REFOCUSING MECHANISM FOR METEOSAT 3RD GENERATION

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ABSTRACT

RUAG Space GmbH has the privilege to develop the Refocusing Mechanism REM for two of the Meteosat 3rd generation instruments.

The main functions of the REM are to support the secondary mirror M2 during all mission phases, to allow on-ground linear pre-adjustment of the mirror position with sub-micron accuracy and to allow commanded adjustment of the M2 mirror position along its optical axis to enable refocusing in-orbit.

To satisfy the requirements for the REM a novel type of a highly integrated monolithic main structure manufactured of one single block of Invar 36 was developed. This monolithic main structure comprises a frame connected to the optical bench on its base side, 4 integrated flexure joints to provide linear guiding, and the interface to the mirror. The same monolithic main structure also incorporates a flexing kinematic geometry reducing a large input motion to a small motion on the mirror interface by a decimal reduction lever. This decimal reduction lever is driven by an eccentric shaft. A high detent torque stepper motor drives the eccentric shaft. The stepper motor is sized to maintain the pointing position of the REM in unpowered condition by its high detent torque. High accuracy is reached via the combined reduction of the planetary gear, the eccentric shaft and the decimal lever formed by the flexures incorporated in the monolithic main structure.

Combining the linear guide, the interfaces and the flexure stage into one single compact monolithic structure of Invar-36 results in a mechanism with high accuracy and repeatability, high thermal stability and low mass.

1. GENERAL SPECIFICATIONS

The REM is a refocusing mechanism, on which the M2 mirror subsystem of the instrument entrance telescope is mounted. In Fig. 1 the optical layout of the Flexible Combined Imager Telescope Assembly (FCI-TA) is shown, which has been divided into the following two sub-assemblies:

1. Scan Mirror (M0)
2. Telescope Optics (M1, M2, M3, M4).

Both MTG (Meteosat Third Generation) instruments, Flexible Combined Imager FCI and InfraRed Sounder IRS, comprise an entrance telescope with an M2 mirror which is quite similar in optical function and properties but exhibits slightly different mechanical properties (CoG, mass,…). By harmonizing the interfaces both to the REM mounting area and the M2 for both instruments and by identifying the design driving requirements throughout both instruments, it was possible to have a common design and thus common procurement of REM for both instruments.

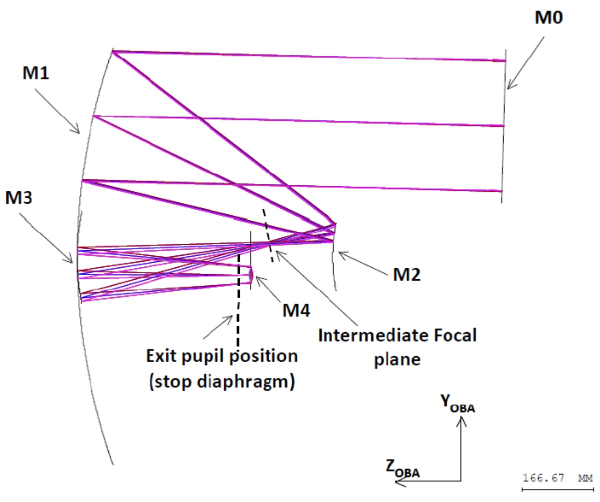

Figure 1. FCI-TA Optical Layout

The main purpose of the REM is to ensure the overall image quality of the instrument by correcting the defocus effects of image degradation due to bias effects like moisture release, gravity release, micro-slippage if any, manufacturing or alignment errors.

The REM is not intended to compensate for orbital effects such as thermo-elastic distortions, radiation effects and aging.

Below a summary of the main functions of REM:

- To link M2 mechanically to the Optical Bench (mirror support structure)
- To maintain M2 in last commanded position without power
- To provide a one-axis adjustment capability of the M2 in order to ensure optical quality in-orbit and the recovery of misalignments due to launch effects (gravity release, dehydration)
- To provide electrical information about reaching the operational limit in both directions
- To limit the translation with a mechanical stop at both ends
- To provide functional information.

An overview of the general concept is shown in Fig.2 with REM (envelope) mounted on a console part of Optical Bench. In front of REM the M2 mirror subsystem is mounted, consisting of M2 mirror and related mirror fixation device (MFD).

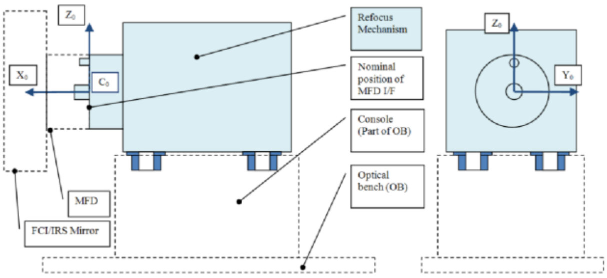

Figure 2. REM Conceptual Overview

Based on the main functions, the following requirements were derived which are also the main design drivers for the Refocusing Mechanism:

- Travel range (along REM X-axis) +/- 150 µm
- Step resolution ≤ 0.25 µm
- Step repeatability ≤ 0.06 µm
- M2 Mirror subsystem mass = 0.55 kg
- REM overall mass ≤ 1.8 kg
- REM size < 166.5 x 142 x 124.5 mm
- 1st Eigenfrequency of REM incl. M2 > 300 Hz
- Operational Temperature Range 10°C to 40°C

Requirements related to mirror position stability in unpowered condition:

- Position stability along X-axis ≤ +/- 1 µm
- Lateral deviation from X-axis ≤ +/-3 µm
- Angular deviation from X-axis ≤ +/- 3 arcsec
- Angular deviation about X-axis ≤ 12 arcsec

The key performance parameters for the refocusing mechanism are the overall travel range and the stability required from the mechanism. This means that the REM has to provide a linear motion with very small increments and high step accuracy. At the same time it has to behave like a high stable mirror support structure which does not negatively contribute to the overall instrument performance. In addition the M2 mirror subsystem is quite heavy in comparison to REM overall mass.

The big advantage of REM concept is the combination of the two functions, high stable mirror support structure and high precision linear adjustment capabilities. It allows for optimizations of the telescope focus not only on-ground during alignment tasks but also in-orbit by remote control.

On FCI-TA side it will be used to compensate for WFE due to bias effects originating from other subsystems.

On IRS side the REM is used to optimize the integrated energy (IE). This is done by fitting the measured integrated energy vs. REM position with a parabola and based on the results the optimal position of the REM is determined.

The capability to optimize the optical performance after launch is an important part of the guarantee of the mission performance. While several ideas such as adaptive optics are coming into the game, a one axis mechanism is the simplest and well working way to compensate for the biggest degradations such as moisture release, temperature difference between ground and flight or radiation, all of which result in a significant defocus effect, which can be well compensated with a one axis mechanism.

2. GENERAL DESIGN

The following paragraphs provide a brief overview of the main design drivers for the REM. They describe the most important elements and design solutions established to meet the stringent pointing accuracy and stability requirements and still providing stable support for the MTG FCI-TA and IRS M2 mirror subsystem.

2.1. Design Driving Requirements

The high accuracy requirements lead to the decision to use flexures for the linear guiding as well as for the reduction stage driven by an eccentric shaft. The advantages of using a flexure as a guiding are the absence of clearance in the drive chain, high structural stiffness at moderate mass and the ability to minimize cross-talk effects. The advantages of using a flexure as a reduction stage compared to a solution which directly drives the mirror are the attenuation of inaccuracies from the drive, the reduction of the loads on the drive. Using the eccentric shaft instead of a spindle drive concept allows for less complex and thus lower mass design due to higher reduction kinematics necessary in spindle drives for coverage of typically higher spindle random inaccuracies.

To satisfy the long term stability requirement internal stresses on the part were minimized in the main load path between spacecraft and mirror and to the drive unit resulting in a monolithic design of the REM main structure comprising the flexures of the linear guiding and of the reduction stage in a single part. Compared to a screwed assembly long term settling of the screwed connections and stacking of manufacturing and assembly tolerances are avoided with this type of design.

2.2. Main Elements

Due to the highly integrated design approach, only a small amount of subassembly and attachment parts is required in the REM assembly which consists of the monolithic main structure, a set of three flexures forming the interface to the instrument, the drive unit and a pretension unit using a compression spring to eliminate backlash in the eccentric drive and the gear.

The monolithic main structure comprises the linear guide and a kinematic reduction stage in a single part. The drive unit comprises an eccentric drive, a geared high detent torque stepper motor assembly, the end-stop and end-switch assembly, and a connector bracket for the electrical interface to the instrument harness, separated in nominal and redundant and power and signals connectors.

Provisions for attachment of optical alignment and positioning equipment as laser tracker targets and an alignment cube as well as dedicated interfaces for GSE lifting and alignment tools are also directly integrated in the main structure. The REM further allows attachment of a blanket with black outer layer surface for thermal performance and stray light reduction purposes.

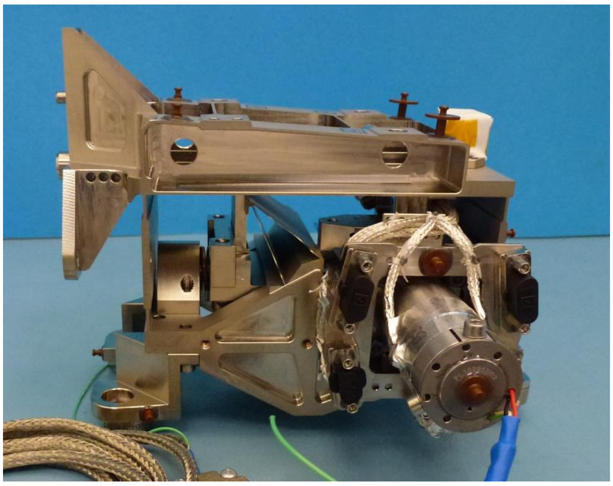

Figure 3. REM STM

2.3. Linear Guide

The linear drive concept of the REM is formed by a linear flexure guiding with a rigid top and bottom structure connected via quasi hinges at the front and rear combined with a reduction stage using flexure blades.

The most important accuracy requirements to be covered by the linear guiding design are the maximum allowed angular deviation of the mirror interface from the X-axis of +/-3 arcsec half cone and the maximum allowed lateral deviation from the X-axis of +/-3 µm.

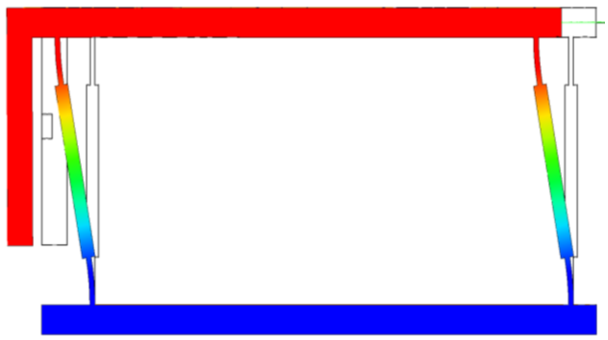

Figure 4. Schematics of the Linear Flexure Guiding

The sizing of the quasi-hinges is a compromise between the stresses caused by the pointing movement over the pointing range and the structural stiffness of the REM, satisfying the required 1st Eigenfrequency.

2.4. Kinematic Reduction Stage

Between the rigid top and bottom main structure elements of the parallelogram flexure guiding, a flexing kinematic geometry is incorporated in the monolithic main structure as shown in Fig.5, to reduce the rather large input motion from the eccentric drive to a small motion on the mirror interface by a decimal reduction lever. The eccentric drive is directly interfacing to a flexure blade input lever at the bottom of the reduction stage. The input motion is transmitted to a flexure output lever connected to the top part of the main structure via the vertical main lever of the reduction kinematics supported by a flexure.

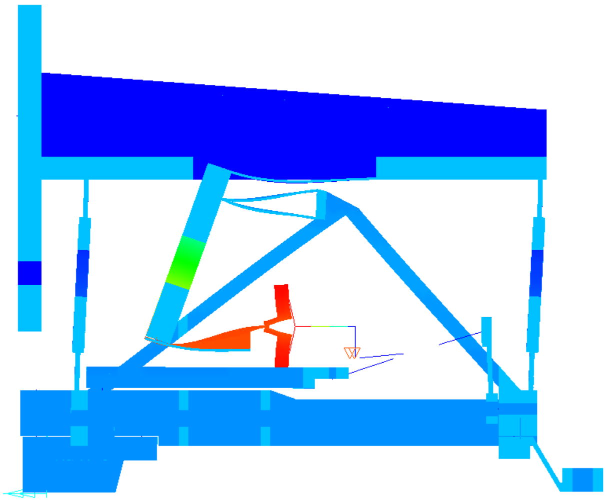

Figure 5. Schematics of the Kinematic Reduction Stage Principle via a Decimal Lever

The achieved reduction ratio is approximately 1:6. The combination of the reduction kinematics with the ratio of the drive unit planetary gear allows meeting the stringent step resolution and repeatability requirements. As a welcome side effect those parameters are further improved due to minimized contribution of the bearing random failure caused by the reduction stage. Moreover it is advantageous in terms of lowering the loads into the drive unit bearings.

2.5. Monolithic Part Design

The specified temperature environment but also the dissipated heat of the stepper motor during pointing operations affects the pointing accuracy and stability of the REM. It was therefore essential to use Invar 36 as structural material due to its very low CTE and, at the same time, sufficient mechanical strength.

In order to minimize ageing and strain relieve effects in the long term of the REM life, several heat treatment steps in the course of the machining process of the main structure were introduced. The initial annealing of the raw material before machining is followed by intermediate stress relief annealing steps during and after rough machining of the main structure by milling. After fine machining by milling and wire erosion of the final high accuracy contour a concluding heat treatment is performed.

The introduction of a REM pre-runner monolithic main structure (pathfinder) as shown in Fig.6 allowed improvement of the main structure design regarding the machining capabilities and optimization of the overall machining process including an optimized heat treatment sequence at an early stage of the project. The pathfinder also revealed essential difficulties in terms of manufacturing inaccuracies, e.g. out-of-tolerance at small wall thickness areas as lessons learnt for improvement of the handling and machining process of the main structures produced for the actual REM models.

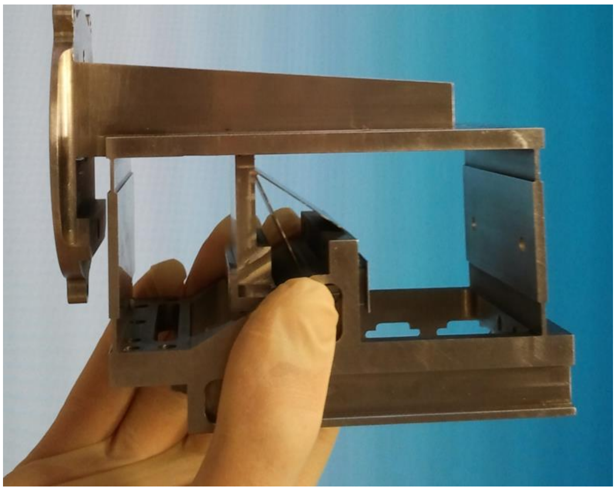

Figure 6. REM Pre-runner Monolithic Main Structure

A European patent is filed for this design.

2.6. Drive Unit

The REM drive unit assembly is designed as a self-standing element in order to allow pre-assembly of the whole unit including geared stepper motor, limit switches, temperature sensors, harness and connectors. Furthermore the fine adjustment of the end stop positions can be performed prior to the final installation in the dedicated main structure cavity and attachment to the linear drive interface.

The four limit switches (±X main & redundant) are fixed on two dedicated beams protruding from the top and side of the drive unit support bearing housing. The limit switches are actuated via an actuation lever directly mounted onto the eccentric shaft end.

The placement of the limit switches on the drive unit allows high accuracy switching, as the reduction by the eccentric drive and by the decimal lever is also attenuating the switch inaccuracy.

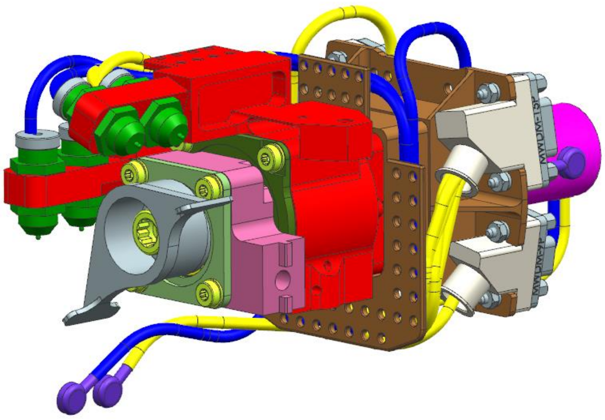

Figure 7. REM Drive Unit Overview

The interface towards the decimal lever of the monolithic structure is formed by a separate movable housing located on the cranked part of the drive unit eccenter shaft. This eccentric drive is well aligned with the centerline of the main structure in order to minimize contribution to cross-coupling effects. The angular range of the eccentric shaft between the two end stops of approximately ±45° results in a linear movement range of the eccentric drive of ±0,9 mm on the input side of the reduction kinematics. Both the drive unit as well as the eccentric housing are supported by pairs of pre-loaded angular contact ball bearings. The bearings are dry lubricated with sputtered lead by ESTL, UK to avoid contribution to molecular contamination.

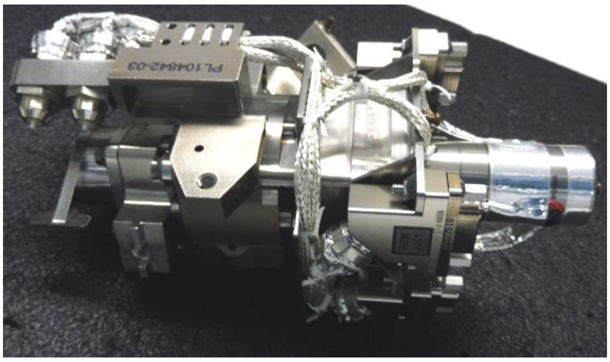

Figure 8. REM Qualification Model Drive Unit

The drive unit is actuated by a geared high detent torque stepper motor. One advantage of this type of actuator is the ability to design the REM without any launch lock due to the stepper motors high unpowered holding torque in combination with the high transmission ratio of the 3 stage planetary gear and the decimal lever of the monolithic structure. The selected motor has a clean detent torque feature, meaning stable high detent torque positions at any full step position and at any half step position.

This clean detent feature enables the motor to maintain its current step position also in unpowered condition and after repowering for further pointing operations allowing for reliable open loop control without any step loss. The transmission ratio of the 3 stage planetary gear also contributes to achieve the required minimum step resolution of the mirror in pointing direction on the output side of the reduction kinematics. The low mass and small dimensions of the geared stepper motor were also main selection drivers due to the stringent mass requirement for the REM and the very limited available space.

2.7. End Switches

For referencing purposes and for a safe and reliable limitation of the driving range acting as end switches, a set of two limit switches in cold redundant configuration is placed at each extreme position of the eccentric drive rotational range. The micro switches are modified commercial switches qualified for use in space mechanisms. The high switch point accuracy and repeatability enable the REM to be reliably referenced on-ground and in orbit. Other advantages of the micro switch are of course the low mass and small dimension of 8 mm external diameter combined with high versatility in terms of integration options due to its external thread over the whole length of its cylindrical housing.

3. TEST RESULTS

The qualification model of the REM was subjected to a full qualification test sequence. Pointing performance was verified at begin of test. Vibration testing, shock testing and TV cycling was performed, followed by a life test. The test sequence is concluded by a final pointing performance test. The testing was performed by Airbus Defence & Space GmbH, Friedrichshafen, using their 6 DOF high precision test facility. The test confirmed high step resolution over the whole pointing range. The step size is less than the specified 0.25 µm over the whole pointing range. The following graph presents the step size vs. the pointing range. The decrease of the step size towards the end of the travel range is caused by the kinematics of the eccentric drive system, having higher reduction at the ends of its travel-way. The black line indicates the predicted step resolution showing good correlation with the measured step resolution.

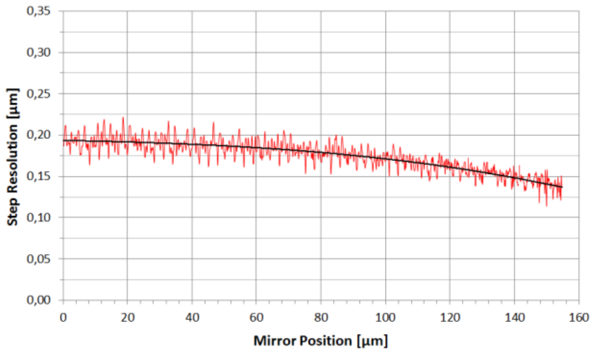

Figure 9. Step resolution recorded over pointing range

The performance tests confirmed pointing performance of the REM.

4. SUMMARY AND CONCLUSION

Combining the linear guide, the interfaces and the flexure stage into one single compact integrated monolithic main structure of Invar-36 results in a mechanism with high accuracy and repeatability, high thermal stability and low mass.

The following experiences were made during development:

- Using monolithic parts with integrated flexures can result in high stiffness, high accuracy and low mass mechanism assemblies.

- Manufacturing of such large thin walled parts of Invar 36 from one solid block requires several heat treatment steps during and after machining. It also needs a proper manufacturing sequence to attain the needed precision of the part.

- Sputtered Lead used as a bearing lubricant provides sufficient low friction since adequate motorization margin is available and long life for its application scenario. Sputtered Lead turned out as an attractive lubricant choice for such mechanism, although it demands attention to the respective design and handling rules.

- Performance testing to sub-micron resolution proved delicate as even small vibrations of the test facility can disturb the test readings.

5. REFERENCES

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