CERN

Juha Kemppinen

CLIC Main Beam quadrupole active pre-alignment based on cam movers

Main Beam Quadrupole (MB Quad) pre-alignment requirements

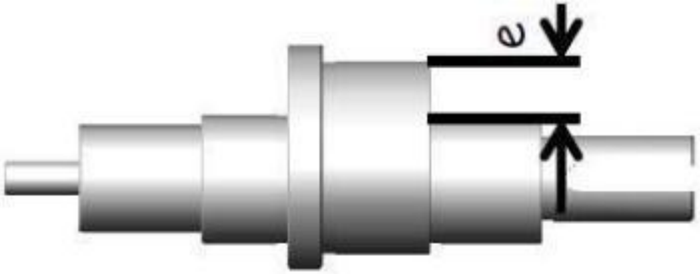
- Pre-alignment within 17 µm in sliding windows of 200 m

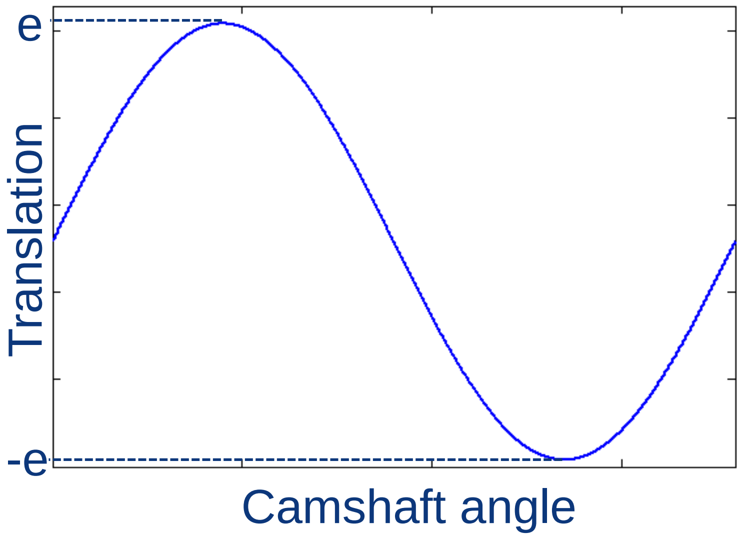
  → active pre-alignment on single MB Quads within 1 µm / 100 µrad in 5 d.o.f.
  (stroke +/- 3 mm)

- Provide rigid support for the nano-stabilization system
  - High first eigenfrequency (preferably above 100 Hz)

Approach: cam movers

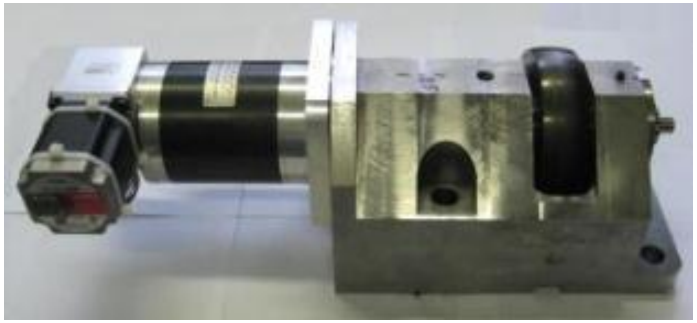
- Originally developed at SLAC and since then successfully deployed in several synchrotrons and light sources
- Transforms camshaft rotation to translation
- Very high movement resolution can be achieved

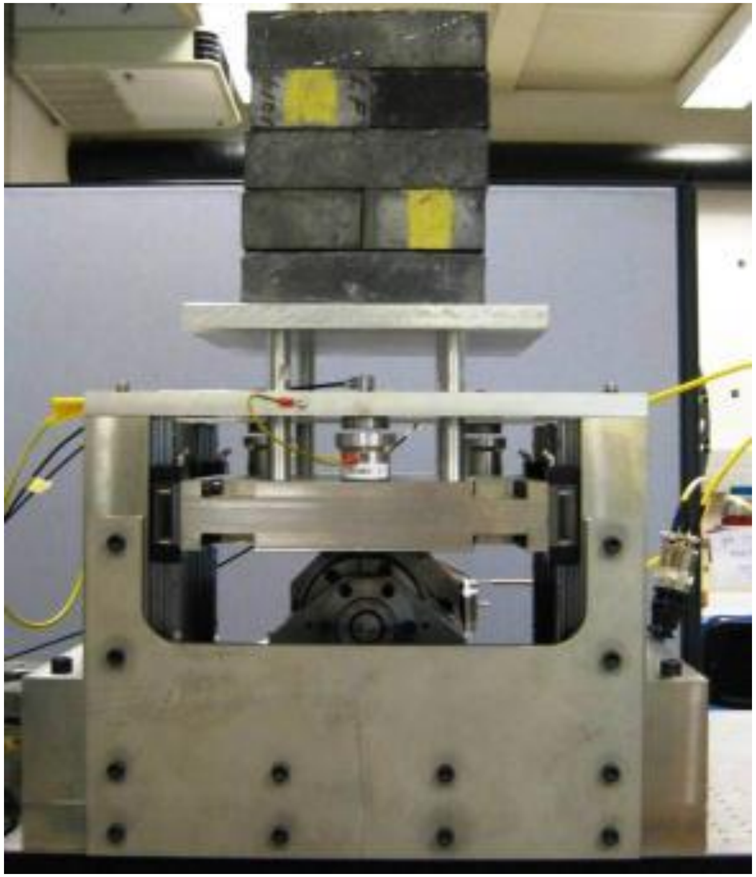




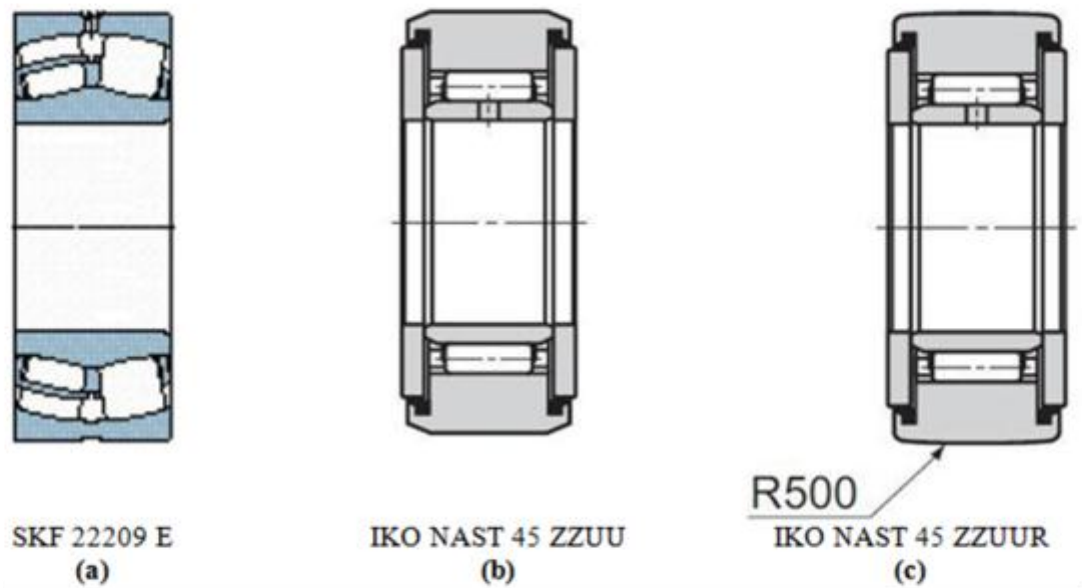
Cam mover prototype

- Based on PSI design
- 1 d.o.f. tests verified sub-micron movement resolution and repeatability
- Stroke +/- 5 mm

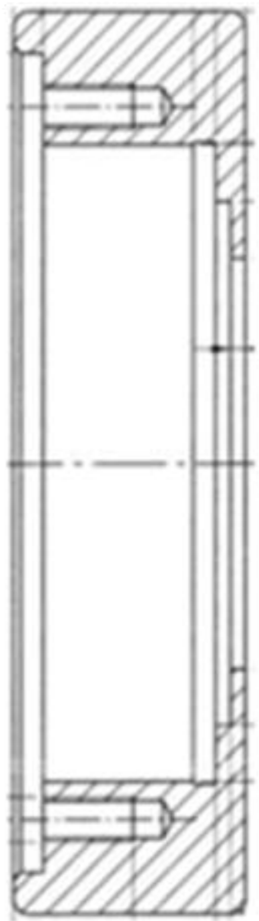




Cam mover prototype

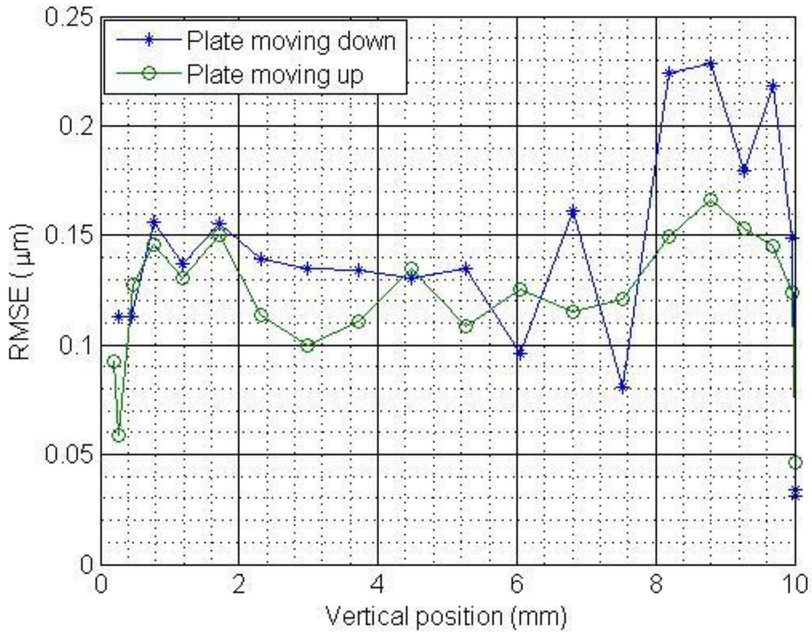


Configuration No.	Bearing type	Bearing reference	Housing type
1	Spherical roller bearing	SKF 22209 E	Cylindrical
2	Roller follower	IKO NAST 45 ZZUU	Cylindrical
3	Roller follower	IKO NAST 45 ZZUUR	Spherical



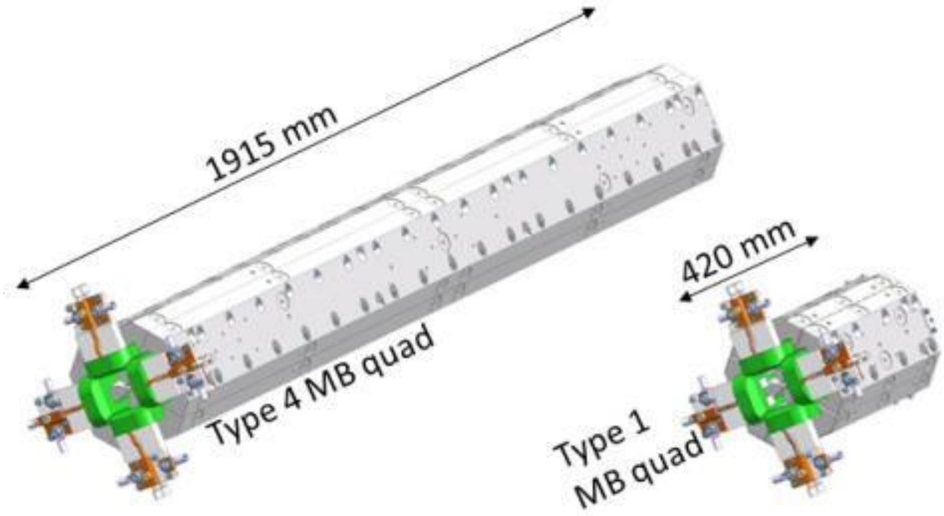
Cam mover prototype - precision

	0-9 Msteps	1-8Msteps
Configuration 1	1.0 µm	0.33 µm
Configuration 2	0.38 µm	0.18 µm
Configuration 3	0.23 µm	0.31 µm



MB Quad types

- CLIC will have 4 types of MB Quads
- At least two different cam mover types will be needed



- Estimated masses (quadrupole + stabilization system)
  - Type 1: 300 kg
  - Type 4: 800 kg

Type 4 cam mover

- Manufacturer: ZTS VVU Kosice from Slovakia
- Design was optimized in an iterative process
  - R. Leuxe, F. Lackner, ZTS VVU Kosice
- 6 cams were manufactured, then tested and calibrated in the 1 d.o.f. mock-up

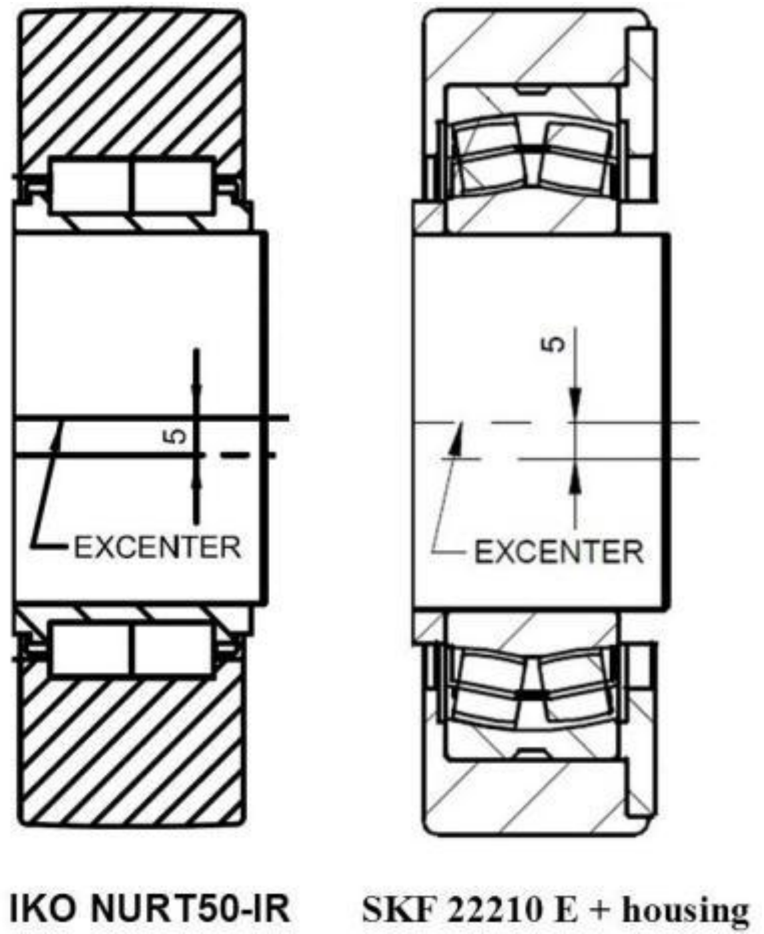
Type 4 cam mover

- Combination of a worm drive (i = 60) and a Spinea reduction gear (i = 85)
  - High movement resolution (< 0.031 µm)
  - Self-locking (worm drive)
  - Negligible backlash (Spinea)
- High precision rotary absolute encoder
  - Keeps track of orientation in case of power cut
  - Eliminates the powertrain's backlash and hysteresis

Type 4 cam mover

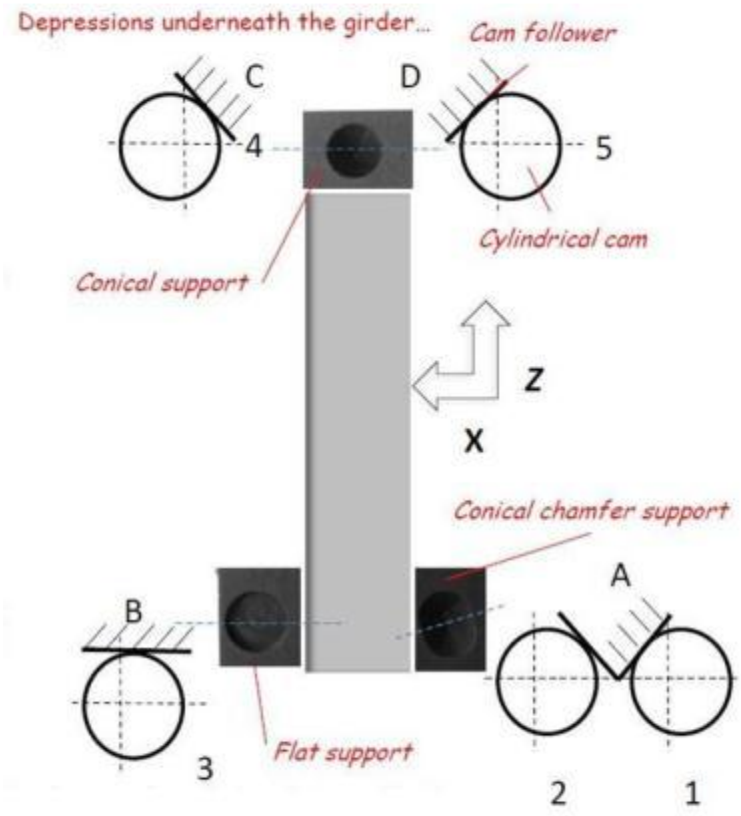
- Two bearing types were chosen for further testing
- So far only the roller follower with spherical housing (point contact) has been thoroughly tested

ZTS VVU Kosice



5 d.o.f. mock-up for type 4

- 5 d.o.f. mock-up was built in the old ISR tunnel at CERN
- 5 cam movers with appropriate interfaces can handle the 5 d.o.f. movements
  - All except longitudinal movement (blocked)



5 d.o.f. mock-up for type 4

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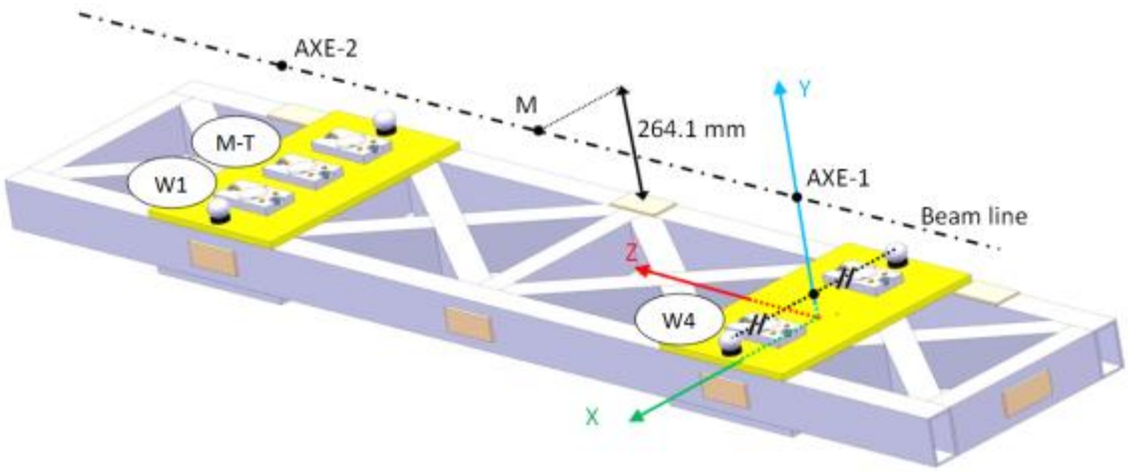
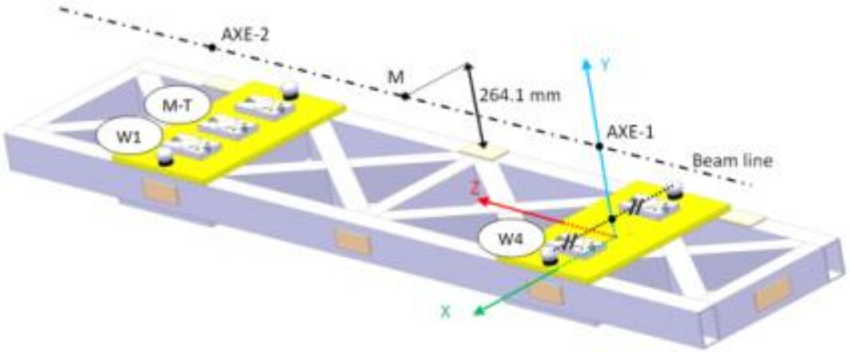
5 d.o.f. mock-up for type 4

- Chassis orientation is measured using a stretched wire, 2 WPS (W1, W4) and an inclinometer (M-T)
- Cam reference angles are calculated based on Dr. Andreas Streun's (PSI) formulas



5 d.o.f. mock-up for type 4

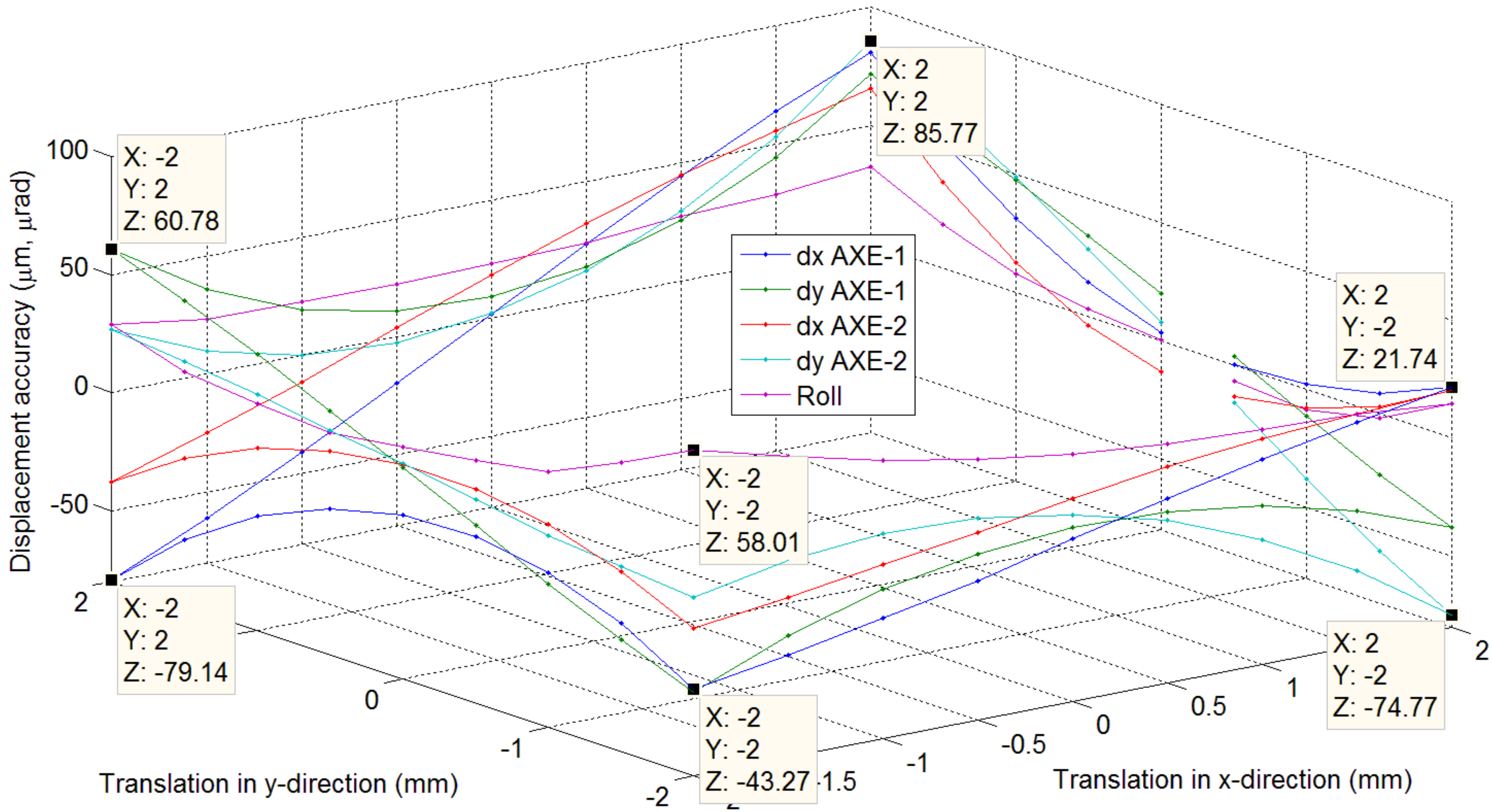
- User inputs
  - dx and dy in points AXE-1 and AXE-2 as well as roll
  - Transformed to point M offsets (input to Streun's algorithms)
- Measured orientation
  - Inclinometer gives roll directly
  - AXE-1 and AXE-2 offsets calculated based on W1 and W4 offsets roll
- Re-adjustment error (movement accuracy) is the difference between user inputs and measured orientation



5 d.o.f. results for type 4

- Positioning repeatability below 5 µm (AXE-1 and AXE-2 offsets) and below 5 µrad (roll)
- Movement accuracy (with respect to a reference position)
  - 10 – 20 µm/µrad for simple movements
  - Up to 100 µm/µrad for complex movements

5 d.o.f. results for type 4



5 d.o.f. control – iterative method

- Clearly the accuracy requirement cannot be met with one movement so an iterative method was applied
- Search position until the chassis is within 1 µm / 5 µrad from reference position
  - 3 – 5 iterations without load
  - 5 – 10 iterations with load

5 d.o.f. results for type 4

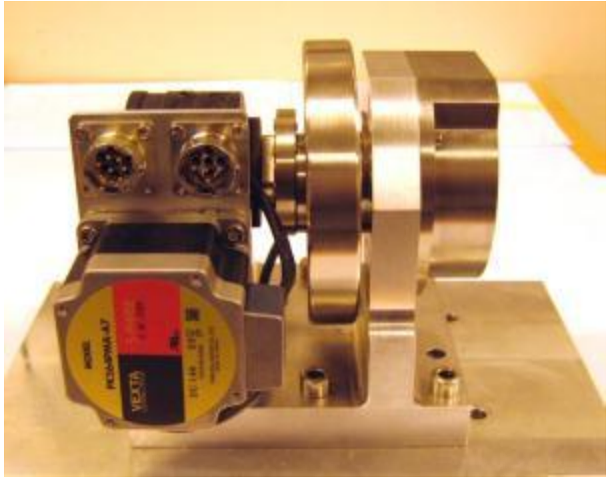
- CERN Mechanical Measurement Lab (EN-MME) performed the experimental modal analysis of the 5 d.o.f. mock-up
  - The lowest natural frequency was found at 15 Hz which is lower than expected
  - This might be due to the support under cam movers → small test setup to verify this will be built shortly (waiting for delivery of parts)

Type 1 cam mover

- Was developed at CERN
- Very challenging to meet all requirements simultaneously
  - Space restriction (no space for two gearboxes)
  - Enough torque (10 – 20 Nm)
  - Resolution (< 0.5 µm)
  - Self-locking
  - Negligible backlash

Type 1 cam mover

- A suitable set of components was finally found (resolution < 0.35 µm)
  - Oriental Motor high resolution stepper motor
    - 0.36°/step
  - Davall Gears custom Spiradrive gearbox
    - i = 90
    - Self-locking
    - Negligible backlash



R. Leuxe

Type 1 cam mover

- The first Spiradrive® series is equipped with high tensile brass pinion to have negligible backlash
  - The pinion broke down while the first cam mover was under 1 d.o.f. tests with 100 kg additional weight
  - Remaining gearboxes should be tested with reduced load in 1 d.o.f. and with full load in 5 d.o.f. to finally determine if they can be used

Type 1 cam mover

- A new series of Spiradrive® gearboxes, equipped with steel pinions, was manufactured
  - Better wear and torque resistance but introduces up to 5 arc minutes of backlash → requires more complex positioning algorithms

Next steps – type 4

- 5 d.o.f. tests using different bearing type in cam movers
  - Spherical roller bearing with cylindrical housing instead of a roller follower with spherical housing

    → Line contact instead of point contact
  - Modifications and calibration on-going
    - More work needed than foreseen
  - 5 d.o.f. mock-up can be re-built when the cam movers are ready (~ 2 – 3 weeks)
- Wearing and temperature tests

Next steps – type 4

- Integration with the nano-stabilization system
  - Ready once 5 d.o.f. tests have been repeated using spherical roller bearings
- Improvement of control software and positioning algorithms
  - Cam mover control software unreliable and inaccessible → mock-up software needs lots of error detection and recovery functions

Next steps – type 1

- Assembly of 10 cam movers
  - 5 with steel pinion (priority) and 5 with brass pinion
- 1 d.o.f. tests and calibration
- 5 d.o.f. mock-up
  - Finalize design and build in ISR
  - Adapt positioning algorithms to new dimensions and backlash
  - Adapt software to new hardware
- Cam mover design optimization (FEA)

Long term (all types)

- Replace expensive absolute encoders with a simpler system to recover position data
  - E.g. high precision proximity sensors (suggested by ZTS VVU Kosice)

- Link MB quad coordinate system to CLIC coordinate system → absolute positioning

Long term (all types)

- Study the possibility to get positioning feedback directly from alignment sensors (no need for iterations)
  - Not possible with type 4 (limited functionality of cam control software)
  - Fast acquisition racks already exist at the CERN Survey section BUT
  - WPS reading stabilizes only after ~ 1s after the end of a movement

Long term (all types)

- Development of a generic 5 d.o.f. calibration process which can handle all 4 types of MB quads and their associated alignment sensors and cam movers
  - Before the calibration process itself can be defined, several studies have to be finished
    - Support under cam movers
    - Control strategy (mathematical model, feedback, trajectory planning…)
    - Alignment strategy

Long term

- Cam mover based alignment in the MDI region

Questions?

- Credits

- Pre-alignment team
  - Michail Anastasopoulos
  - Mathieu Duquenne
  - Sylvain Griffet
  - Andreas Herty
  - Hélène Mainaud Durand
  - Antonio Marin
  - Sylvain Mico
  - Michel Rousseau
  - Vivien Rude
  - Jacek Sandomierski
  - Mateusz Sosin

- Kurt Artoos
- Michael Guinchard
- Friedrich Lackner
- Raphaël Leuxe

- Paul Scherrer Institute
- Andreas Streun
- ZTS VVU Kosice

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