custom analog down mix electronics to shift the signal of interest to an intermediate frequency which is subsequently digitized and then further processed. The details of the custom electronics and different digital signal processing schemes will be discussed.

WP 4 / 11

EM field alignment of the CLIC accelerating structure with help of WFM signals

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Summary:

The CLIC TD24 accelerating structure is a traveling wave structure working on the accelerating monopole TE010 mode at 12 GHz. It consists of two coupling cells and 24 disks which its transverse section decreases gradually in order to achieve the 100MV/m constant gradient required for CLIC.

The RF is coupled in each disk though an iris of 5.5 mm diameter of mean aperture. With such small apertures, the alignment of the electrical center of the accelerating structure with respect to the beam is extremely important since the effect of the wakefields could be very harmful for the beam creating, for instance, beam instability and shape deformation of the bunch.

It has been determined that the electrical center of the accelerating structure should be aligned with respect to the center of the wakefield monitors with an accuracy of 3,5 um.

A test bench has been designed in which a dipole mode at 18 GHz is going to be excited in the structure and measured using the wakefield monitors that are ment for alignment proposes.

The results of the simulation work are going to be presented as well as the laboratory strategy in mind in order to achieve the goals.

WP 4 / 12

Stretched wire measurements and impedance matching

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WP 4 / 13

Wake field monitors conception, installation and measurements in the CTF3 TBM and TBTS

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WP1 / 14

Some physical aspects of tactile measurements

Corresponding Author: juergen.schneider@hexagonmetrology.com

Summary:

Concerning CMMs tactile probing is the most popular type of measurement during the process of quality-control. The different types of tactile sensors (switching and measuring) will be described with some of their advantages and disadvantages. The dependency of the measurements on certain physical properties like spring-constant, mass, probing-speed and damping-effects will be described as well as the time needed for measurement. The effect of the force on the surface will be shown and the impact of dirty environments will be described. There is a lot of principles which can be applied for the calibration of the probes. Some of these principles will be discussed as well. These principles reach their limits if one considers materials with a deformable surface. As one example a thin plate is measured and the different principles of measurements will be shown.

Some principles for checking and guaranteeing the quality of the probeheads will be described in a short outlook.

WP1 / 15

Non contact high precision sensor for Leitz Infinity Coordinate Measuring Machine

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Summary:

The LSP-S4 probe head of the Leitz Infinity Coordinate Measuring Machine (CMM) is a complex assembly which changes its shape when a force is applied on the extremity of the probe tip during a contact measurement. This change in shape provides part of the information about the position of a measured point. A magnetic field may induce a force on some parts of the probe head. The behaviour of the mechanical parts of the probe head is very well-known when used in usual conditions, nevertheless it had never been assessed within a strong magnetic field.

Historically, the CMM were based on contact measurements, so the first trials were to measure the wire' s position with a contact probe tip: the results were not stable and the diameter of the measured circle was found negative as the wire was pushed during the probing. This wire will define one of the axis of the coordinate system of a quadrupole magnet therefore it must not move during the measurements, which is why a non-contact probe tip is required. Several possibilities exist and are being tested for this application, namely LASER sensors such as the KEYENCE, capacitive sensors such as the Wire Positioning Sensors, and optical sensors such as the Precitec Lateral Resolution sensor, the white light Precitec sensor and the SHARP optical switch.

WP1 / **16**

FSI developments at NPL

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Summary:

Frequency Scanning Interferometry (FSI) is a well-known one-dimensional absolute distance measurement technique. Recent research at the National Physical Laboratory (NPL) in the UK has focused on adapting FSI and combining it with multilateration to produce a traceable, self-calibrating 3D coordinate measurement system. This presentation will start by giving a brief overview of conventional FSI and show how we have been adapting it to operate with multiple targets simultaneously in 3D and how we have applied novel solutions to overcome the well -known vibration sensitivity of FSI and to increase the range of operation of a 3D FSI system.

WP1 / **17**

Development and validation of an absolute Frequency Scanning Interferometry network

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Summary:

One of the tasks of PACMAN is to transfer the position of the functional axes of CLIC components to external reference marks also known as fiducials in order to facilitate their alignment in the tunnel. Project 1.2 seeks to develop an alternative solution of coordinate measurement using Frequency Scanning Interferometry (FSI), an absolute distance measurement technique. Etalon's Absolute Multiline Technology; an implementation of FSI, will provide distance measurements with sub-micron precision that are traceable to the SI meter. These distances will be combined with the technique of multilateration, a coordinate determination technique based on distances only to provide a highly accurate coordinate measurement system. As part of this project, we shall modify the fiber end housing to enable absolute distances between two points to be measured. In order to build a self-calibrating multilateration network we shall develop a new mount to enable several distances to be made from a single point. Additionally, in order to produce precise coordinates with multilateration it is essential to have good geometry which is limited by narrow viewing angle retroreflectors. To this end we are conducting tests with targets that can

provide a viewing angle of up to 360°. Simulations will be conducted using LGC++, to determine the most precise network configuration and the optimum number of channels within existing constraints.

WP1 / 18

Development of targets for laser interferometry

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Summary:

The retroreflecting targets of light beam are used in interferometers, laser trackers, and alignment systems. The most common mirror retroreflectors have one principal disadvantage of application - the possibility to work at only one angle of incidence. Different types of reflectors are utilized for wide angle range measurements;: open-air comer cubes with an acceptance angle of 20°, corner cube prisms with an acceptance angle of 50°, and a Cat's eyes with an acceptance angle of 60°. Best measurement results can be achieved by using an open-air corner cube that eliminates the need for the laser beam to travel through a different medium before it returns to the instrument detector. However, these retroreflectors still use a small acceptance angle, and can't be applied for measurement from all directions. The glass balls with high refractive index, very close to 2, can eliminate this problem. They can be placed anywhere with high precision, and can be illuminated and observed from all directions. But beside these advantages they have some drawbacks too, so the interpretation of results of position and movement measurement is not trivial, especially for the coherent light. Theoretical analysis, optical simulation and experimental results, both for coherent and incoherent light, are presented to help explain this observed optical phenomenon.

WP1 / 19

Multilateration for machine calibration and deformation analysis

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Summary:

The talk will summarize the work done at Etalon for the precision calibration of machines and the deformation analysis of technical structures. It will introduce the concept of sequential multilateration and will show a number of industrial applications.

WP1 / 20

micro-triangulation for Automated Contactless High-Precision metrology

Summary:

QDaedalus is a measurement system developed at the Institute of Geodesy and Photogrammetry at ETH Zurich. It is composed of both, hardware and software developments. The basic idea is to replace the eye-piece of an existing total station by a CCD camera in a non-destructive way in order to measure fully automatically very accurate spatial directions to visible objects without using corner-cube targets as in standard Automatic Target Recognition (ATR). In addition to the CCD camera and the total station, the hardware is composed of a motorized focuser and a small electronic interface for hardware synchronization of several systems.

The dedicated software of QDaedalus is based on a user-friendly graphical interface and controls all sensors including the total station. Furthermore it allows calibrating the system properly before starting the measurement of the targets. These measurements are based on different optical target object recognition and extraction algorithms (OTR), i.e. template least-squares matching, center of mass operator, robust circle and ellipse matching. Thus a fully automatic acquisition of numerous kinds of objects can be carried out. The performance of the system QDaedalus in terms of capability, precision, and automation level will be outlined in two practical examples. The first in concerns automatic 3D deformation measurements of reinforced concrete beams for stress analysis at ETH Zürich.

The second, in relations with the development of an alternative fiducialisation strategy at the European Organization for Nuclear Research in Geneva (CERN). The experiment focuses on the determination of high-precision 3D-coordinates of accelerating components (1x4x1 meters) of a future linear particle collider. In this application, several QDaedalus systems were set up simultaneously for measuring fully automatically the spatial directions of small ceramic spheres in order to realize a micro-triangulation network.

The results obtained reveal a 3D-accuracy at a level better than 10 microns. Comparisons with a commercial laser tracker and a coordinate measurement machine (CMM) are presented in order to demonstrate the performance of the system.

WP1 / **21**

Micro-triangulation for high accuracy short range measurements of dynamic objects

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Summary:

The aim of this talk is to describe the contribution of the Micro-triangulation method and the QDaedalus system in the PACMAN project. More specifically, we explain how the triangulation works in order to calculate 3D coordinates using horizontal and vertical angle measurements. Then, we define the precision of the measurements and the quality of the results, given the instruments and the working space. In addition, we present the advantages of the system as well as the main future improvements. The presentation finishes with an attempt to outline the strategy of the detection and the measurement of the stretched wire.

WP3 / **22**

Ultra precise quadrupoles magnet assembly and testing. Integration of an alignment test-bed towards an industrial production

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Summary:

For the realisation of the CLIC Project the present state-of-the-art on precision assembly and alignment techniques (for a big size series (˜ 4000 units) of "modules"each one including several complex components) must be developed to new limits. PACMAN Marie Curie Project intend to study these aspects integrating several components assembly/alignment steps at a single location and time. This talk will present the first studies on the precision engineering for the components assembling and some evaluation of the final expected alignment precision. The precision assembly of the quadrupole magnets MBQ will be addressed in detail. The magnet iron quadrants assembly with shape tolerances of the order +/- 10 micrometer have to be performed and correlated with the required magnetic field precision (0.1% dG/G as maximum magnetic field error). Discussion on the critical aspects and issues for this quadrant assembly will be done. Another topic addressed will be the analysis of the global allowed error budget for all the main components of the "modules". The influence of all mechanical static, quasi-static, dynamic errors to the global precision envelope will be discussed. Applicable precision engineering methodology and correlated techniques will be outlined looking at which strategy/methodology could be applied in future for the PACMAN components integration.

WP3 / **23**

Challenges, experience and expectations for precise machining

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WP3 / **24**

Actuation and alignment challenges of LHC collimators

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Summary:

The LHC collimation system has the functions of beam cleaning and protection of the superconducting magnets from quenching due to particle losses.
Each collimator jaw has to be moved with a very high accuracy to place the active surface at the required position with respect to the proton beam; at the same time, the system must be adjustable and flexible to adapt to the uncertainties and variations in the beam tuning. This presentation illustrates the technical challenges of the actuation system and the solutions found to meet the specifications.

WP3 / **25**

Seismic sensor development and vibration characterization

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Summary:

Knowledge of the ground motion and its propagation through the PACMAN bench is very important when the position of the beam is measured with nanometre resolution. Therefore, we need a very sensitive seismometer which would be able to measure this motion in whole bandwidth of interest and which

will also meet all the other PACMAN requirement like magnetic fields resistance, very low self-noise, compact size and light weight. Of course, very sensitive sensors are already available on the market but none of them meets all the requirements. I will present an overview of these state of the art seismic sensors, compare their advantages and disadvantages from PACMAN point of view and discuss possible modification or improvements.

WP3 / **26**

Seismology: sensors, measurements, modelling and analysis

WP3 / **27**

Nano-positioning of the main linac quadrupole as means of laboratory pre-alignment

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Summary:

The trend in future linear particle colliders is to generate high luminosity collisions at the interaction point inside the detector by producing particle beams with smaller and smaller size. In CLIC the particle beams are foreseen to have nanometric dimensions at the interaction point. As a consequence, pre-alignment and stability requirements for all the electromagnets distributed along the machine become more stringent. A high stiffness coarse-fine resolution stage approach combining cam movers and piezo stack actuators has been studied. The coarse stage is used to apply pre-alignment of the magnets and the fine stage for vibration isolation and nano-positioning. A limitation in this setup lies in the speed of the coarse stage, which renders it inoperable during beam time. Another limitation is the small range of the piezo stack actuators. This research will look into the possibility to, in a first time extend the range of the fine resolution stage. At a second time the possibility will be studied to combine all the above mentioned functions into one actuator by combining the required sub-nanometric resolution for active vibration isolation and the nanometric repeatability for nano-positioning along the required stroke for the pre-alignment of the quadrupoles.

WP3 / **28**

Design and validation of a nanopositioning system for the MB quadrupole

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Summary:

The future Compact LInear particle Collider (CLIC), under study at CERN, requires the stabilization to 1.5 nm integrated root mean square in vertical and 5 nm in lateral direction of heavy electromagnets. Further it requires nanometre precise positioning of these magnets. This talk will present the concept developed in order to address both goals and the first test results obtained.

WP3 / **29**

Discussion

WP2 / **30**

The activities and the equipment available in the magnetic measurement working group at the PTB

Summary:

The essential task of the working group is the realization and maintenance of the unit Tesla of the magnetic flux density B as the base unit of magnetic quantities. The dissemination of the unit Tesla is realized by: Magnetic measurements basing on nuclear magnetic resonance (NMR), calibration of field coils as standards of DC fields and AC fields, and calibration of magnetometers in DC fields and AC fields. Special tests are done on request, such as: the measurement of field profiles on the coil axis and the characterization of the field in front of the pole tips of permanent reference magnets. One more task of the working group is the characterization of magnetic materials and the development of the equipment needed for these measurements.

WP2 / **31**

Theory and applications of the vibrating stretched wire technique for high-precision quadrupole alignment

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Summary:

The Vibrating Wire (VW) magnetic field measurement technique is based on the phenomenon of excitation of the stretched wire vibrational modes by Lorenz forces between AC electrical current flowing through the wire and surrounding magnetic field. The technique allows to measure magnetic field along the wire using information on the wire vibration amplitude and on the phase between wire vibration and driving AC current.

Because the VW technique employs a thin stretched wire as a magnetic field sensor, it is ideal to use in case of magnets with small apertures. The technique has extraordinary sensitivity and is most suitable for accurate magnetic axis finding. In many occasions, the method has been used for high-precision alignment of quadrupole, sextupole and solenoid magnets.

In the talk I will present the theory and describe applications of the technique.

WP2 / **32**

Stretched wire systems for the magnetic measurement of small-aperture magnets

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Summary:

The PACMAN project involves the measurement of the magnetic centers of the main beam quadrupoles to be installed in CLIC (the future Compact Linear Collider) to the micro-meter scale. The magnetic center of a quadrupole magnet is defined as the locus of points where the magnetic flux density is zero. By using a single stretched wire, positioned inside the aperture of the quadrupole, the center can be determined in two different ways. One is to displace the wire in two opposite directions across the center and measuring the voltage induced in the wire loop by the variation in the magnetic flux. The asymmetry of the two measured voltages is then related to the offset between the initial position of the wire and the magnetic center position. This method, referred to as the classical stretched wire method, works well for large aperture, high-gradient magnets.

The second way is to use a vibrating wire, excited by a sinusoidal current at the mechanical resonance frequency, which vibrates due to the Lorentz force. The magnetic center is found by measuring the wire oscillation amplitudes and determining the position where this vibration takes its minimum. Because of its high sensitivity, this method is suitable also for small aperture, low gradient magnets.

This talk will focus on the comparison between the classical stretched wire method and the vibrating wire method for measuring the magnetic center of a reference quadrupole. The two methods will be compared in terms of sensitivity, measurement uncertainty, and repeatability. Some critical aspects of the vibrating wire system will be further discussed.

WP2 / 33

A review of the state of the art, present norms and future trends in the field of measurement uncertainty estimation

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Summary:

In this talk I will give an updated vision of the views internationally agreed on the evaluation and expression of uncertainty in measurement. Emphasis will be on the Guide to the expression of uncertainty in measurement, currently under revision, and on its Supplements. I will also present the activity in this field of the Joint Committee for Guides in Metrology, WG1. Finally, I will talk about the changes introduced in the next edition of the document, showing thus the evolution from a purely frequentist view to a Bayesian perspective.

WP2 / 34

PCB Coil and stretched wire systems for high-precision quadrupole alignment

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Summary:

In the measurement of magnetic fields of accelerator magnets, induction-type probes are among the predominant devices relied on for stable and accurate determination of field quality and alignment parameters. There are many advantages in using these systems, though fundamentally they are limited by the precision of conductor localization and the sizes of the signals generated. Here we give an overview of the Single Stretched Wire and Printed Circuit Board techniques: how these address the limitations of induction probes and are useful in obtaining high-precision results in demanding applications. We

focus particularly on alignment of quadrupole magnets.

WP2 / **35**

PCB technology for small diameter field probes

Summary:

Rotating coil systems are the most important tools to test the magnet field quality, strength and harmonics. This is a key task for the quadrupoles of the future linear collider that aims at aligning the accelerator components at the nanometre scale. The future accelerator will work with high-energy beam and the magnets will have an extremely small aperture, CLIC quadrupoles achieving only 8 mm diameters. With so small dimension, the use of new technologies as PCB design becomes necessary to build small sensing coil with high precision. As all sensors, sensing coils need to be opportunely calibrated to achieve high precision measurements. The different kind of sensing coils will be illustrated in this paper, with relative advantages and disadvantages, together with the calibration steps adopted in particular for small dimension coil. Challenges related to the centering of very small rotating coils will be introduced. Future work includes the optimization of a measurement setup dedicated to extremely small diameter coils, exploring new coils'design and studying axis fiducialization within rotating coils.

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Conclusion of the workshop

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Brainstorming/discussion meeting