Quality Assurance of Actuators for the Medium-Sized Telescopes of the Cherenkov Telescope Array

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MST prototype in Berlin Adlershof
Image credit: CTAO

The Cherenkov Telescope Array (CTA)

- Future ground-based observatory for gamma-ray astronomy
  - Energy range from 20 GeV up to 300 TeV
  - Telescopes of three different sizes located at two sites
- The Medium-Sized Telescope (MST) covers energies from 150 GeV to 5 TeV
  - This energy range is essential for the CTA Key Science Projects
  - The MST is the only telescope type foreseen to be deployed at both CTA sites for the Alpha configuration (9 MSTs at CTA-North, 14 MSTs at CTA-South)

The Mirror Design of the Medium-Sized Telescope (MST)

- 12 m modified Davies-Cotton reflector with a tessellated mirror design of 86 mirror facets
  - Facet flat-to-flat diameter of 1.2 m
- Each mirror facet is mounted on the mirror support structure with
  - Two actuators (actuator stroke adjustable in length)
  - One fixpoint (freely tilting)
- Knowledge of the mirror facet tilts paramount for the pointing and image resolution qualities of the telescope

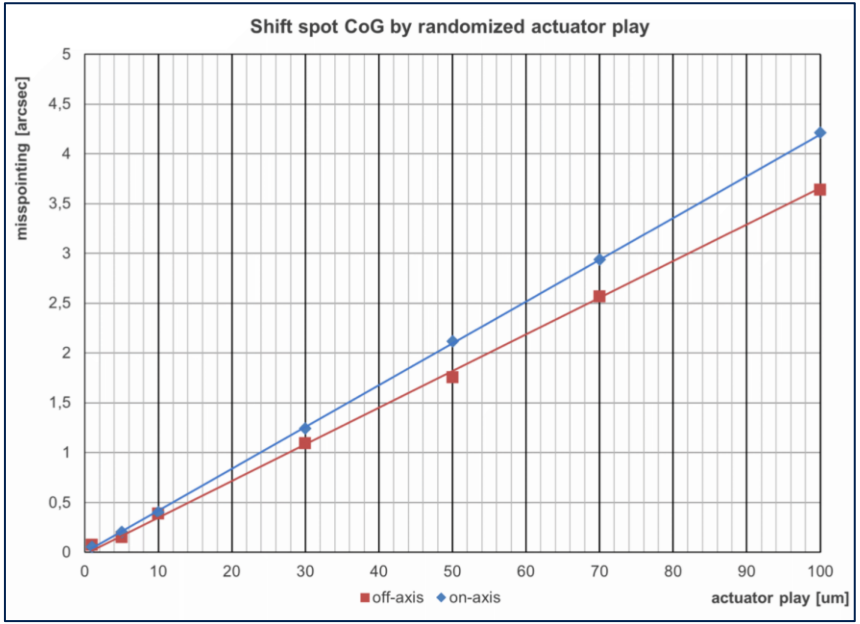
Quality Assurance of Actuators

Mirror Facet Tilt

- Accuracy: limited by the finite resolution of the actuator stroke position (±5 µm)
- Reproducibility: influenced by backlash as well as elastic and plastic deformation of actuators and fixpoint
    - Impacts the image resolution and pointing accuracy
    - Depends on observation conditions, like
        - Different wind loads
        - Varying weight loads due to changing elevation angles

Quality Assurance of Actuators

- Limits on backlash and deformation of actuators and fixpoint need to be verified in order to fulfill the requirements on the
    - Image resolution (80% light containment diameter $\Theta_{80\%}<0.18$ deg up to 2.8 deg from center of field of view)
    - Pointing accuracy (<7'')
- Development of a test stand at the "Institut für Astronomie und Astrophysik Tübingen" (IAAT) to measure the backlash and the deformation behavior of actuators, fixpoints and single actuator components (gimbals, ball joints)



Impact on the pointing accuracy as determined with ray-tracing simulations assuming a randomized actuator backlash between ±100 µm for a fully equipped MST. The requirement on the pointing accuracy dominates the limits on the backlash and deformation of actuators and fixpoints.

Annotation: CoG = Center of Gravity

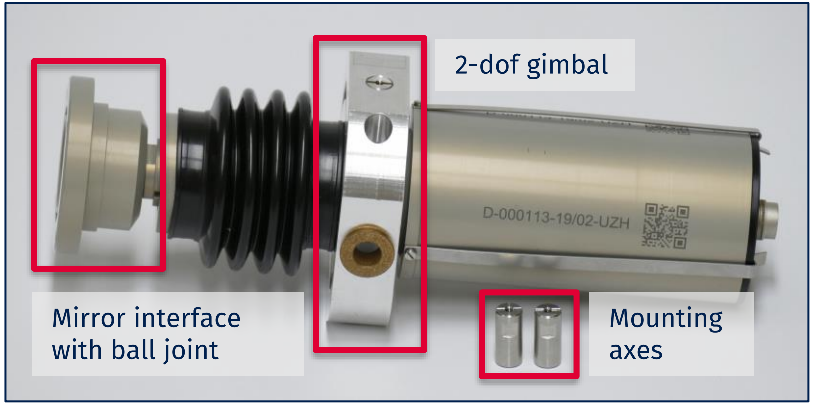
Image credit: M. Garczarczyk (DESY Zeuthen)

Measurement Theory and Principle

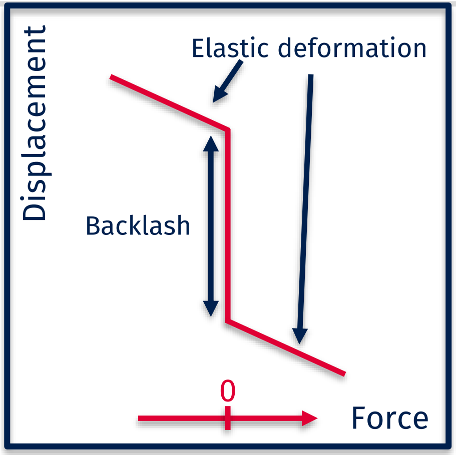
Definitions
- Backlash: clearance between mechanical parts (force-independent)
- Elastic and plastic deformation: reversible and non-reversible deformation after the application of an external force (force-dependent)

Sources of Backlash for an Actuator
- Actuator-internal components (e.g. spindle-nut interface)
- Ball joint in mirror interface
- Gimbal

Prototype MST actuator with 2-degree of freedom (dof) gimbal



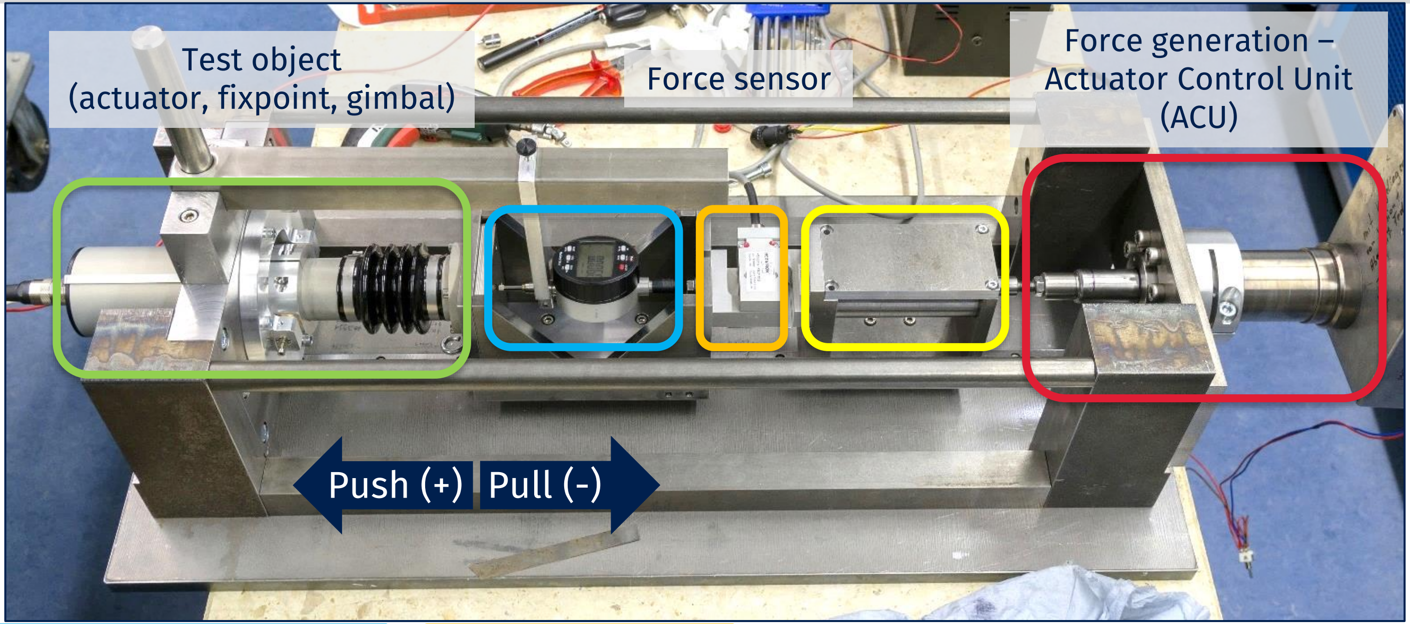
Schematic sketch of a force-displacement diagram in the case of backlash and elastic deformation only



Measurement Principle
- Measurement of the deformation of a test object under variable external force representing various weight and wind loads present during telescope operations
- Challenge: Measurement of an intrinsically tilting object requires very precise alignment of test setup

→ Quantification of the positioning inaccuracies of the test object

Test Stand for the Actuator Quality Assurance



Patent pending

Dial gauge measuring deformation of the test object (systematic error ±1.0 µm)

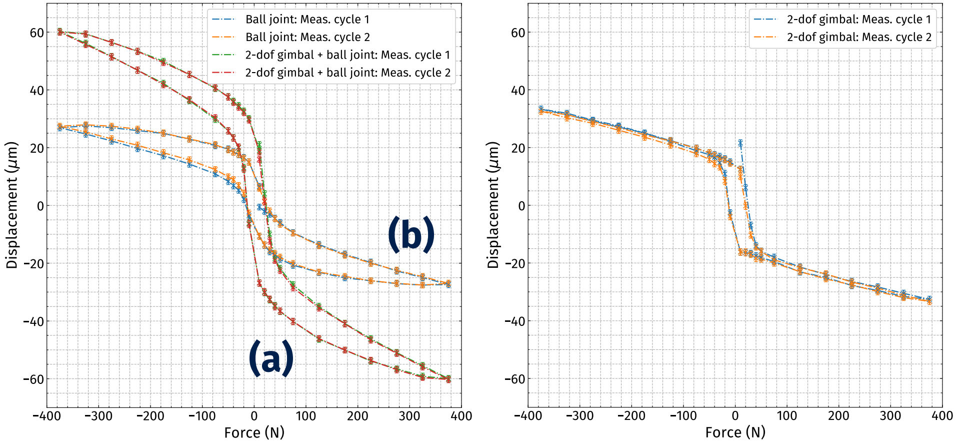
Force sensor provides force feedback

Linear force translation via springs

Push/pull force generated by ACU

Pre-tensioned guiding rail between ACU, force sensor and test object
→ precise alignment of force and measurement direction

Preliminary Gimbal and Ball Joint Measurements



Left: Force-displacement diagram for a) a measurement of a combined 2-dof gimbal and a ball joint system, and b) a ball joint.
Right: Force-displacement diagram of the 2-dof gimbal corrected for the effects of the ball joint.

Measurement Conditions

- Measurement of exemplary 2-dof gimbal and ball joint
- Maximum force of ±375 N is substantially larger than that of weight and wind loads during telescope operations
  - Chosen to verify the measurement procedure
  - Maximum expected forces during telescope operations in the order of ±100-150 N

Measurement Results

- The ball joint introduces a reproducible, force-dependent hysteresis in the positioning accuracy
- The gimbal introduces backlash due to movement of the mounting axes in the interface to the mirror support structure
  - Installation of set screws foreseen to improve fixation of the mounting axes with respect to the interface to the mirror support structure

Conclusions

- Challenging (but possible) to disentangle the backlash introduced by the gimbal from the hysteresis of the ball joint
- Total, force-dependent deformation limits the non-reproducible positioning accuracy, not only the simple, force-independent backlash
- Qualification of final MST actuator (after improvements) pending