2nd PACMAN workshop

Sunday 12 June 2016 - Wednesday 15 June 2016

Debrecen

Book of Abstracts

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Introduction by Chairman

Corresponding Author: joe.woodford@cern.ch

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Emittance preservation in CLIC

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As introductory talk to the workshop the whole logical chain from the required luminosity performance of CLIC over optimization of the total power consumption down to smallest possible beam emittances and their preservation in the main linac will be explained on a basic level.
The importance of alignment for emittance preservation will be high-lighted.

Summary:

General introduction to CLIC and PACMAN / 85

Effects of elements misalignment on Accelerator Performance

Author: Andrea Latina[1]

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Misalignments of accelerator components can affect the beam transport through several processes, and lead to emittance growth, beam losses, and beam break-up. In future particle accelerators like CLIC, where the beam size is of a nanometer scale, the effect of the smallest imperfection can be the most dangerous and harm the machine operability. In this talk the main mechanisms for emittance growth and beam instability will be discussed, and some of the most advanced mitigation techniques will be explained.

Summary:

General introduction to CLIC and PACMAN / **91**

The PACMAN project

Author: Helene Mainaud Durand[1]

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The PACMAN project is a study on Particle Components' Metrology and Alignment to the Nanometer scale. It is an Innovative Doctoral Program, funded by the EC and CERN where 10 students work towards a PhD thesis. It is a muti-disciplinary project with 16 industrial and academic partners.
The talk will introduce the technical objectives of the project as well as the first results obtained.

Summary:

Metrology and alignment challenges / **76**

The European Extremely Large Telescope

Author: Bertrand Koehler[1]

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The European Extremely Large Telescope (E-ELT) is a 39m diameter optical/infrared telescope to be located on Cerro Armazones about 25 km away from the current ESO VLT Observatory at Cerro Paranal, Chile. After initial conceptual studies and a formal approval of the Programme by ESO Council back in 2012, the actual start of construction was actually authorised in 2014 when the required funding level became available. Since then, the programme has entered a very busy phase leading to the signature of the first major industrial contracts as well as agreements with scientific institutes in ESO Member States to design and built the first suite of science instruments.
One of the new technological challenge of the E-ELT is its primary segmented mirrors made of 798 hexagonal segments that need to be phased with each other to nanometres precision. Another challenge is the 2.5m-diameter adaptive optics mirror (M4) which will correct the wave front errors due to atmospheric turbulence with 5316 voice-coil actuators bending the 1.95mm thin mirror also to nanometre precision.
This presentation will summarise the current status of the E-ELT Programme and present some aspects related to scientific objectives, managerial and programmatic organisation, engineering approach and procurement strategies put in place to achieve the goal of the Programme: building the "world's biggest eye on the sky"within the next decade.

Summary:

Metrology and alignment challenges / **78**

The LUMINAR project

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In 2012 a consortium of parties interested in Large Volume Metrology was formed to submit a Potential Research Topic into the European Metrology Research Programme. The topic was subsequently selected for the second stage of the call process and a project consortium consisting of 5 National Metrology Institutes, 3 Universities and 3 unfunded industrial partners was formed to bid into the call. The bid, presented at a competitive selection process in November 2012 was successful and the three year research project started on 1 June 2013.

The research consortium was charged with addressing the prioritised objectives:

1. To develop innovative measuring systems which bridge the gap between photogrammetry and laser trackers, working over volumes of 10 m × 10 m × 5 m, to a target accuracy of 50 μm.
2. To develop novel absolute distance meters which are intrinsically traceable to the SI and which operate over tens of metres range.
3. To develop a method to provide on-line compensation for refractive index effects in ambient air in industrial environments, targeting 10E-7 accuracy over a volume of approximately 10 m × 10 m × 5 m.
4. To model, understand and predict the behaviour of multi-component assemblies (up to 5 m dimension) in non-ideal environments (5 ℃ temperature deviation).

Furthermore, these techniques had to be demonstrated at the end of the project in typical end user environments. As reported at the end of project workshop (NPL UK, 18-19 May 2016) all of the partners have achieved success in their research and several on-site measurement campaigns have been concluded.

The presentation will summarise the LUMINAR project, its aims, participants, research, and outputs (knowledge, instruments, techniques, IP)

Summary:

The LUMINAR project (Large Volume Unified Metrology for Industry, Novel Applications and Research) is a collaborative research project in Large Volume Metrology involving 5 National Metrology Institutes, 3 universities and 3 unfunded industrial partners.

Metrology and alignment challenges / **106**

Precision Motion Control and Metrology in Lithographic Scanners

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Lithographic steppers and scanners are highly complex machines used to manufacture integrated circuits (ICs). These devices use an optical system to form an image of a pattern on a quartz plate, called the reticle, onto a photosensitive layer on a substrate, called the wafer. The circular wafer can contain many ICs, typically 100 or more, and needs to be repositioned from exposure to exposure. Moreover, different patterns need to be put exactly on top of one another, even when the wafer has left and re-entered the machine to accommodate for intermediate process steps. To be able to pack more functionality into each IC and to increase the productivity of the machine, the required accuracy and speed for the repositioning is increasing as well.

In this presentation, the lithographic process will be explained and the motion control and metrology architecture of ASML's scanners will be detailed. It will furthermore be shown which evolutions were necessary to keep up with the ever increasing demands for shrink and increasing throughput.

Summary:

Characterization of individual components / **74**

Wake field monitors - design, implementation and first experiences

Author: Micha Dehler[1]

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State of the art free electron laser and linear collider
projects require a tight control of emittance dilution
caused by transverse wake field of misaligned components. An attractive option in RF structures are wake field
monitors (WFMs), measuring directly internal transverse
higher order modes.

In collaboration between CERN, PSI and
Sincrotrone Trieste, X band structures with integrated WFMs
have been designed and manufactured, which will serve as longitudinal
phase space linearizers for free electron lasers as the SwissFEL.

I will present the basic ideas in designing such a monitor and how to integrate
this device into a accelerating structure without perturbing the basic
properties of the accelerating mode. Furthermore, I will describe the practical
implementation into the mechanical design. An interesting feature of the system
is the front end, where we are currently developing an electro-optic version
for transport and down conversion of the large bandwidth signals in the
15 GHz domain. As I will show,
first tests with a basic prototype system used in
the SwissFEL injector test facility SITF proved
the basic concept as well as advanced features as the direct measurement of
structure tilt via spectral analysis of the WFM signals.

Summary:

Characterization of individual components / **77**

Accelerating Structure Alignment with laboratory radiofrequency methods

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To reach a high accelerating gradient of 100 MV/m, the CLIC project under study at CERN uses a 23 cm long tapered normal-conducting travelling wave Accelerating Structure (AS) operating at 12 GHz. To preserve beam emittance at the 1 nm vertical-size collision point, 7 μm accuracy is required in the pre-alignment of the AS wrt the supporting girder. We have developed a dedicated test bench where a wire is used to materialize the electromagnetic axis in the AS and serves as a reference to fiducialise the structure in the accurate environment of a 3D Coordinate Measuring Machine (CMM). Our simulations have shown that a resolution of 1 μm is possible using a calibrated VNA. The recent experimental results and improvements will be presented and discussed.

Summary:

Characterization of individual components / **109**

Advanced RF applications on the NI Platform

Author: Adam Cseh[1]

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In the Advanced RF application on the NI platform presentation the following topics are covered:
• NI's RF offering: overview of NI's RF instruments, platforms and software tools
• PXIe-5668R: the widest band Vector Signal Analyser with Real-Time Spectrum Analysis capability. Supporting phase coherent applications and full bandwidth streaming.
• PXIe-5646R: The Vector Signal Transceiver with programmable FPGA. Radar and Target generation using the VST
• PXIe-5632: High performance Network Analyser for PXI.

Summary:

Nowadays the increasing complexity of the applications in the field of RF measurements requires the instruments to offer ever increasing performance at an affordable price point. The wide field of application areas further require built-in flexibility and foreseen means of reconfiguration depending on the task the instruments should perform.
National Instruments offers a wide range of software defined instruments to empower scientists and engineers to solve the main technical challenges.

Characterization of individual components / **93**

Characterization and study of the PACMAN RF-BPM

Author: Silvia Zorzetti[1]

Co-authors: Luca Fanucci [2]; Manfred Wendt [1]

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The Beam Position Monitor (BPM) studied in the frame of the PACMAN project and used for CLIC is a passive resonant cavity operating at about 15GHz, optimized for holding both good spatial (<50nm)

and temporal resolutions (<50ns). This BPM has been fully characterized with stretched-wire techniques on a standalone test bench. The nanometric spatial resolution has also been observed through an innovative methodology using a piezo stage as an actuator and the same conductive wire as a sensor to scan the cavity.

Summary:

Characterization of individual components / **108**

Calibration and performance of nanometer resolution RF-BPM

Author: Stewart Takashi Boogert[1]

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Radio frequency resonant cavity beam position monitors (CBPMs) offer stable nano-meter scale (10s to 100s nm) resolution measurement of transverse beam positions in particle accelerators. The performance of these devices depends critically on system considerations, such as calibration and operation. This talk outlines the main issues with stably operating CBPMS, RF processing, calibration and beam position jitter subtraction. Examples are taken from the Accelerator Test Facility 2 (ATF2) an ILC/CLIC test accelerator which has to date produced the worlds smallest electron beam of approximately 47 nm.

Summary:

Characterization of individual components / **84**

High precision miniaturized rotating PCB coil for small magnet aperture

Author: Giordana Severino[1]

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The rotating coil is one of the preeminent methods used to characterize the magnets'harmonics content and magnetic center. The rotating coil technique for magnetic measurements of accelerator magnets uses complex patterns of passive coil transducers with the aim to reach the most accurate and precise measurements.
Nowadays, the printed circuit boards (PCB) technology is the predominant manufacturing process used for rotating coil transducers production. The talk of PACMAN Ph.D. student aims to provide a full characterisation of PCB rotating coil transducers covering the core topics: design, manufacturing, calibration and performance analysis. The presentation will focus in particular on miniaturized PCB for magnets characterized by small aperture (below 10 mm).
Therefore, the two PCB miniaturized coil prototypes for CLIC magnet and the studies performed for new alternative coil designs will be introduced.

Summary:

Characterization of individual components / **104**

Vibrating-wire measurements for the alignment of small-aperture magnets

Author: Domenico Caiazza[1]

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To achieve the tight alignment requirements demanded for CLIC, its components need to be pre-aligned on a common support within the micrometer range. Among these components, the main beam quadrupoles will be pre-aligned with respect to their magnetic axis by using the vibrating-wire technique. The measurement method and the characteristics of the PACMAN stretched-wire system will be illustrated. Preliminary measurement results taken on a CLIC main beam quadrupole will be presented and the compatibility of the stretched-wire system with the environment of a coordinate measuring machine will be discussed.

Summary:

Characterization of individual components / **72**

Advances on magnetic measurements by stretched wires at the ESRF

Author: Gael Le Bec[1]

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The European Synchrotron Radiation Facility (ESRF) has started a major upgrade: the present storage ring will be dismantled in 2019 and will be replaced by a new one. More than 1000 magnets, with apertures ranging from 25 mm up to 37 mm, will be installed. Most of these magnets will be measured with Single Stretched Wire (SSW) benches developed in house.
The basis of SSW alignment and some aspects of advanced measurements will be presented. Then, the error budget for SSW alignment and fiducialization will be discussed. The accuracy of the alignment and measurements depends on the calibration of the wire actuators: a specific calibration bench has been developed for this purpose. Finally, measurement results obtained on individual magnets and on magnet girders will be shown.

Summary:

Characterization of individual components / **60**

Magnetic measurement techniques and systems at the Paul Scherrer Institut

Author: Stephane Sanfilippo[1]

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The talk will be mainly focused on the magnetic measurement techniques and systems used at the Paul Scherrer Institut (PSI) to characterize the field quality and qualify the magnetic elements (magnets and undulators) needed in the large scale facilities. In the frame work of the Swiss Free Electron laser (SwissFEL), the next facility in construction at PSI, the techniques for magnetic measurements have been enhanced and the instrumentation has grown significantly with the use of small diameter rotating coils, single axis multi-probes and three axis Hall sensors, and a moving-vibrating wire. The presentation will be composed of an overview of the measurement techniques followed by a description of the systems. Their potentialities are illustrated by some results obtained during the magnetic measurement campaigns of the SwissFEL magnetic elements.

Summary:

Frequency Scanning Interferometry / 96

Developments and Applications of the Absolute Multiline Technology

Author: Heinrich Schwenke[1]

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The presentation will report recent developments and applications of the Absolute Multiline Technology. Examples are the deformation measurements of telescopes or the monitoring of large CMM. It will also introduce a company/institute wide installation to deliver the “absolute meter” to different applications.

Summary:

Frequency Scanning Interferometry / 73

Status of FSI network development for the PACMAN project

Author: Solomon William Kamugasa[1]

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We present our strategy for fiducialising CLIC components within the final PACMAN alignment bench using Frequency Scanning Interferometry (FSI). We have developed a device to enable Absolute Multiline Technology perform absolute distance measurement to targets in different directions from the same point. This allows us to employ the multilateration technique to determine the coordinates of fiducials within the test bench. Using spherical high index glass targets with a wide acceptance angle we optimise the geometry of the measurement stations with respect to the fiducials for improved precision of coordinates. We demonstrate through simulations that the tight CLIC component fiducialisation requirements in the vertical and lateral axes can be attained using FSI multilateration

Summary:

Frequency Scanning Interferometry / **79**

Recent developments in the field of frequency scanning interferometry

Author: Michael Campbell[1]

Co-authors: Andrew Lewis [1]; Ben Hughes [1]

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Two questions for which people ask for help from NPL are: 'How good is my instrument?'and 'what are the uncertainties associated with my measurements?'At NPL we felt an instrument was needed which would inherently answer these questions with every measurement. Therefore we have built a coordinate measurement system that is self-calibrating with compensation for systematic errors, calculates in-process uncertainty estimates, has continuous traceability to the SI metre, and makes rapid coordinate measurements. These attributes are achieved using frequency scanning interferometry which is used to make absolute distance measurements and multilateration which is used to calculate target coordinates with uncertainty estimates.
In our measuring system, multiple sensors each measure the distances to multiple targets, simultaneously. Using a minimum of four sensors and six targets, the location of both the targets and the sensors can be determined without prior information about the system. Increasing either the number of sensors or targets leads to data redundancy, which can be used to infer uncertainty estimates for the coordinate measurements. By including systematic effects (associated with e.g. the measuring sensors) into the multilateration model they can be compensated for within the solution. With our current implementation, each sensor head can measure multiple targets simultaneously out to a radial range of 10 m and angular range of ± 35˚. Traceability and scale reference are obtained using a HCN gas cell as a frequency reference. Distance measurement uncertainties of 1 ppm are achieved and by correcting for systematic errors in the multilateration model it is possible to retain this uncertainty through to coordinate measurement uncertainties.

Summary:

At the previous PACMAN conference in 2015 we presented a novel optical coordinate measurement system operating over a (1 x 1 x 0.75) m3 volume. The system utilises frequency scanning interferometry (FSI) to determine the absolute distance between targets and sensors and multilateration to calculate target coordinates. This presentation will cover the developments we have made at NPL over the last year in order to extend the measurement volume up to (10 x 10 x 5) m3.

Frequency Scanning Interferometry / **81**

Results of the "Absolute Multiline"Measurements on the Very Large Telescope

Author: Samuel Lévêque[1]

Co-author: Stephane Guisard [2]

[1] *ESO*

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The "Absolute Multiline"has recently been tested on the Very Large Telescope (VLT) to monitor the Rigid Body Motion between its primary and secondary mirrors by forming an optical hexapod. This test is part of a more general evaluation of the adequacy, performance and robustness of such a measuring technique for monitoring the inter-mirror position of the future European Extremely Large

Telescope (E-ELT). In this case, the "Absolute Multiline"may represent an asset, not only during the integration phase, but also to insure a proper collimation of the telescope to enter in the capture range of the star guiding sensors and finally to help identifying collimation degeneracy that cannot be captured by wavefront sensors. This presentation will cover the rationale, the experimental set-up and the results of the test performed on the VLT as well as future perspectives.

Summary:

Handling the nanometer / 101

Active isolation of an extended structure with fused sensors

Author: Christophe Guy R Collette[1]

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Corresponding Author: ccollett@ulb.ac.be

This talk presents an active vibration isolation strategy combining centralized interferometric inertial control and decentralized force control loops. The strategy will be illustrated on simple models, and then applied to isolate an extended structure from ground vibration. Preliminary experimental results will be presented and discussed.

Summary:

Handling the nanometer / 94

Design and optimization techniques for a nano-positioning system

Author: David Tshilumba[1]

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The objective of this research project is the design of a long range nano-positioning system for the CLIC electromagnets (m $80kg$).

CLIC (Compact Linear Collider) is a next generation particle collider under study at CERN. The accelerator will operate beams of nanometric size ($1nm$ ×$40nm$) and produce a high density of collisions at the interaction cross section (2 x 10^{34} $hits/(m^2s)$). To guarantee this collision quality, the pre-alignment tolerance of the main components of the accelerator must lie within $10m$. In addition, the quadrupole magnets must be extremely stable ($1.5nm$ rms at $1Hz$). The beam further can be steered by displacing these quadrupole magnets in between beam pulses, with nanometric resolution. This critical process is the nano-positioning.

The positioning stage for the magnet must combine several features: a high stiffness ($400N/m$) and robustness against environmental disturbances (i.e. from the turbulent water cooling) and also fast positioning ($t_{settling} < 20ms$) with sub-nanometric resolution to perform beam trajectory correction and active vibration isolation. X- and Y- are the critical degrees of freedom for these processes. For the pre-alignment, all the degrees of freedom are critical except the translation along the magnet axis. For this process a long range of $\pm 3mm$ is required.

I will present the design techniques that will be used for the development of the long range nanopositioning system.

Summary:

Handling the nanometer / 87

Sub-nanometer displacement measurements in seismic sensors

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Specific requirements for vibrational characterisation and isolation of big scientific projects like CLIC have led to the development of the seismic sensors which utilise different types of sub-nanometric displacement transducers to measure relative displacement between an inertial mass and the sensor housing. Considering the nature of accelerator environment, magnetic based transducers are usually not considered and thus the recent development is focused mainly to the interferometers, the optical encoders and the capacitive sensors. They all have they pros and cons, but when it comes to a decision which one should be used, it is the resolution which plays one of the most crucial role. Determination of the resolution in sub-nm displacement measurement is however a complicated task, since it is influenced by many factors like mechanical design, ambient environment or data acquisition chain and processing algorithm. This is also a reason why the results of vibration measurements usually have no statement of uncertainty which is very important for reliable comparison of individual transducers.

To overcome these difficulties a sensor design was proposed which implement all of these technologies within the same mechanical body and it will use the same data acquisition and processing. This will remove any ambiguity between the measured data and allow to compare directly the resolution of the different transducers for a given design.

A multireflection Michelson interferometer will also be implemented to the same sensor in order to improve current state of the art sensor's resolution and will be used for the vibrational characterization of the final PACMAN bench.

Summary:

Handling the nanometer / 88

Development of a high-resolution optical inertial sensor for sub-Hz seismic isolation

Author: Jennifer Watchi[1]

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Precision engineering tasks require active isolation systems that are efficient especially at low frequencies. The limitations of such control systems include the resolution of the sensor used and the magnetic coupling between the sensor and the actuator. In order to bypass these limitations, inertial sensors using Michelson interferometer are being developed. A first prototype has been built and tested. It has been shown that it has a sub-nanometer resolution over a large frequency range,

extending from 0.1 Hz to 100 Hz. To further improve the resolution, a new optical design will be presented in this paper. The elements of the setup are chosen to lower the noise of the whole system. Actually, two main sources of noise can be reduced. The first one is due to the optical components, inducing a phase shift which is converted into a displacement error. The second is a consequence of the pendulum movement of the piece/spring holding the moving mass. It couples the vertical translation and the rotation. By choosing correctly the optical components, the first source can be diminished. The resolution reached is compared with that predicted by the optical model implemented on MATLAB. With the best optical resolution of the setup achieved, the interferometer had been integrated into a STS1 seismometer to reduce the pendulum movement. The optical sensor replaces the conventional capacitive sensor of the device without disturbing the mechanical parts. The resulting modified STS1 has a spectral resolution below 10^{-13} m/rtHz, while at the same time is insensitive to magnetic field.
The final objective of this research consists in introducing the inertial sensor into a single-axis isolation system equipped with a voice coil actuator. In feedback configuration, the setup will allow to reach an unprecedented high level of isolation, opening a new window in gravimetry and gravitational wave detection.

Summary:

Handling the nanometer / **99**

High resolution interferometry for sub-nm displacement measurements

Author: Marco Pisani[1]

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After an introduction on the principles of laser interferometry, the most popular interferometers (Michelson and Fabry-Perot) will be briefly described. Then, practical realization set-up (homodyne, heterodyne synthetic wavelength) and related application fields will be discussed. Finally, particular attention will be given to short distance interferometers and to the techniques used to achieve sub nanometers accuracy, with some applicative examples.

Summary:

Posters session / **92**

Women in Science, Technology, Engineering and Mathematics

Author: Martine Lumbreras[1]

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In the Strategy for equality between women and men 2010-2015 (European Commission 2010) the link with gender balance and competitiveness is again emphasised: «The prevailing gender imbalance in science and research is still a major obstacle to the European objective of increasing competitiveness and maximising innovation potential».
In spite of the young global disaffection with all the scientific domains, the evolution of the proportion of women in Mathematics, Sciences, as well as Technology and Engineering, confirm that women continue to be vastly underrepresented in all the cases. I will first present an overview of

European or governmental statistical studies on the place of women in these disciplines, in all the position levels. Then I will give an overview of actions and initiatives to encourage young women in favour of scientific studies, and/or to promote female researchers in each scientific field, proposed by EU, European governments and also industrial enterprises in Europe. After a short review of the main stereotypes and barriers faced by women, I'll conclude with a non-exhaustive list of Associations and/or Women Networks allowing cooperation between women scientists in Europe in order to improve the gender imbalance in science and research.

Summary:

Statistical results given by EU or several governmental sources show that a great effort ùust be done to encourage girls to scientifical sciences and jobs. Taking into account the main stereotypes which wheigh on the girl motivation, EU and European government propose actions to improve this situation. Association and/or women networks can be also a great help to reach this objective.

Posters session / **110**

Innovation Program of National Instruments Hungary

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Botond Barabás, manager of the National Instruments Hungary Innovation Program is going to present the background of the program and the possibilities it holds for young researchers across Europe. Through this program early stage researchers and hardware startups can validate their ideas by building a proof of concept based on NI's technology.

Summary:

Metrology and alignment using a wire / **80**

Error sources and mitigation in dimensional metrology

Author: Ben Hughes[1]

[1] *NPL*

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This short presentation will cover the concept of the metrology loop and introduce some examples of error sources that can affect dimensional measurement systems and how these errors can be mitigated.

Summary:

Metrology and alignment using a wire / **90**

Evaluation and positioning of the PACMAN reference wire to a sub-micron level

Author: Claude Sanz[1]

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The PACMAN project's aim is to develop and build a pre-alignment bench on which components are assembled and aligned to the required accuracy using a stretched wire. During the process of this measurement, the centre of a stretched wire is aligned with respect to the reference axis of the components. The Cu-Be wire with a diameter of 0.1 mm considered for this task has been evaluated. The first part of the talk will focus on the form error measurements performed on the wire, whereas the second part will discuss the design of a sensor to measure the wire axis position within the volume of the Leitz Infinity coordinate measuring machine.
The conclusion drawn from the form evaluation presented in the first part of the talk is that a form measuring sensor should be used to increase the precision of the positioning measurement. The Shape Evaluating Sensor: High Accuracy & Touchless SESHAT is being designed for this task: its challenge is to measure the form error of this stretched wire with 0.1 µm accuracy and its axis position with 0.5 µm precision on the coordinate measuring machine. The singularity of the SESHAT' s design is an opening in the radial direction. Indeed, during the talk the requirements will be introduced: no magnetic fields created, high accuracy on the positioning, low error motion, and open on the side; and the technical solutions will be described and discussed: from the material to use to the bearings type, including the kind of sensor, motor and encoder.

Summary:

The PACMAN project's aim is to develop and build a pre-alignment bench on which components are assembled and aligned to the required accuracy using a stretched wire. This talk will focus on the wire quality evaluation and the way planned to be used to localise the wire axis.

Metrology and alignment using a wire / **71**

Improvements of the precision and the reliability of underground geodetic networks by using stretched wires

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In underground geodetic networks, the orientation along the tunnel is generally limited in precision and reliability by, on one hand, the "corridor" configuration of the network and, on the other hand, by lateral refraction effects. As a stretched wire, if it is protected from air drafts, belongs to a section of a catenary function inside a vertical plan, it can be used as a precise and reliable orientation reference for total stations. Hence it will be shown how angular observations of a same stretched wire by different total stations can significantly improve the precision and the reliability of the orientations.

Summary:

Keywords: Geodesy, underground surveying, total station, stretched wires, catenary, least-squares adjustment

Metrology and alignment using a wire / **100**

Recent developments on micro-triangulation for fiducial points and wires

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In the frame of the Particle Accelerator Components'Metrology and Alignment to the Nanometre scale (PACMAN) project, we develop the micro-triangulation method for the magnet fiducialization. The wire detection algorithm and the wire reconstruction algorithm are the most important parts of this study. High accuracy robotic theodolites observe the stretched wire, used for the determination of the magnetic axis, and the fiducial points in one coordinate system. The theodolites are equipped with the QDaedalus measuring system, mainly consisting of a CCD camera and a focusing mechanism. The advantage of QDaedalus is the capability to perform accurate, automatic, remote controlled angle measurements. The dedicated software controls the hardware and applies online computer vision techniques to detect and measure the targets. We examine how variation of environmental factors, such as light condition, focus, camera calibration, etc., may affect the measurements, and what is the precision of the QDaedalus system in a considerably stable environment. Preliminary results of simulations reveal the level of precision we can achieve given the instrumentation and the configuration constraints of the final PACMAN bench.

Summary:

Integration and conclusions / 105

The path to a new CLIC main-linac module

Author: Markus Aicheler[1]

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In this presentation we will show the path which the CLIC module has come over the last years, where we are today and finally, where we plan to go and how we plan to go there. In particular, the state of the module design with respect to the CDR version from 2012 and the experimental work for the study will be presented. Additionally, we will highlight how PACMAN influences our future direction of development. Finally, some considerations for design choices will be show exemplarily.

Summary:

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The stochastic finite element method and its possible use in thermo-mechanical drift calculations

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The finite element method is a well established technique used to predict the performance of engineering materials, components and structures under a range of environmental and loading conditions (Smith et al, 2014). In recent work, the authors have investigated why cracks in nuclear graphite bricks do not appear in the same location as predicted by simulation. We have shown that one of the issues is that engineers typically use mean values for any mechanical property and the virtual material is therefore "too perfect". Real materials, even homogeneous isotropic materials (such as Gilsocarbon), will have some degree of spatial variability in their properties. We know this as the experimental methods used to determine properties invariably give a range of values for a set of test samples (Arregui-Mena et al, 2016). When our computer simulation includes tiny spatial fluctuations in the material properties (calibrated using random fields based on the mean and standard deviation values derived from the experimental data), stress concentrations (sometimes) arise in regions of the brick where cracks are observed to develop (Arregui-Mena et al, 2015). This methodology is also useful in the context of understanding and predicting thermo-mechanical drift. The deterministic finite element method (using mean values) will predict that an unconstrained isotropic material will expand or contract freely and elastically under a uniform temperature change (without the generation of internal stresses). When there are tiny spatial fluctuations in the thermo-mechanical properties, internal stresses arise and the surface of the component will become distorted. Cyclic thermal loading may result in increasing distortion as some of these stresses will lead to permanent inelastic deformation. The authors propose that the stochastic finite element method (Arregui-Mena et al, 2014) could be a valuable predictive tool in designing new materials that are less susceptible to thermo-mechanical drift.

Summary:

Smith IM, Griffiths DV and Margetts L, "Programming the Finite Element Method", 5th Edition, Wiley, 2014.

Arregui-Mena JD, Bodel W, Worth RN, Margetts L and Mummery PM, "Spatial variability in the mechanical properties of Gilsocarbon", Carbon, 2016 (accepted for publication).

Arregui-Mena JD, Margetts L and Mummery PM, "Practical Application of the Stochastic Finite Element Method", Archives of Computational Methods in Engineering, 2014

Arregui-Mena JD, Margetts L, Griffiths DV, Lever LM, Hall GN, Mummery PM, "Spatial variability in the coefficient of thermal expansion induces pre-service stresses in computer models of virgin Gilsocarbon bricks", Journal of Nuclear Materials, 2015.

Integration and conclusions / **98**

Pre-alignment measurement uncertainty evaluation and thermal influences

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Presentation

Summary:

In this presentation the targeted uncertainty budget for PACMAN systems for pre-alignment is described and elaborated on. A new strategy of uncertainty budgeting following the state of art in International standard (GUM, Supplement 1) is proposed as alternative to current classical methods of error budgeting applied for accelerators pre-alignment. This methodology follows stochastic like modelling for providing probability density function as quantification of the various sub-systems measurement uncertaintys. The aim is to create a Virtual model of PACMAN Multisensorial Measurement System, trough which the

various error sources probability density functions are propagated do define the final PACMAN measurement uncertainty. This provides the first so called 'task specific' or 'measurement specific'uncertainty budget for accelerator pre-alignment according to GUM, Supplement 1 international standard. The first experimental and modeling results are shared with emphasis of one of the biggest error contributors the environmentally/thermally induced errors.

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Thank you and wrap-up of the session

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Posters session / **86**

Development of an Automated Measurement Device for the Multipole Components of the HESR Sector Bends

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For the High-Energy Storage Ring (HESR) of the future Facility of Antiproton and Ion Research (FAIR) 44 bending magnets are being produced.
For beam dynamics simulations the precise knowledge of the harmonic content of their magnetic field is of major importance.
As the magnets are strongly bent (approximately 8.2 degrees with a total length of approximately 4.5 m) a measurement based on a rotating coil through the whole magnet is not feasible.
As an alternative we are considering hall probe-based measurements. The present layout comprises a movable disk with several radially placed hall probes.
For the measurement the disk is automatically moved to fixed positions along the central trajectory.
A rotation of the disk is also considered in the design.
The measurement will be taken while the probe is at rest. The multipole coefficients will be estimated by Fourier transformation of the recorded values.
This contribution will present the status of the design but may as well serve as a basis for an exchange of experiences and ideas.

Summary:

Posters session / **89**

Rotating sensor for new possibilities on Leitz Infinity Coordinate Measuring Machine

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A rotatory mount is being designed in CERN to determine the position of the axis of a 0.1 mm in diameter stretched wire with a sub-micron accuracy.
As part of its role as world-wide leader in high energy particle physics, CERN studies the feasibility of a Compact Linear Collider (CLIC). One of the biggest challenges of this electron-positron collider is the alignment required for all the components acting on the beam: thousands of components will have to be assembled and aligned at the micrometre level. PACMAN, a study on Particle Accelerator Components Metrology and Alignment to the Nanometre scale, is a Marie-Skłodowska Curie Program supported by the European Commission (FP7 Program) whose aim is to develop and build a pre-alignment bench on which components are assembled and aligned to the required accuracy using a stretched wire.
During the process of this measurement, the centre of a stretched wire is aligned with respect to the reference axis of the components. The Cu-Be wire with a diameter of 0.1 mm considered for this task has been evaluated and its quality led to the conclusion that a form measuring sensor should be used to increase the precision of the measurement. The Shape Evaluating Sensor: High Accuracy & Touchless SESHAT is being designed for this task: its challenge is to measure the form error of this stretched wire with 0.1 µm accuracy and its axis position with 0.5 µm precision on the coordinate measuring machine. The singularity of the SESHAT's design is an opening in the radial direction. Indeed, this paper introduces the requirements: no magnetic fields created, high accuracy on the positioning, low error motion, and open on the side; and it describes and discusses the technical solutions: from the material to use to the bearings, including the kind of sensor.

Summary:

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A Magnetic Measurement System for Extracting Pseudo-Multipoles in Accelerator Magnets

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For accelerator magnets such as capture solenoids, fragment separator dipoles and insertion quadrupoles, it is important to measure not only the integrated field errors but also the local field distributions in the magnet extremities. In three-dimensional field problems the transversal multipole coefficients do not constitute a complete orthogonal function set. This gives rise to pseudo-multipoles in Fourier-Bessel series that can also account for field variations in axial direction.

In the magnetic measurement section of CERN's TE department we have started to design, construct, and characterize metrologically a measurement bench composed of high precision mechanics with integrated real-time automatic control and drive system, encoders, and measurement transducers with iso-perimetric search coils. A suitable post-processing tool is being developed based on the theory of pseudo-multipoles as well as field reconstruction from boundary data.

Scientific challenges stem from the need to calculate higher-order derivatives of the measured flux densities, which in turn boosts the requirements of the data acquisition systems and digital integrators, as well as the mechanical stability of the bench and transport system. Other challenges stem from the coil design, which results in convoluted signals because of the non-negligible thickness and the short length of the search coils.

Summary:

Posters session / **97**

Characterization of magnetic materials for accelerators component

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In recent years, the need for replacing the materials for the construction of several accelerator components has arisen from the framework of the high-luminosity upgrade for the Large Hadron Collider (HL-LHC). To address this, new materials have been considered, and a proper characterization of their magnetic properties has become essential. This poster describes the magnetic measurement procedure and presents the reference method adopted at the Magnetic Measurement Section, a standard fluxmetric method based on a split-coil permeameter. In particular, the magnetic characterization of three materials is reported: ARMCO, for the construction of the yokes of new magnets; and CRIOPHY, for the magnetic shield of the crab cavities (CC), and feebly magnetic materials, such as austenitic stain steel, to validate the use of the same inductive method for their magnetic characterization.

Summary:

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Preliminary results of the metrological characterization of the bunch length measurement by RF deflector

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Bunch length measurement in linear accelerators can be carried out using a Radio Frequency Deflector (RFD). A RFD provides a transverse kick (vertical or horizontal) to the beam introducing a correlation between the longitudinal and the transverse coordinates of the bunch. Therefore, the bunch length can be obtained by means of a transverse beam size measurement on a screen, placed after the RFD. In this poster, a metrological characterization of this measurement technique is proposed. Preliminary results were obtained through simulation by means of ELEctron Generation

ANd Tracking (ELEGANT) code on the parameters interesting for the electron linac of the Compton source at the Extreme Light Infrastructure –Nuclear Physics (ELI-NP).

Summary: