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ALIGNMENT CONCEPT FOR THE THREE MIRROR ANASTIGMAT TELESCOPE ASSEMBLY OF THE METEOSAT THIRD GENERATION FLEXIBLE COMBINED IMAGER

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I. INTRODUCTION:

This paper gives an overview over the alignment concept for the Telescope Assembly (TA) of the Meteosat Third Generation Flexible Combined Imager (MTG FCI).

The MTG Program is being realized through the well-established cooperation between EUMETSAT and ESA. It will ensure the future continuity with and enhancement of operational meteorological (and climate) data from geostationary orbit as currently provided by the Meteosat Second Generation (MSG) system.

The industrial prime contractor for the space segment is Thales Alenia Space (France) with a core team consortium including OHB-Bremen (Germany) and OHB-Munich (Germany). This contract includes the provision of six satellites, four Imaging satellites (MTG-I) and two sounding satellites (MTG-S), which will ensure a total operational life of the MTG system in excess of 20 years.

The paper is structured in the following manner; in chapter II the design and alignment requirements of the FCI-TA are described. With chapters III and IV follow details of the alignment concept and already performed bread-board tests.

II. OVERVIEW AND OBJECTIVES:

A. MTG FCI-TA design overview

The FCI-TA telescope optics (TO) is a Three-Mirror-Anastigmat (TMA) consisting of four light-weight Zerodur mirrors. An overview over the components of the FCI-TA is given in Fig. 1. The FCI-TA images the scenery seen by the scan mirror (SCA) onto the spectral separation and detection assembly in a spectral range of 400nm to 13.3µm and a field of view of 0.4° times 0.74°. The FCI can fulfill both the Full Disc High Spectral Imagery Mission (FDHSI) by scanning the full earth disc in 16 channels every 10 minutes with a resolution of 1-2 km and the High Resolution Fast Imagery Mission which will cover a quarter of the earth in 4 channels every 2.5 minutes with a resolution of 0.5-1 km. A one-axis refocusing mechanism (REM) translates the M2 mirror to compensate for gravity and moisture release in flight.

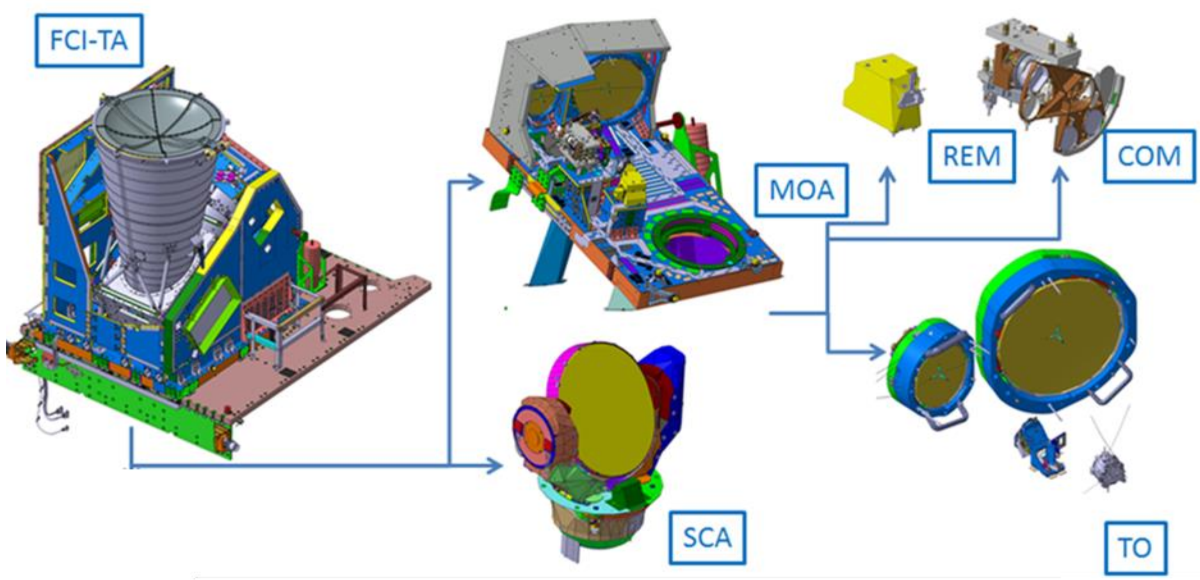

Fig. 1. Components of FCI-TA

The instrument is designed to withstand the regular solar intrusions during its operational phase to ensure a minimum of outages. It is envisaged to allow uninterrupted observation even when the instrument is subjected to solar intrusions inside its cavity. Hence, all parts of the FCI-TA are thermally regulated. To cope with thermo-elastic deformations (TED), the TO mirrors and Optical Bench Assembly (OBA) are mounted via isostatic mounts to the OBA and interface support structure respectively. The OBA is made out of CFRP to ensure a small coefficient of thermal expansion (CTE), but it is susceptible to deformations, e.g. introduced by gravity during alignment on-ground. These need to be compensated for during alignment.

The TMA telescope has an 1.4° off-axis angle in the nominal configuration. The telescope is purely reflective to be compatible with a multi-channel instrument. It is composed of a folding mirror and 3 aspheric mirrors, as illustrated in Fig.2. The imaging telescope comprises:

- A concave mirror M1
- A convex mirror M2
- A concave mirror M3

The fourth mirror M4 is flat and used as a folding mirror to image the light onto the detectors.

The focal length of the FCI-TA amounts to 1650 mm and the f number is 5.5. The telescope includes an intermediate focal plane between M2 and M3, where a physical field-stop is placed. The exit pupil is located closely before the M4 mirror, while the entrance pupil is situated close to M0. The chief ray is tilted by 90° with respect to the OBA. The telescope exhibits design wavefront errors from 20 nm for the visible channels up to 30 nm for the infrared channels.

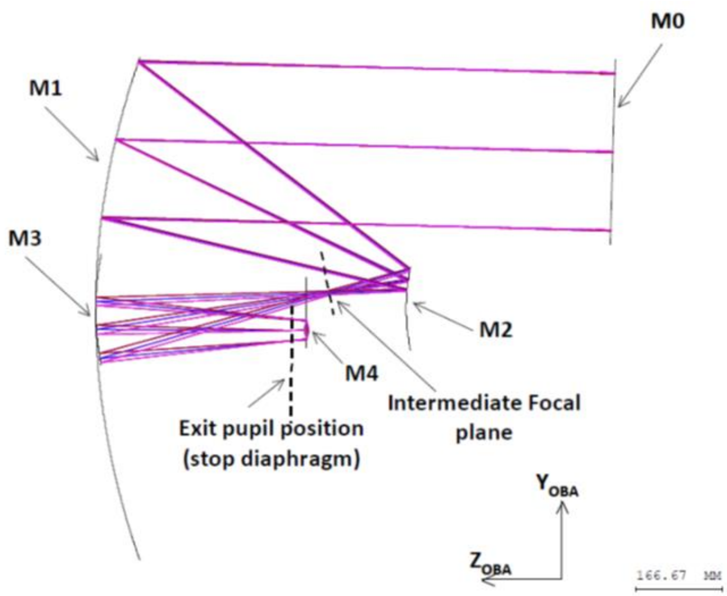

Fig.2. FCI-TA optical layout

B. Alignment requirements

The FCI-Ta alignment concept was developed to cope with a highly sensitive FCI-TA and challenging performance requirements. The rms WFE, including manufacturing and alignment, needs to be below 57nm. The geometric focus position within the OBA coordinate system is specified with an accuracy of ±30µm in-plane and ±200µm out-of plane. In addition, the chief ray angle between M4 and focal plane needs to be achieved with an accuracy of ±0.1 degree.

III. ALIGNMENT CONCEPT:

The alignment concept of the FCI-TA is based on a combination of position and angular measurements with laser tracker (LT), theodolites and Shack-Hartmann sensor (SHS) measurements. The movement of each mirror will be performed by highly accurate six axis stages (hexapods).

A. Mirror placement

In a first step, each mirror will be mounted to an hexapod via dedicated interfaces and adapter plates. The mirrors will be placed at their nominal position by moving them with the hexapod and measuring their position and orientation with laser tracker (LT). The nominal position is calculated with Zemax, based on the nominal optical design and the actual measured WFE of each single mirror. To allow for LT measurements, each mirror is equipped with three conical holes for reproducible placement of Laser tracker targets (LTTs). These mechanical references will be characterized by the mirror supplier against the optical axis of the mirrors. The OBA serves as reference for mirror placement. Therefore, the OBA will be equipped with seven LTTs and five mirror cubes. The position of alignment cubes and LT targets will be pre-characterized against the OBA coordinates system with a coordinate measurement machine (CMM). The setup for placement of M2 and M3 mirrors is shown in Fig.3 as an example. The M2 will be installed onto the REM before start of the alignment activity. The hexapod is then directly attached to the REM.

Placement accuracies of about ±140µm can be achieved, limited by characterization accuracy of optical axis of the mirrors and the LT accuracy of about ±25µm.

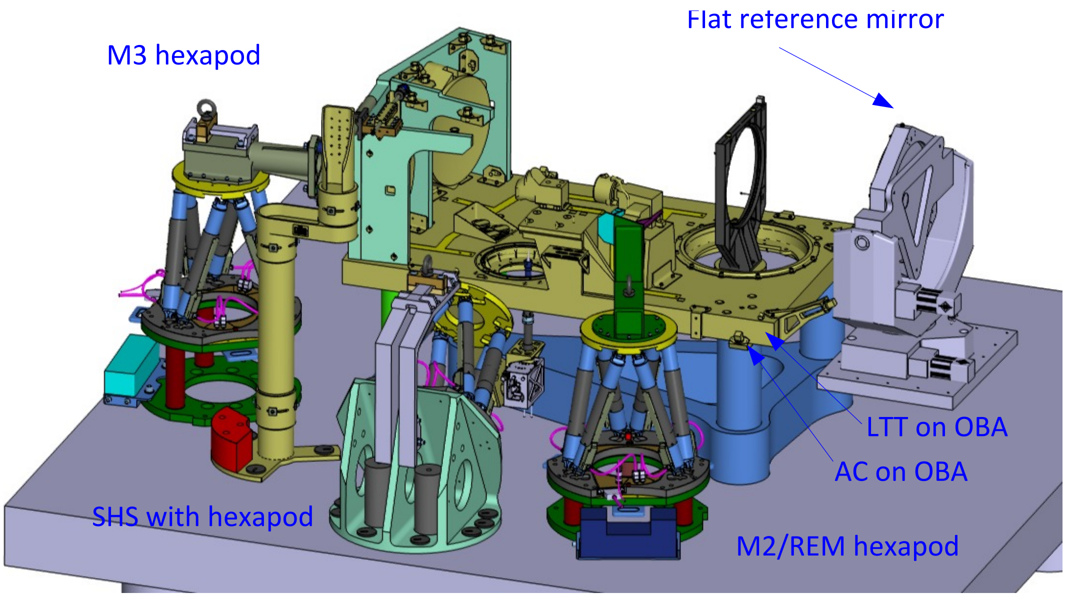

Fig. 3. Setup for alignment of M2 and M3

B. Mirror fine-alignment with SHS

For M2, M3 and M4 fine-alignment steps will be performed, whereas M1 will be attached to the structure without further alignment. During fine-alignment, the WFE is measured with a SHS and minimized by moving the mirrors with the hexapods. The SHS is equipped with an internal light-source and a beam splitter, allowing for WFE measurements in double-pass. To this end a flat reference mirror is mounted close the entrance pupil of the FCI-TA (see Fig. 3).

Fine-alignment is first performed by moving M3 in tip and tilt and M2 in all degrees of freedom. After attachment of M1 and M3, the position of M2 is re-optimized in another fine-alignment step in order to compensate for movements of M1 and M3 during attachment.

A dedicated software tool, which was developed by OHB, will be used to predict the required movements of M2 and M3 to minimize the WFE deterministically. It relies on mirror sensitivity matrices.

As last step, fine-alignment of M4 is performed by measuring tilt and defocus WFE and adjusting the M4 position with the hexapod accordingly. M4 is a flat mirror, which will be used to place the focus of the FCI-TA at the required geometrical position. Since not only the focus position is specified but also the chief ray angle (see chapter II.B), M4 can be only used in a certain range for focus position correction. Therefore, already during M2 and M3 fine-alignment, the focus position and chief ray need to meet certain success criteria.

After attachment of all mirrors (see chapter III.C), field stop and aperture mask will be aligned.

C. Mirror attachment

After each mirror was placed and fine-aligned with the required accuracy, it will be attached with shims to the OBA.

For attachment of M1 and M3 wedged shims will be used to limit interface deformations, which introduce local deformations of the mirror surfaces. Large alignment angles and limited manufacturing tolerances of the OBA necessitate the use of wedged shims. Two different sets of wedged shims will be employed per mirror. A first set is calculated from characterization data of OBA and mirror interface flatness and serves to only compensate the manufacturing tolerance of OBA interface and respective mirror. These shims will be pinned to the OBA interfaces before the start of alignment. A second set of wedged shims is used for final attachment of the mirrors and takes into account manufacturing tolerances of interfaces as well as final position of mirrors. These shims replace the first set of shims. Their dimensions will be determined with laser tracker and theodolite measurements by measuring the position and orientation of the respective mirror once directly after placement

(M1) or fine-alignment (M3) and once when the mirror is attached with the first set of wedged shims to the interface. The dimensions of the shims are calculated from the various measurement data with the help of the interface generation software. This software tool was developed by OHB for the EnMAP program (see [1]) and adapted for MTG FCI-TA alignment. Its strength lies in processing measurement data from different metrology tools (LT, Theodolite, CMM) and performing coordinate transformations to deduce shim dimensions.

For attachment of M2 and M4 parallel shims will be used on top of the wedged shims. Parallel shims can be manufactured with very high accuracy of 2µm. This is mandatory for M2, because the mirror needs to be attached with an overall tolerance of below ±10µm and ±10 arcsec. Furthermore, parallel shims can be produced quicker than wedged shims.

The same concept as for M1 and M3 will be applied for determining wedged shim dimensions for M2 and M4. Whereas dimensions of parallel shims will be calculated from WFE measurements. To this end the same software as for fine-alignment will be used.

Both types of shims (wedged and parallel ones) can be produced by OHB. Dedicated lapping jigs were developed, which allow to lap wedged shims with accuracy of ±10µm in thickness and ±5arcsec in angle. Parallel shims can be produced with an accuracy of ±2µm. The angular accuracy of wedged shims will be verified with an auto-collimator.

A challenging step is the transfer of the mirror from the hexapod to the OBA without major movements of the mirror. Screws are inserted and torqued, while the mirror is still attached to the hexapod. The hexapod is used to stabilize the mirror at the OBA interface during torqueing. The entire attachment process, starting from the theodolites and laser tracker measurements for the determination of the dimensions of wedged shims, up to torqueing of the mirror was realized with a bread-board (see chapter IV).

D. Theoretical verification of alignment concept

Suitability of alignment concept was verified with a ZEMAX Monte-Carlo simulation. The achievable performance was calculated taking into account the above described alignment concept and accuracy budgets, which were established for each alignment step.

E. Gravity compensation

Gravity on earth leads to deformations of the OBA during alignment and testing of the FCI-TA. These deformations won’t be present in orbit. Therefore, the WFE in orbit will deviate from the one measured on ground by around 50nn for the VNIR channels at the central field point as shown by analysis. A strategy was developed in order to actively compensate the deformations due to gravity during FCI-TA alignment and thereby reduce the expected difference of WFE between on-ground and in-orbit to around 20nm. The magnitude of the deformations will vary during the alignment procedure, because the weights of the mirrors are added step by step to the OBA. During the alignment, the OBA will be supported by two push-bars. The push-bars are piezo-actuator, which apply forces to the OBA from below. The push-bars will be mounted to the optical table. This is possible, because the OBA will be removed from the FCI-TA interface support panel and mounted via MGSE bipods to the optical table. In addition to the push-bars, confocal and inductive sensors are employed to monitor the deformation of the OBA. The sensor read-out is then taken into account for the amount of actuation of the push-bars. The setup with push-bars and sensors in shown in Fig. 4.

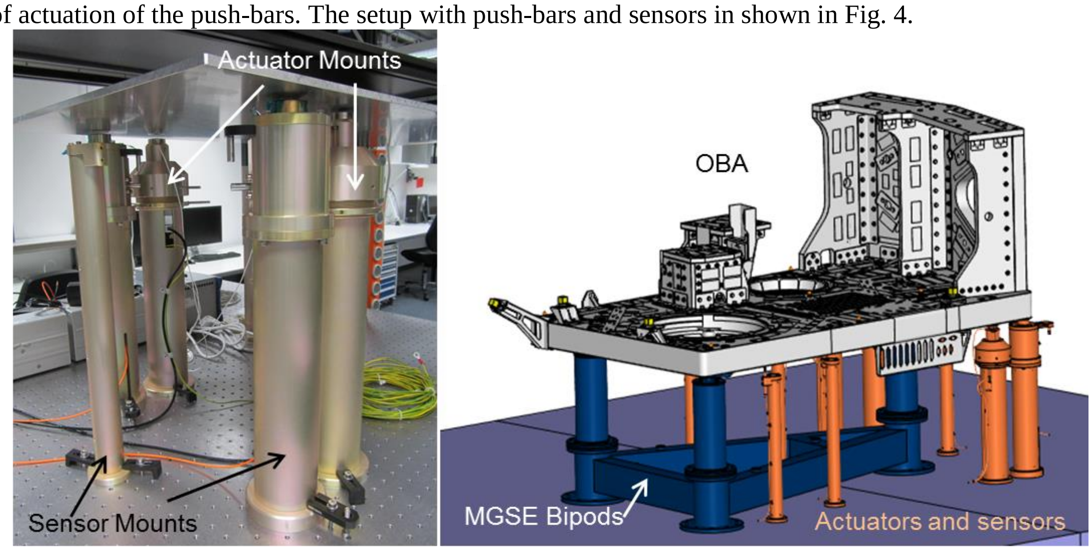

Fig. 4. Picture and sketch of push-bar setup with actuators and sensors

IV. BREAD-BOARD TESTS:

For verification and practice purposes a series of test-setups and dedicated bread boards were planned throughout the MTG project phase. All critical aspects of the alignment concept are addressed within the scope of the following 3 breadboards and mounting practices:

1) The placement described in section III A is covered in a Risk Mitigation Bread Board (RMBB) that comprises of a mirror dummy and model structure with the relevant isostatic mounts as well as alignment features (LTTs and ACs, refer to Fig. 5). Results and findings of this bread board are discussed below.

2) The placement of the REM will be practiced using STM hardware and specific GSE for accurate monitoring of the position. This mounting practice will also cover the highly sensitive mounting of the REM to the OBA, needed for the fine alignment (section III B).

3) The optical alignment including the verification of the fine alignment software will be practiced on a breadboard including mirrors with optical quality.

Activities 2) and 3) are planned for beginning of 2017.

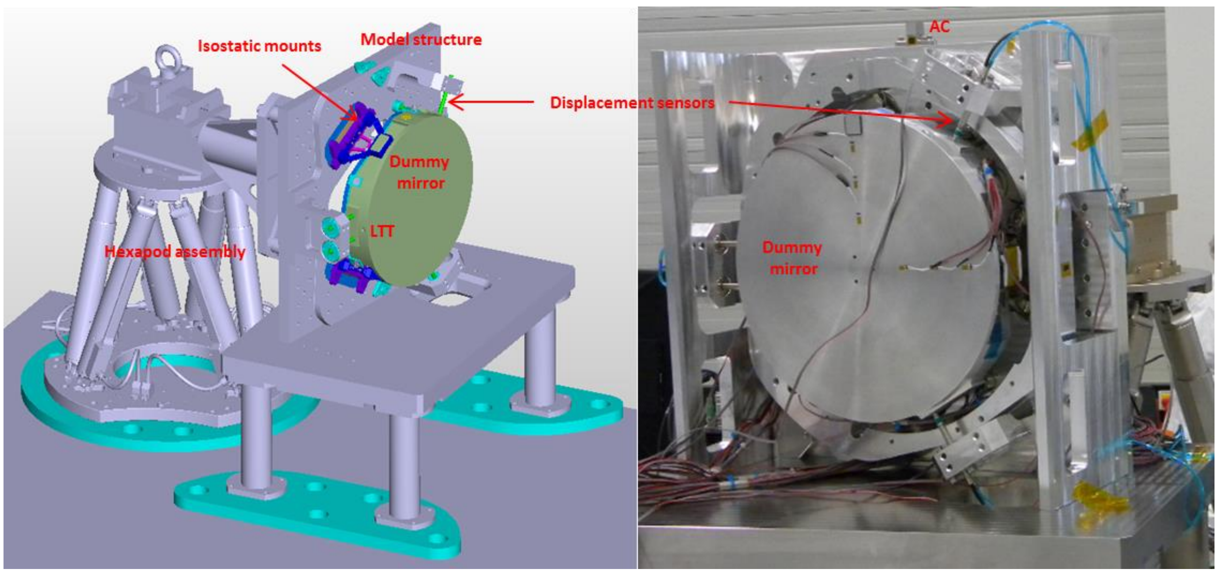

Fig. 5. Sketch and photograph of the RMBB.

The RMBB was primarily designed to verify the placement comprising of the shimming concept and as well as the accurate attachment of the dummy mirror to the structure. To this end the coordinate measurements of the structure- and bipod-interfaces were processed by the interface generation software for the calculation of the parameters for the first primary shim. This shim provides a strain-free reference position of the mirror mounted to the structure, which is characterized by LT and Theodolite measurements. Laser trackers are used for the position measurements, whilst Theodolites can increase the accuracy of the angles. Both measurements agreed in terms of angle within the respective measurement accuracies. From this reference position the mirror was then brought by the hexapod to an arbitrarily defined as-aligned position, which was equally characterized by LT and Theodolites. The second primary shim was then calculated based on those two sets of measurements. Based on the calculated shim parameters, the shims were fabricated to accuracies of 5 arcsec in angle and 1 µm in thickness. Using those shims, the dummy mirror could then be attached to the structure within an overall translational accuracy of better than ±31 µm along and ±22 µm lateral to the optical axis. The angular accuracy amounted to ±23 arcsec. Different effects contribute to attachment tolerances. For movement in the plane perpendicular to the interface, main contributors are static interface deformations and mounting repeatability due to handling and torqueing. It could be shown, that the transfer of the dummy mirror from the hexapod to the interface mounting and subsequent torqueing can be done with a repeatability of better than ±10µm. These accuracies are in-line with the budgets.

V. CONCLUSION:

The alignment concept is still in the validation phase. However, important results such as the production of shims to the highly challenging angle-requirements as well as accurate placement of the mirror have been achieved within the scope of the RMBB program. Further bread-board activities (see chapter IV) are planned for 2017.

VI. ACKNOWLEDGEMENT:

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REFERENCES

[1] J. Kolmeder et al, "Optical Integration Process for the Earth-observing Satellite Mission EnMap", unpublished.