Workshop on Special Compact & Low Consumption Magnet design

Magnet alignment challenges for future accelerators

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CERN

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Agenda

Outline

- 3 steps of magnet alignment:
  - Fiducialisation
  - Pre-alignment on common support
  - Alignment in the tunnel
  - State of the art versus requirements
- Two examples from the CLIC project:
  - DB quadrupole
  - MB quadrupole

Steps of alignment

Fiducialisation

Fiducialisation: determination of the magnetic axis w.r.t. external targets

➔SU case: determination of the mechanical axis w.r.t. fiducials

Choice function of….

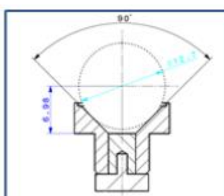
Fiducials: ⟷ **Means of measurements:**

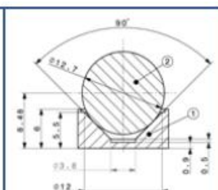
Fiducials:

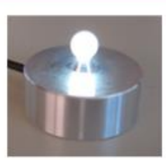
- Size of the magnet
- Means of measurements
- Configuration
- Fixation

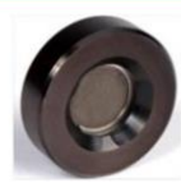
Means of measurements:

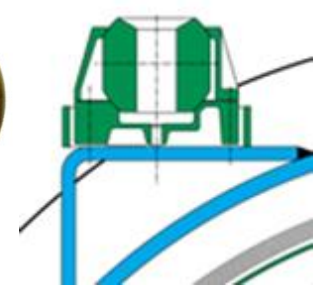
- Precision / accuracy required
- Size, weight of the magnet
- Environment


0.5'' holder with removable magnet


0.5'' holder


Micro-triangulation target


1.5'' holder



Steps of alignment

Fiducialisation | Means of measurements

More accurate, less portable →

Portable measuring arm	Laser Tracker	CMM

- MPEp: 8 μm (2σ)

- Measurement uncertainty: ±15 μm + 6 μm/m (AT401)

- MPEE: 0.3 μm + 1 ppm
- Major axis stroke = 1.2 m

In some cases, this step is complicated by the fact that there is a cryostat
➔ monitoring of cryo-mass inside the cryostat needed (WPM, FSI under study for HL-LHC).

Steps of alignment

Pre-alignment on common support

- ✓ Several magnets on the same girder
  - Fiducialisation of all magnets needed + support
  - Transfer between referential frames of components and support guarantied by measurements

- ✓ Coupling of BPM to quadrupole for example (the offsets of the reference axes must be known)

- ✓ During the pre-alignment process on the support, it is important to have accurate & precise means of measurements combined with accurate means of adjustment (shims are not recommended for micrometric adjustments).

Steps of alignment

Alignment in tunnel

w.r.t to the geodetic network

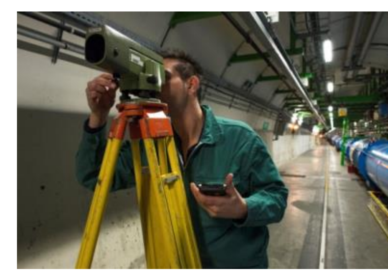
w.r.t the adjacent components

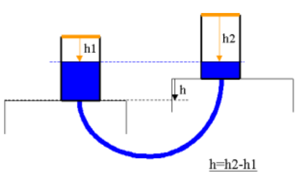
Alignment systems

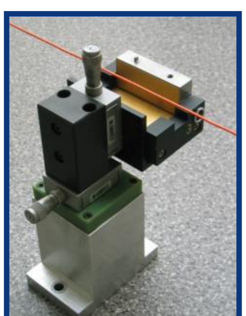
- Continuous measurements
- In severe environment
- High precision & accuracy
- With kinematic sensor mounts

Standard means

- Alignment of fiducials







Magnet alignment: state of the art

State of the art…

- Mechanical fiducialisation ~ 50 µm, better with CMM for smaller components
- Pre-alignment on common support: capacities of fine adjustment to be developed ~ 20 µm (on small components)
- Alignment in tunnel: 11 µm reached over 140 m

2 cases where requirements are above this state of the art, with a magnet alignment challenge:

→ DB quadrupole

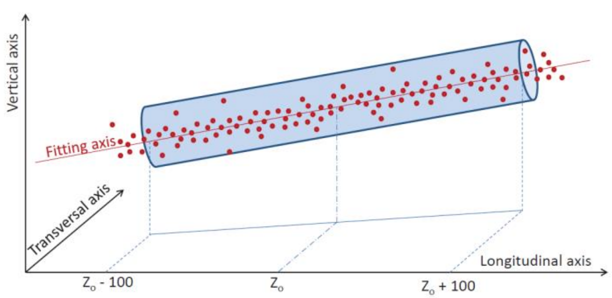
→ MB quadrupole

Example 1: Case of DB quadrupole

DB quadrupole for CLIC project

- 40 000 DB quadrupoles foreseen for CLIC
- 2 DB quadrupoles per girder of a module

Alignment requirements



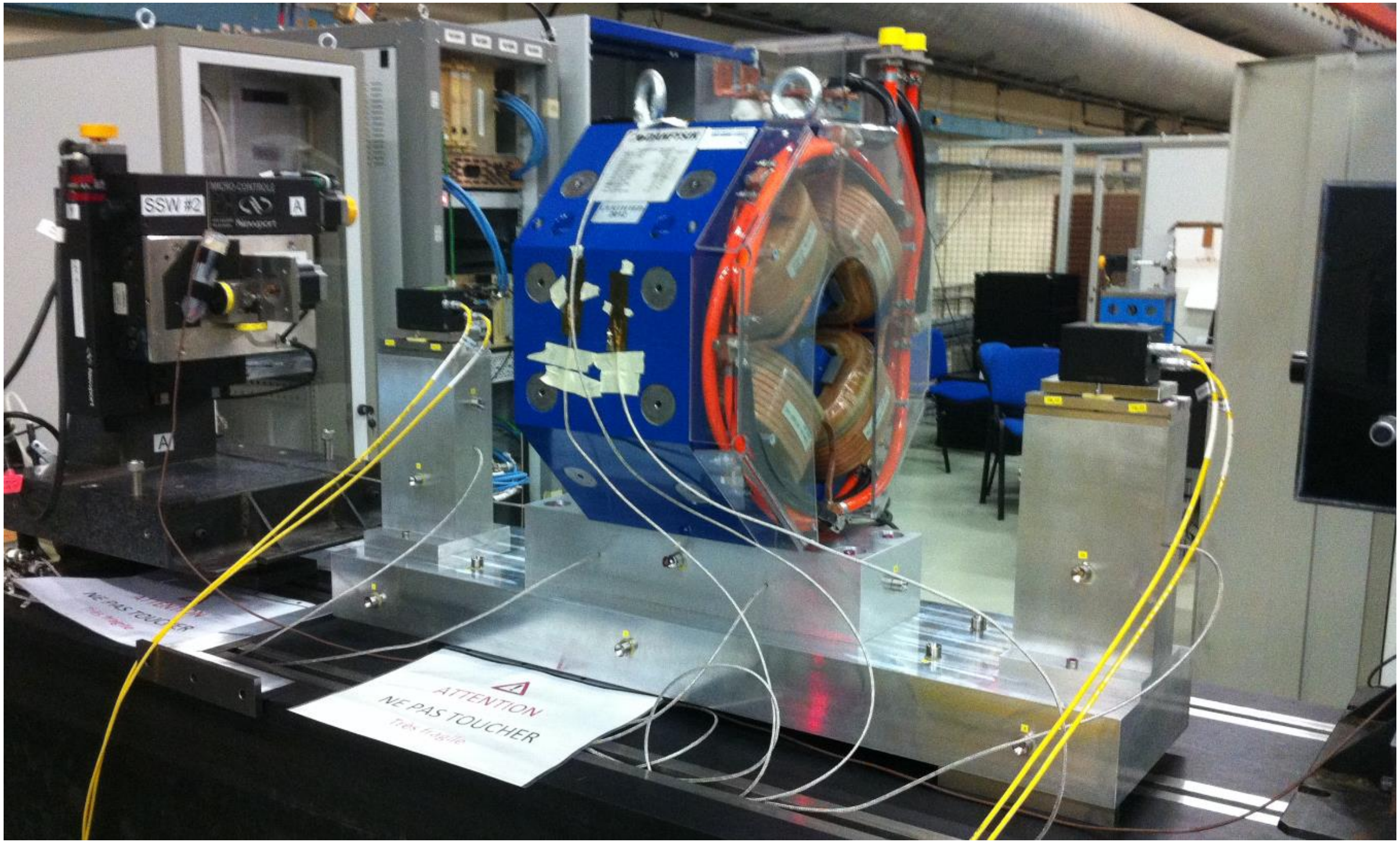
- For a sliding window of 200 m
- Std deviations of magnetic axis of DB quad w.r.t a straight line fit < 20 µm

Example 1: fiducialisation of DB quad

The whole setup

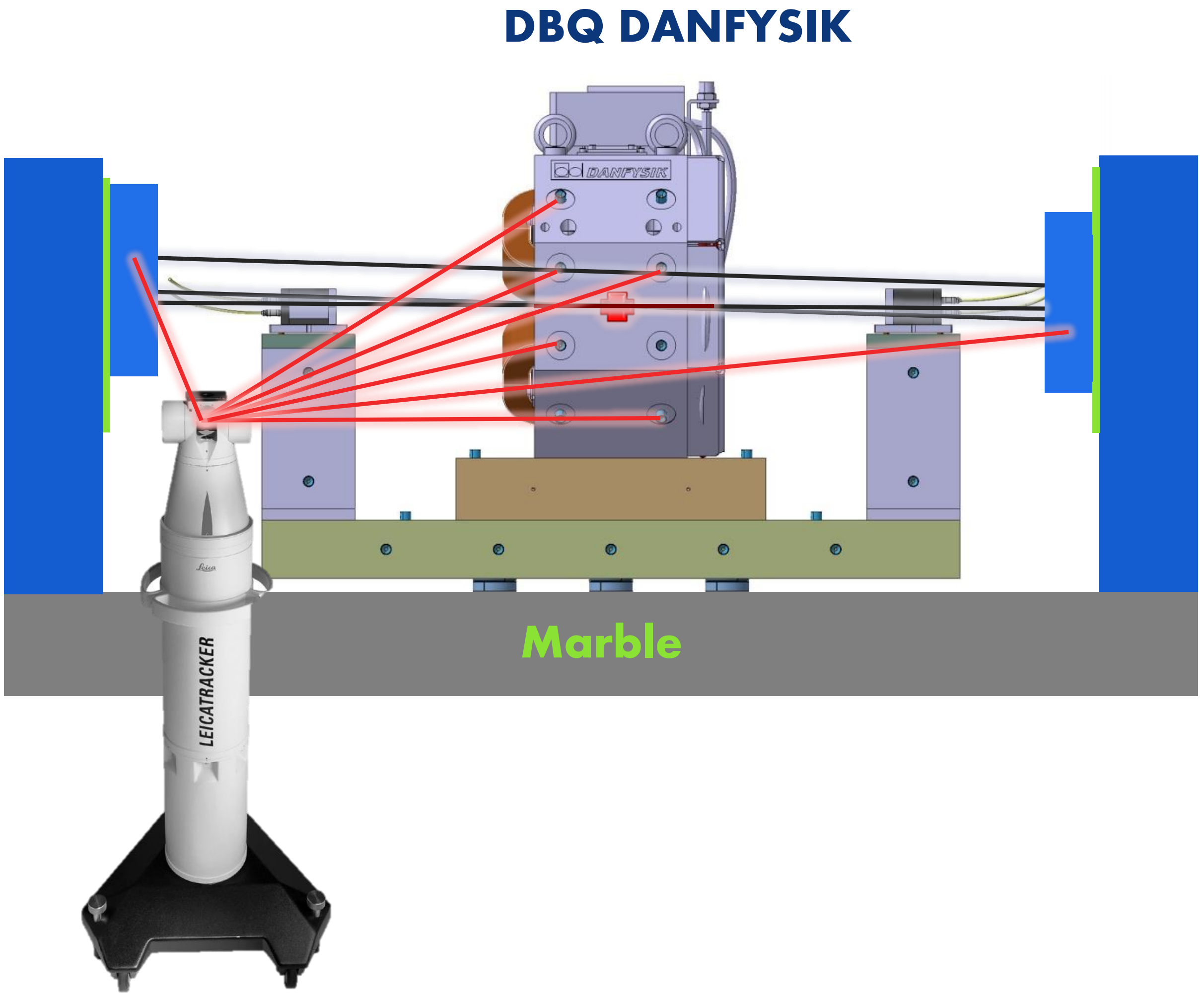
Determination of magnetic axis with an oscillating wire

➔ new method to determine the position of the wire

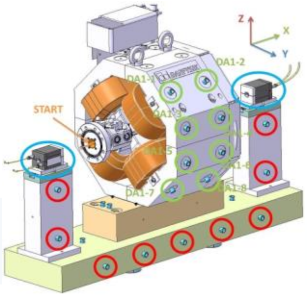


Example 1: fiducialisation of DB quad

Process of measurements



Example 1: fiducialisation



Repeatability of the method

Measurements performed on 3 types of wires (Ø 0.1 mm):

- Cu-Be (2003) 5 sets
- Cu-Be (2013) 4 sets
- Cu-Ni 4 sets

Std dev. of coords	Y (µm)	Z (µm)
Entrance of magnetic axis	4	4
Exit of magnetic axis	4	5

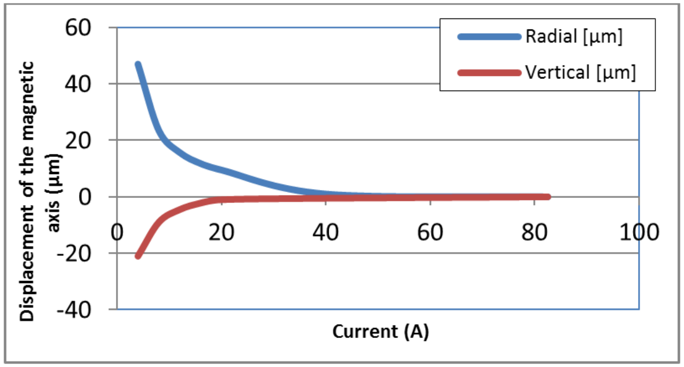
Inter-comparison between methods

Std dev. of coords	Y (µm)	Z (µm)
Entrance of magnetic axis	2	7
Exit of magnetic axis	2	7

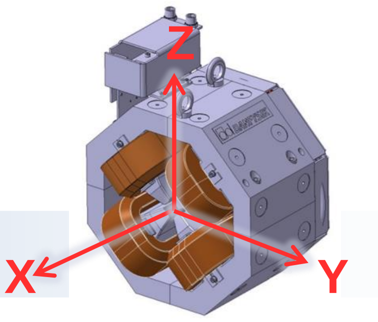
- Entrance & exit of magnetic axis determined by both methods

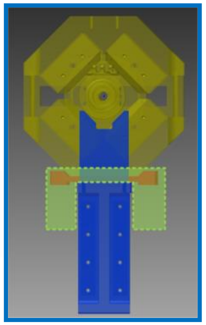
Position of magnetic axis vs current

- Impact of the current in the position of the magnetic axis not negligible,
- Repeatable



Example 1: adjustment

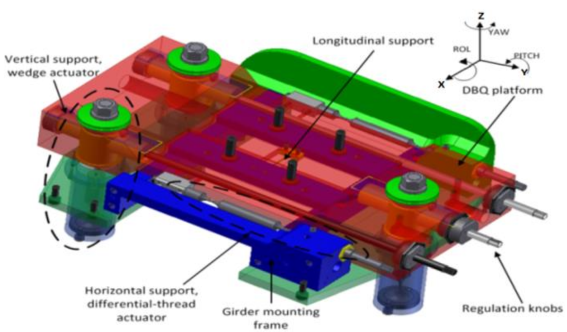


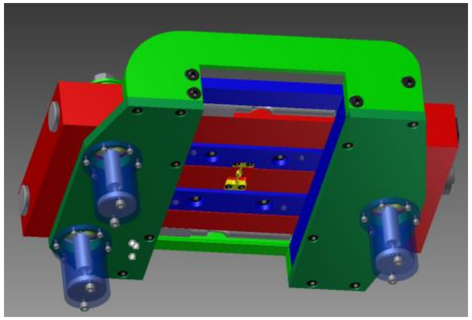


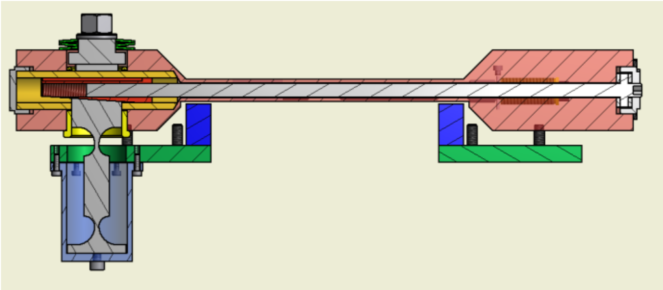
From the requirements…

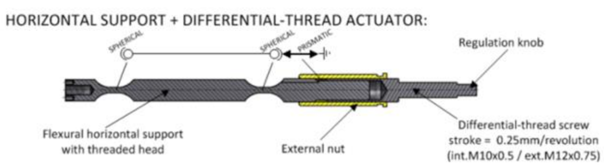
- Adjustment according to 5DOF (Y, Z translations & 3 rotations)
- Stroke:
  - ± 1 mm in Y and Z (X blocked)
  - ± 4 mrad in all rotations
- Resolution < 5 µm
- Must fit the available space
- User access only on one side
- Load 170 kg

…to the design









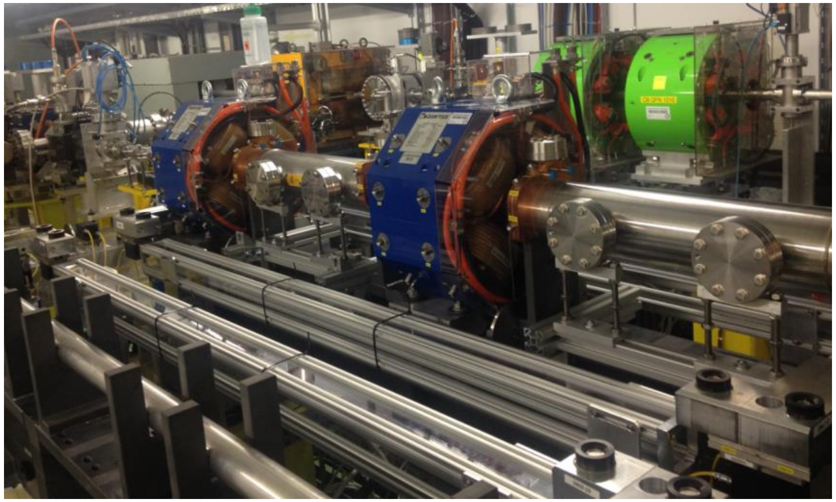
Results

- Resolution of translations < 4 µm
- Resolution of rotations < 40 µrad
- No drift or creeping
- Nominal adjustment < 10’

Example 1: perspectives

Combination of both methods during the fiducialisation process of DB quads

- 2 DB quads installed on the same girder, via the 5 DOF micrometric adjustment system
- Whole assembly installed on a magnetic calibration bench, on a special bench, equipped with additional targets and cWPS interfaces (determined by CMM measurements)



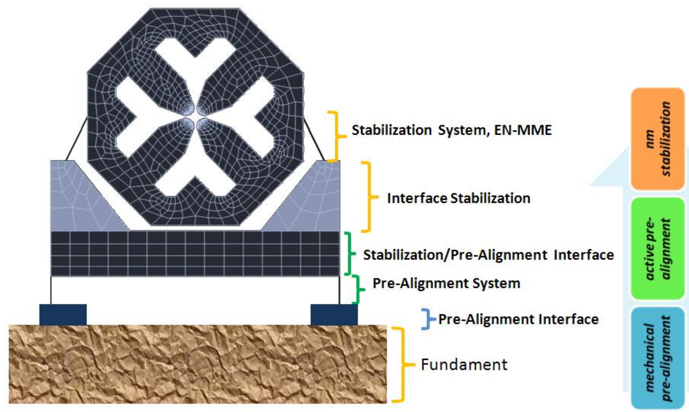
- A wire is stretched to perform the magnetic measurements
- It is not the wire that will be displaced to look for the magnetic axis of the quadrupole, but the quadrupole using the 5 DOF adjustment system
- Once in position, the position of the wire is measured, using a combination of cWPS, laser tracker, CMM measurements, in the girder referential frame.

This is an extrapolation of the PACMAN project…

Example 2: Case of MB quadrupole

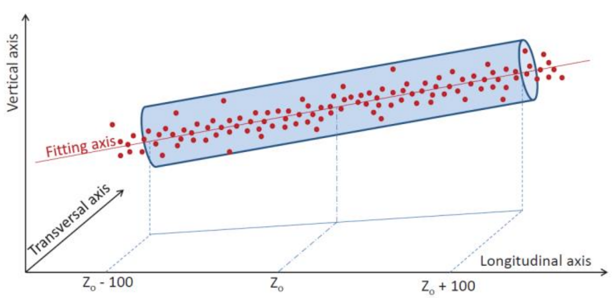
MB quadrupole for CLIC project

- 4000 MB quadrupoles foreseen for CLIC
- One additional step: a nano-positioning / stabilization system!



TYPE1	
Aperture (Ø)	10 mm
Length	420 mm
Gradient	200 T/m
Current density	6.1 A/mm2
Current	126 A
Voltage	8 V
Power	990W
Weight	85 kg

Alignment requirements



- For a sliding window of 200 m
- Std deviations of magnetic axis of MB quad w.r.t a straight line fit < 17 μm

Example 2: Case of MB quadrupole

PACMAN = Particle Accelerator Components' Metrology and Alignment to the Nanometer scale

- Metrology
- Survey & alignment
- Beam instrumentation
- Radio Frequency
- Nano-positioning
- Magnetic measurements

PACMAN

Develop very high accuracy metrology & alignment tools and integrate them in a prototype alignment bench

Extrapolate the tools & methods developed to other projects

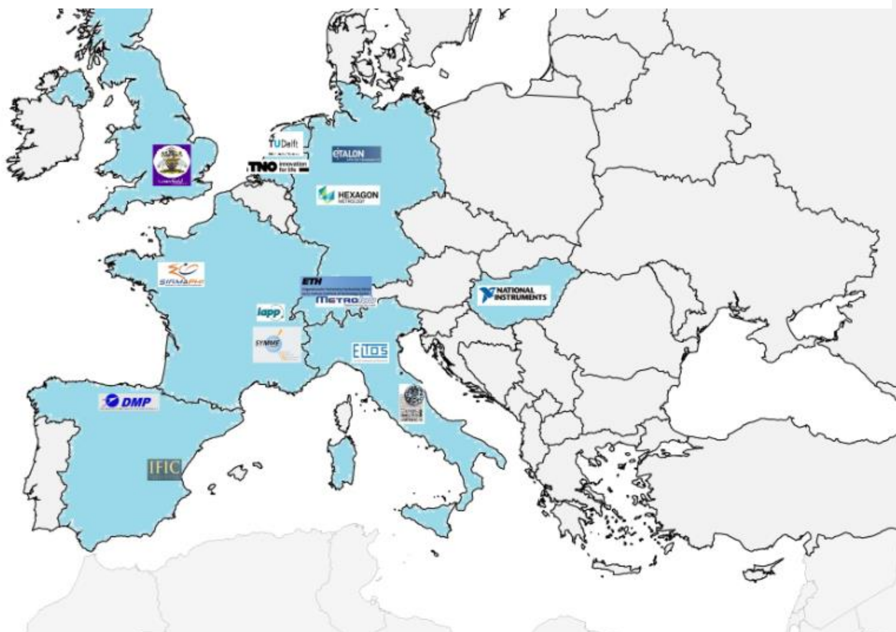
Example 2: PACMAN

- PACMAN = ITN (Initial Training Network)
- PACMAN= IDP (Innovative Doctoral Program)
- Funded by EC
- 10 PhD students
- Duration = 4 years (started on 1/09/2013)
- High quality training program
- Management @ CERN

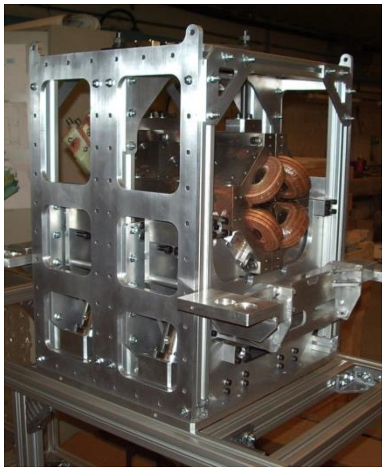
DMP	ES
ELTOS	IT
ETALON	DE
METROLAB	CH
SIGMAPHI	FR

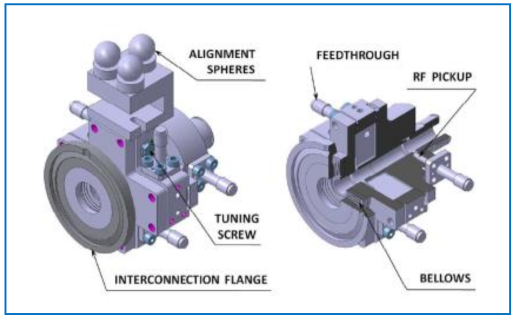
Hexagon Metrology	DE
National Instruments	HU
TNO	NL

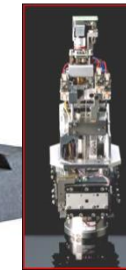
Cranfield University	GB
ETH Zürich	CH
LAPP	FR
SYMME	FR
University of Sannio	IT
IFIC / FESIC	ES
University of Pisa	IT
Delft University	NL

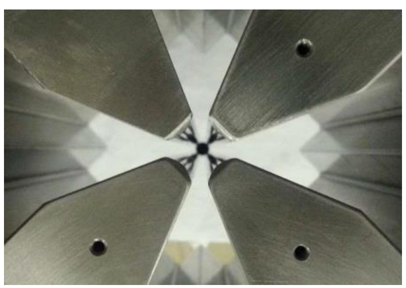


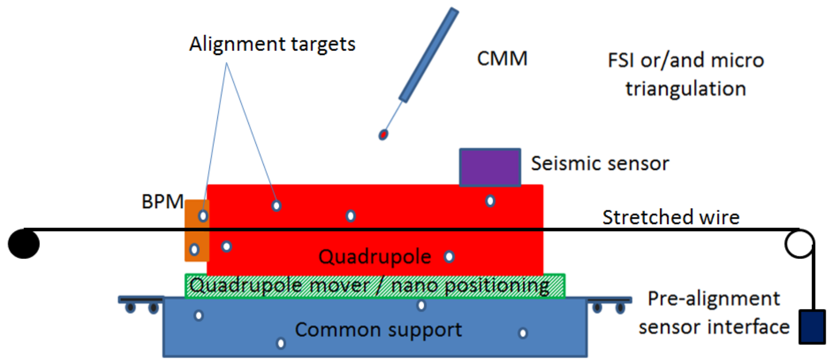
Example 2: PACMAN



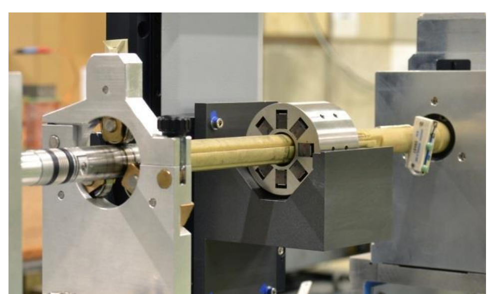


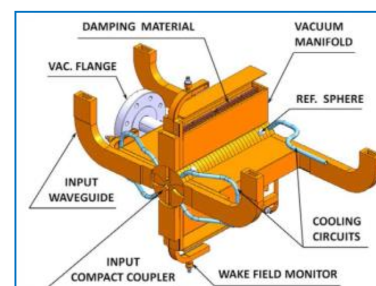






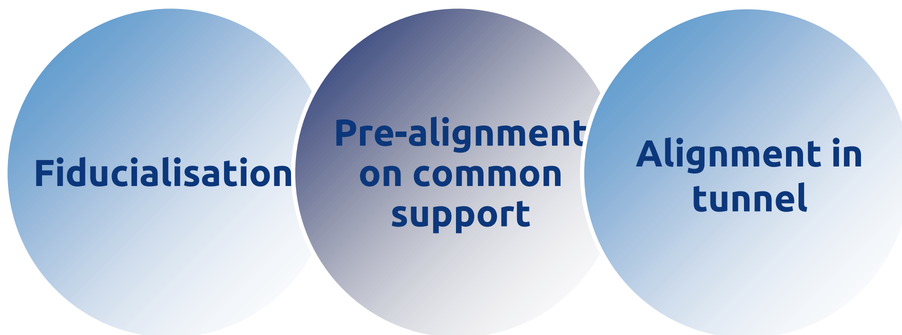
Prototype alignment bench





Summary

3 steps of alignment



The two examples introduced show that an alignment of a short magnet within 20 µm seem reachable, at stable conditions (20 °C, rigid support, etc.)

Next challenge concerning the alignment of magnet will be to master the impact of temperature variations

Concerning long magnets, inside cryostats, we hope that the tools developed by the PACMAN project will help improving the current tolerances of alignment

Bibliography

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