ELT - MICADO

Phase D

CWM – Pinion Lifetime test

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CHANGE RECORD

ISSUE	DATE	SECTION/PARAGRAPH AFFECTED	REASON/INITIATION DOCUMENTS/REMARKS
0.1	06-10-2025	All	New document (first Draft)
0.2	20-10-2025	All	Changes were made based on the feedback from the review. This is the final before-test version of the document.

2. Scope of this document

The CWM (Central Wheel Mechanism) of MICADO contains three wheels – two filter wheels and one pupil wheel. Each of the wheels is made of Nituff treated aluminum and driven by a gear-rack mechanism that consists of a large geared wheel containing the filter and pupil optics and a pinion. Two possible pinion materials, bronze and Vespel SP3 are considered, but the wear behavior of these materials when used for a pinon in cryogenic conditions and in contact with a Nituff wheel is unknown. To learn more about this, and to see which material is most suited for the CWM pinions, a lifetime test is to be performed. This test report describes the experimental setup of the CWM – Pinion lifetime test, the results of the test, as well as a recommendation for the choice of pinion material.

MICADO, or the Multi-Adaptive Optics Imaging CameraA for Deep Observations, is one of the first-light instruments for the Extremely Large Telescope (ELT). It is an imager and spectrograph with a wavelength coverage in the near-infrared (0.8–2.4 μm).

MICADO will equip the ELT with a first light capability for diffraction limited imaging at near-infrared wavelengths. The design of MICADO was driven by a desire for high sensitivity and resolution, astrometric accuracy, and wide wavelength coverage spectroscopy.

3. References

RD Nr	Doc Nr	Doc Title	Issue	Date
[RD1]	ELT-TRE-MCD-56305-0039	Central Wheel Mechanism:Test Report	2.0	15-09-2025
[RD2]	ESO-254547	Common Requirements for E-ELT Instruments	3.6	-

4. Test Requirements

4.1. Contextual information

The CWM is one of the subsystems of the MICADO instrument. It contains 2 wheel mechanisms – the Pupil Wheel Mechanism (PWM) and Filter Wheel Mechanism (FWM), that each contain one and two wheels respectively. These wheels have a large diameters of ~120 cm and must be able to move optical filters and pupil masks into the optical beam with a high precision. The way this is achieved is by constraining the wheels with three radial and three axial bearings of which some are preloaded. The wheel itself is driven by a gear system: the outer circumference of the wheel has teeth that mesh in with the teeth of the pinion that is in direct connection with the drive the motor. The drive system are essentially two gears, a large one representing the filter or pupil wheel, and another smaller one representing the pinion. The gear ratio between the pinion and the wheel depends on the mechanism, for the PWM it is 41.55 and for the filter wheel it is 42.

All the wheels in the CWM are made of Al6061-T6 that has received a Nituff treatment which creates a layer of hard anodized aluminum on the surface that is impregnated with PTFE. The advantage of this coating is that it creates a self lubricating layer with high hardness and corrosion resistance. A picture of Filter Wheel 1 inside the FWM can be seen in Figure 1.

The counterpart of the wheel, the pinion, in the nominal design is made out of Vespel SP3. Vespel SP3 is a polyimide that is filled with molybdenum disulfide (MoS_2) that acts as a lubricant. The material was chosen for its low friction, high dimensional stability, and it has little outgassing in a vacuum. Since it is a plastic, Vespel SP3 is much softer than the aluminium. The reason for this choice of pinion material is that, despite making more rotations, the lifetime of the filter and pupil wheels is more important as they contain the optics, are larger, and more costly to replace than the pinions.

After the warm and cold tests with the PWM, a large amount of particles was found on and around the Vespel SP3 pinion, indicating that there was already some wear after 88 rotations of the wheel (and therefore 3682 rotations of the pinion). For photos taken during the inspection after the cold PWM test in March 2024, see Figure 2.
Since these particles were found over a large area around the pinion and might end up on inside the bearings or on the optics, it was decided to explore the option of using a different material instead of Vespel SP3 for the CWM pinions. Bronze does not have the same self-lubricating properties as Vespel SP3, but it is also softer than Nituff and since it is not a plastic it should not generate 'flakes' when wearing down. A picture of the bronze pinion in the FWM is shown in the right panel of Figure 1. After the warm and cold tests with the FWM, the pinions were inspected and no significant wear could be seen on the bronze pinion. It is important to note that Filter wheel 1 and 2 are estimated to have rotated 41.0 and 40.8 times while the Pupil wheel moved more than twice as much: 88 times.

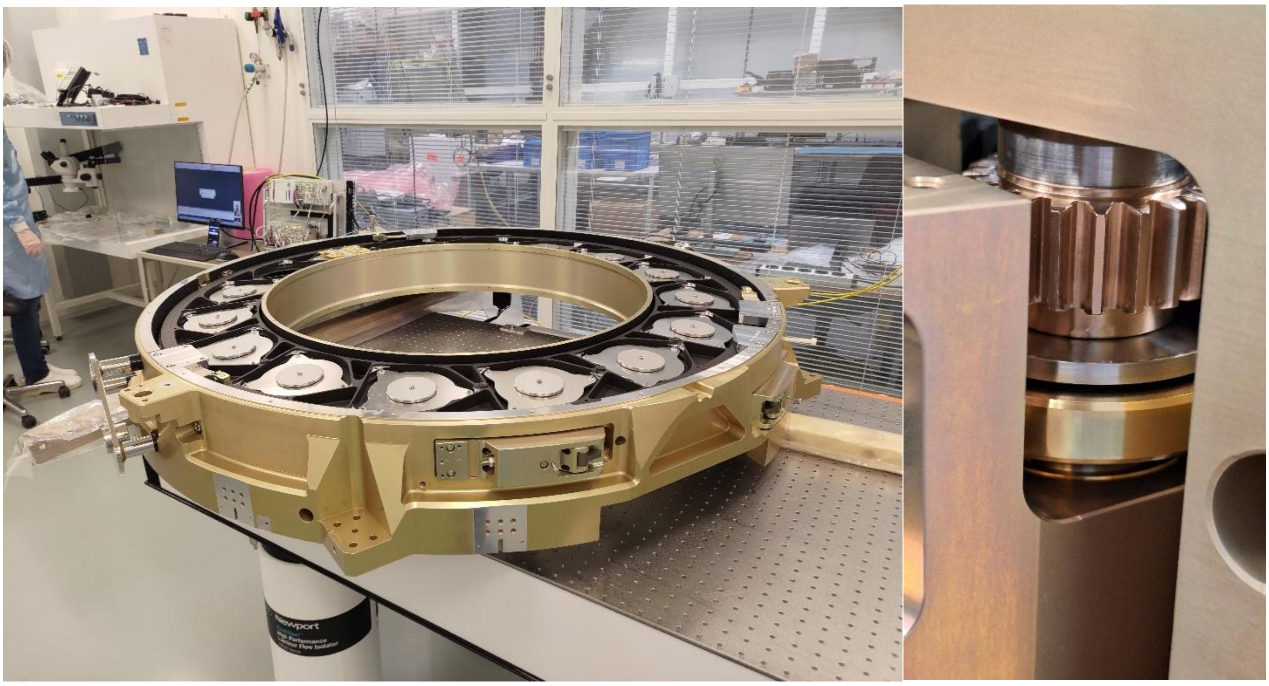

Figure 1 *Left:* A photo of the FWM in the cleanroom at ASTRON during integration. On the top, inside the FWM basering, Filter Wheel 1 is visible. The wheel is black as a result of the Nituff coating that is on the wheel. *Right:* a photo of the bronze pinion that is driving FW1.

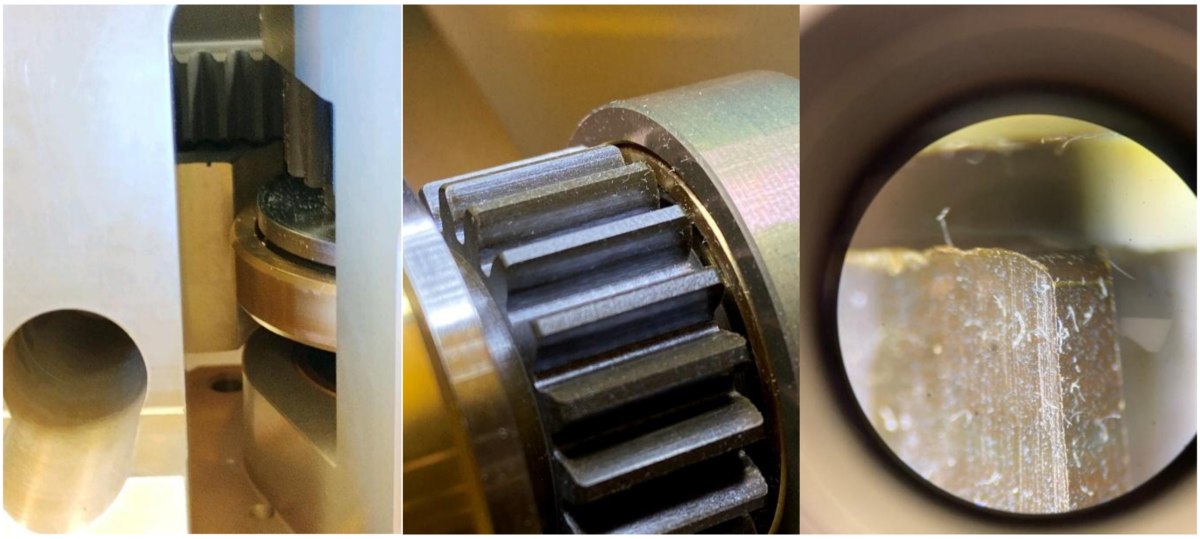

Figure 2 Photos of the PW - Drive unit and Vespel SP3 pinion taken during an inspection after the cold PWM test in March 2024.

4.2. Aim of the test

The goal of this test is to simulate a lifetime of wear on a pinion made of Vespel SP3 and a pinion made of bronze. Based on the results of this test, we can decide if we want to equip all the drive mechanisms in the CWM with either pinions made out of bronze, or Vespel.

The other questions that will be answered by this test are:

- Which pinion wears faster?
- What wear mechanisms are at play over the lifetime of the wheel and the pinion?
- Which pinion material generates the most particles when it wears down?
- Is the generation of particles only a running-in phenomenon, or is it sustained during the entire lifetime of the pinion?
- Which pinion generates more wear on the Nituff coating of the wheel?
- How does the torque of both pinions evolve over the duration of their lifetime?

The questions are further discussed and the answered in Chapter 9: Conclusion.

4.3. Environmental conditions

The test will be performed inside the box cryostat at a temperature of 82 K and a pressure of 10^{-7} mbar.

5. Wear mechanisms

In tribology many different wear mechanisms are studied out of which three are relevant for the gear-rack design in the CWM. These are: adhesion, abrasion, and fatigue. Their definition and consequences can be found in
Table 1. The pinons will most likely be affected by adhesive and abrasive wear, since these parts are in contact with the much harder Nituff layer on the rack.
It is expected that the bronze pinion will show more adhesive wear, because unlike the Vespel-SP3, it does not contain any lubricant that can act as a barrier to prevent direct contact of surfaces.

For the Nituff treated aluminium, surface fatigue as the result of cyclic loading is expected to be dominant form of surface wear. However, since the anodized aluminium is much harder than the bronze and Vespel pinions, it is expected that the pinion will wear at a faster rate. As explained in the previous chapter, this was a conscious design choice.

Table 1 Several wear mechanisms that can occur during the pinion lifetime test.

Mechanism	Definition	Result
Adhesion	Wear due to transfer of material from one surface to another	Material removal from the surface
Abrasion	Wear due to hard particles or protuberances sliding along a soft solid surface	Plows, wedges and cuts on the surface
Fatigue	Wear caused by fracture arising from surface fatigue following cyclic loading	Crack propagation and eventually breakoff of the top surface layer, resulting in pits on the surface

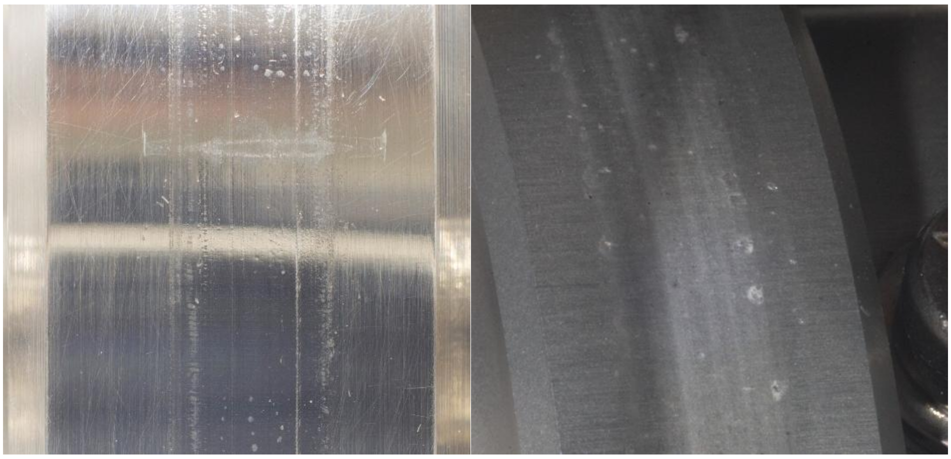

Figure 3 Examples of wear mechanisms that were observed during the bearing lifetime tests. *Left:* a combination of adhesive and abrasive wear on an aluminium roller. *Right:* pitting on the surface of a Surlon coated aluminium roller caused by surface fatigue.

5.1. Calculation of pinon lifetime

For the lifetime test the total number of rotations performed by the pinion during the lifetime MICADO needs to be calculated. This calculation is based on the motion of the filter wheels, as these will be used more than the pupil wheel. For the total number of rotations during the entire AIT campaign of the CWM, it is assumed that it will be twice the number of rotations performed during the warm and cold FWM tests.

Table 2 Parameters used for calculating the total rotations of the pinion during the lifetime of MICADO.

Parameter	Value	Symbol
Operation time of MICADO [years] / [nights] (taken from [RD2])	10 / 3650	t_{op}
Fraction of ELT observation time for MICADO [%]	50	t_{frac}
Observation blocks of 1 hour long per night	10	n_{OB}
Filters used per observation block	6	n_{filt}
Calibrations per night	3	n_{calib}
Average rotation per filter switch [°]	60	r_{filt}
Rotation per calibration [°]	360	r_{calib}
Gear ratio of the FWM wheels	42	GR
Safety factor	1.25	SF
Rotations during AIT	82	r_{AIT}

Using the values in Table 2, the total number of rotations of the pinion during the lifetime of MICADO can be calculated. During the instrument lifetime, the pinons in the FWM make 1.5 million rotations. For the full calculation of this value, see below.

$$\#\,rotations\ during\ pinion\ lifetime = \mathrm{SF} \times \mathrm{GR}\ [\ t_{op} \times (t_{frac} \times n_{OB} \times n_{filt} \times r_{filt} + n_{calib} \times r_{calib}) + r_{AIT}]$$

$$\#\,rotations\ during\ pinion\ lifetime = 1.25 \times 42\ [3650 \times (0.5 \times 10 \times\ 6 \times 1/6 + 3 \times 1) + 82] = 1537305$$

6. Test Setup

A model of the pinion test setup can be seen in Figure 4 and a schematic overview in Figure 5. The test setup consists of three main parts: the warm drive unit, the camera unit, and the cold drive unit. Only the latter is located in the test cryostat. The warm drive unit consists of a stepper motor that rotates the shaft of the pinion in the cold drive unit. Between the stepper motor and the cold drive unit are a torque meter to monitor the friction of the setup and a rotary feedthrough to the inside of the cryostat.

The cold drive unit forms the main part of the setup. A detailed overview of all the components of the cold drive unit can be seen in Figure 6. The cold drive unit was designed to allow for simultaneous testing of 2 pinions and is built around a drive shaft containing the pinions that is directly driven by the stepper motor. The upper one is made out of Vespel SP3 and the bottom one out of bronze. These pinions in turn are each in contact and drive one gear rack. Each gear rack is constrained in vertical and lateral direction by six bearings of which the upper vertical bearing is preloaded. In lateral direction, a preloaded arm with a brakeshoe presses onto the back of the gear rack. This brakeshoe arm serves to both keep the rack in place, as well as to enable us to control the amount of friction on the pinion-rack system. This control is achieved by varying the preload on the arm by turning a nut that compresses the preload spring.

From measurements during cold FWM tests (see [RD1] for more information), the torque required to drive FW1 and FW2 was calculated, and had a value of 91.3 mNm and 67.3 mNm respectively. For the pinon test, the brakeshoe must be preloaded so that each gear-rack combination adds 91.3 mNm of torque on the drive shaft. How this can be done while also taking into account the friction of the bearings in the setup and the cryo feedthrough is detailed in section 7.3.

The temperature of the test setup is monitored by 3 temperature sensors. One sensor is located on the upper gear rack, while the other two are attached to the top and base plates.

Camera unit consists of a camera mounted to the cryostat, that looks through a window in the cryostat to the upper pinion and the gear rack. An example of the camera view is shown in Figure 7. During the lifetime test pictures are taken of the upper pinion which will show the gradual wear of Vespel SP3. To also view the wear on the lower bronze pinion, a mirror is placed behind gear-rack setup.

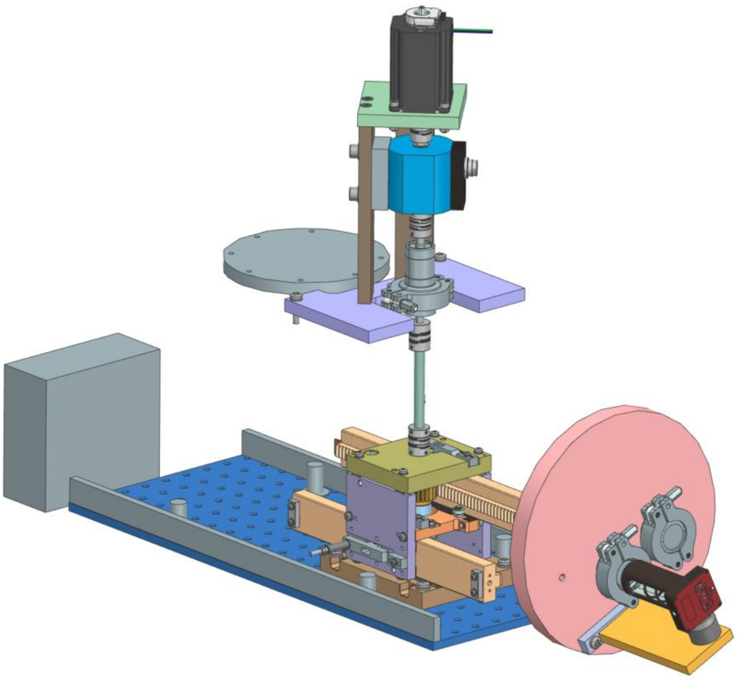

Figure 4 The test setup of the pinion lifetime test inside the box cryostat. The housing of the cryostat is made invisible for clarity.

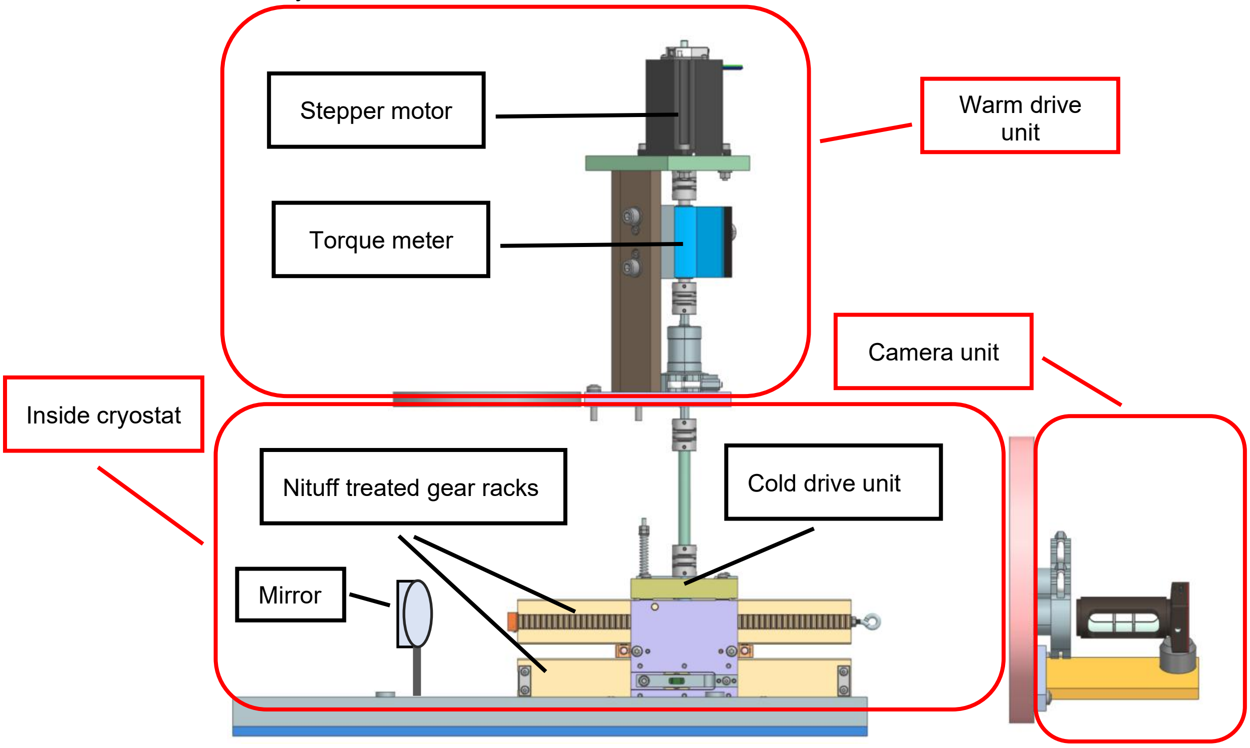

Figure 5 Sidewards view of the pinion test setup inside the box cryostat.

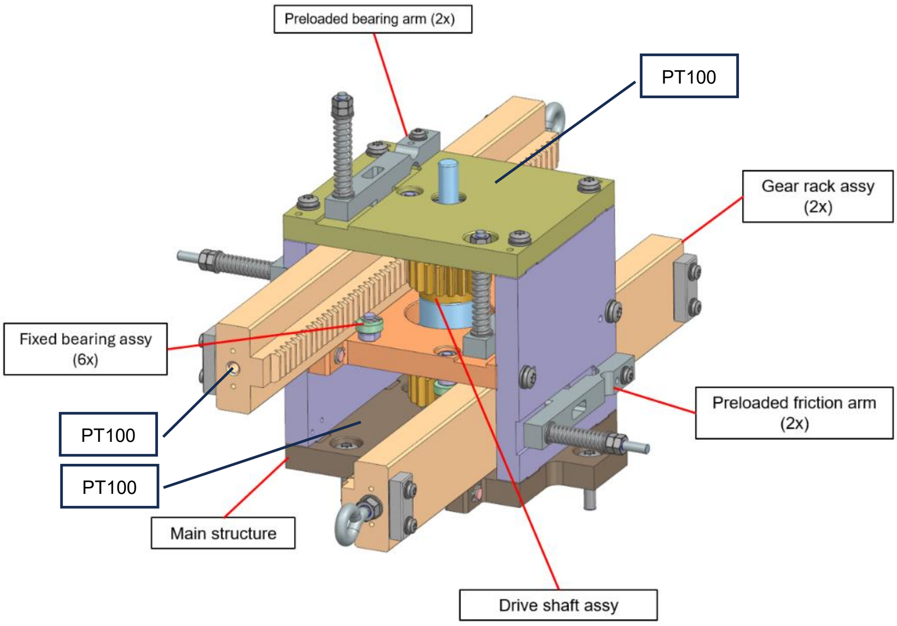

Figure 6 The cold drive unit. It consists of a shaft containing 2 pinions that each drive a single gear rack. The friction between the pinion and gear rack and therefore the torque on the drive shaft, is set by preloading the bearings of the preloaded friction arms that push against the gear racks.

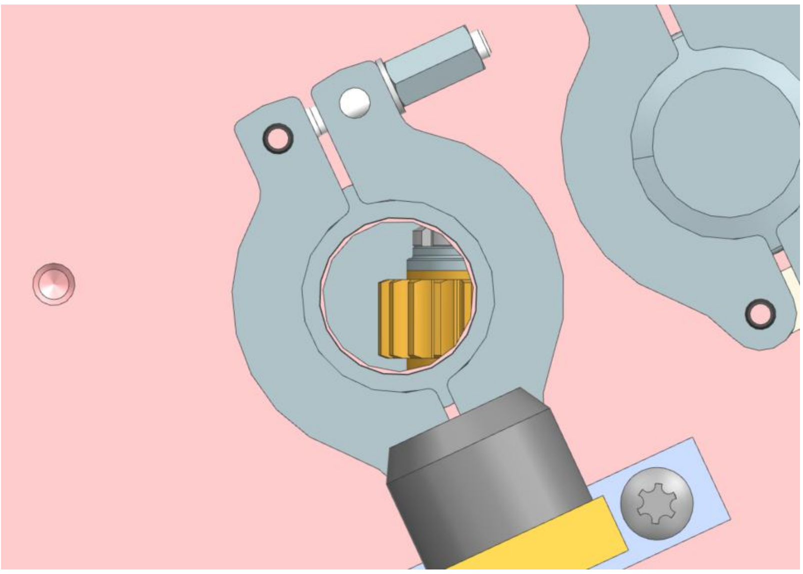

Figure 7 View of the upper pinion made out of Vespel SP3, through the cryostat window. A mirror tilted at an angle is located behind the upper pinion, allowing us to also see the lower pinion.

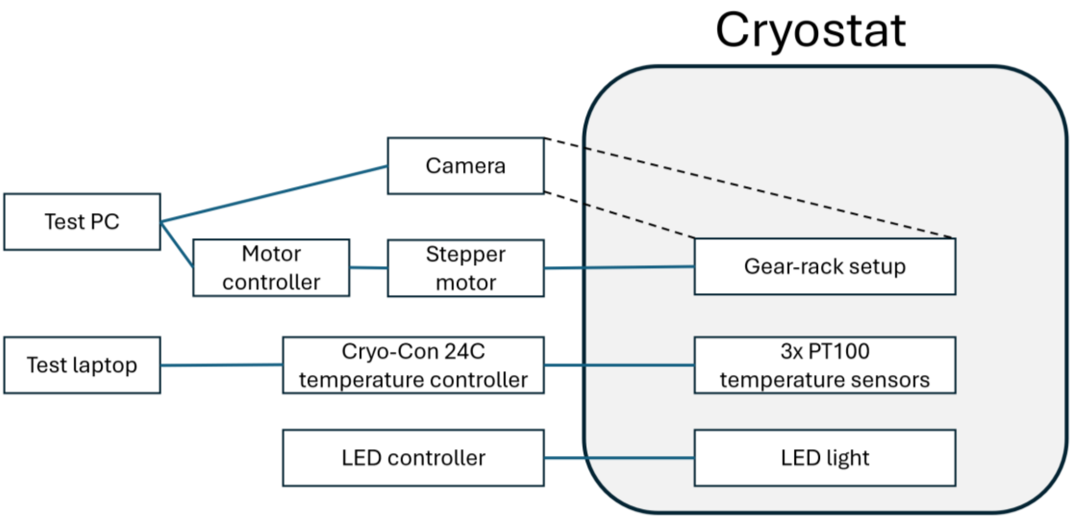

Figure 8 Schematic overview of the pinion test setup.

Test equipment

- Box cryostat
- Cryocon 24C temperature controller (with PID control set to standard settings)
- Kistler 4520A001 torque meter (should be calibrated before the test)
- Thorlabs CS165MU camera
- Test laptop (for temperature logging)
- MICADO test PC
- NEMA23-31-01SD-AMT112S stepper motor (torque should be limited to prevent overloading of the torque meter)
- Stepper motor controller
- 3x PT100 temperature sensors
- 2x Cryogenic LED light for lightening the pinion (one for redundancy).
- LED power source.

7. Test plan

7.1. Duration of the test

During a single cycle of the test, the rack moves fully back and forth once. One cycle, taking 8.72 s to complete, can fit 3.18 rotations of the pinon. If 1537305 rotations are required to test the lifetime of the pinion, the total duration of the lifetime test will be 1169 hours, or 49 days.

7.2. Take before-test photos

- Take pictures under the microscope of the teeth on the Vespel and bronze pinions. These can be later compared to the pictures taken after the test.
- Take pictures with a smartphone or camera of the teeth on the Nituff coated racks.
- Take pictures with a smartphone or camera of the two Teflon brakeshoes.

7.3. Assembly and setting the preload on brake shoe arms

Before the test starts it is crucial that the preload force on the brakeshoes are set to the correct preload. This ensures that the pinions experience the same friction as in the CWM.
It is important to keep the pinions as clean as possible during assembly. So that any particles on the pinions can be assumed as solely coming from wear and not external contamination.

7.3.1. Measuring torque of the empty setup without gear racks

- Assemble the setup without the gear racks.
- Drive the pinion at the test programme.
- Measure the torque of the setup when the pinion is moving at a constant speed.

7.3.2. Setting the friction on the upper gear and rack

- Assemble the setup with the upper gear rack.
- Read out the torque on the torque sensor live on the test laptop.
- Gradually increase the preload on the brakeshoe arm of the lower rack until the torque measured by the sensor is the same as 91.3 mNm plus the torque of the empty setup without the rack (as measured in 7.3.1).

7.3.3. Setting the friction on the lower gear and rack

- Reassemble the full setup containing the upper and lower gear rack.
- Read out the torque on the torque sensor live on the test laptop.
- Set the length of the spring of the brakeshoe arm of the lower gear rack to the same length as the spring on the upper gear rack. Then check if the torque measured by the sensor is the same as 91.3 mNm plus the torque of the setup with the upper gear rack installed (as measured in 7.3.2).

7.4. Test procedure

- To prevent failure of the bearings, do a gradual cooldown of the setup using manual heating.
- When the test setup reaches a temperature of 90 K, activate PID control with a set temperature of 82 K. Adjust the PID parameters to achieve a stable temperature.
- When the test setup is in a high-vacuum and the temperatures recorded by the three temperature sensors are at or very close to 82 K, the lifetime test can be started.
- Set up the test in the software in the following way:
    - Divide the test into 10 parts, each part consists of 99.645 rotations of the pinion (31.334 cycles).
    - Between the parts is a break in which it is checked if the setup still runs smoothly and take pictures of the pinion.
- Perform an inspection at 33% (328.829 rotations) and at 66% (657.657 rotations) of the lifetime. During the inspection, open the cryostat and take closeup pictures of the pinons, the racks, and of any possible debris below the pinions.

7.5. Measuring the final torque of the setup

- After the test is finished, the friction of the gear-rack pairs is measured again to determine the change in torque caused by wear on the rack and pinons, an due to wear of the rest of the setup (e.g. the bearings and brakeshoes).
- Measure the torque of the full setup at room temperature.
- Remove the upper rack and measure the torque of the lower gear rack.
- Remove the lower rack and measure the torque of the ‘empty’ setup without any gear racks.
- These measurements are done at room temperature, but can nonetheless provide an estimate of the increase in torque of the gear-rack combinations at 82 K. For this we assume that the torque ratio’s measured in the warm are also applicable for 82 K.

7.6. Take after-test photos

- Take pictures under the microscope of the teeth on the Vespel and bronze pinions. These can be compared to the pictures taken before the test.
- Take pictures with a smartphone or camera of the teeth on the Nituff coated racks.
- Take pictures with a smartphone or a camera of the two Teflon brakeshoes.

8. Results

9. Conclusion

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