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Light-weighting, polishing and bonding for the SEOSAT/Ingenio telescope mirrors

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Light-weighting, Polishing and Bonding for the SEOSAT/Ingenio Telescope Mirrors

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Abstract— Sagem presents its recent developments in light-weighting, polishing, bonding and testing of Zerodur space mirrors equipped with pads and fixation devices. The presentation is based on Sagem's recent successful project for the SEOSAT/Ingenio satellite.

Index Terms— Zerodur, Lightweighting, polishing, testing, telescope, Ion Beam Figuring

I. INTRODUCTION

Ingenio/SEOSAT is a Spanish consortium project in the framework of an ESA contract, led by EADS-CASA, together with INTA, THALES ALENIA Space-E and SENER specifically responsible of the primary payload. Ingenio/SEOSAT, named for the Spanish Earth Observation Satellite, is a multi-spectral high-resolution optical satellite for Earth Remote Sensing that provides imagery to different Spanish civil, institutional and governmental users in the frame of GMES and GEOSS [1]. Sagem-Reosc has been awarded a contract by SENER to manufacture and test the component mirrors of the Ingenio/SEOSAT twin telescopes. The project involved manufacturing challenges to meet surface quality, light-weighting and vibration load requirements (lightweighting up to 72% with random acceleration up to 88.1g). Sagem applied enhanced manufacturing technologies for the implementation of the mirror assemblies.

Ingenio/SEOSAT is a Low Earth Orbiting mission, featuring a Primary Payload (PP) with one 2.5 meter resolution panchromatic channel and four 10 meter resolution visible/near infrared spectral channels.

The PP swath close to 55 km ensures a frequent revisit period, and offers quick accessibility to any point on Earth in emergency situations [1]. Figure 1 provides a 3D view of the Ingenio/SEOSAT satellite. It is composed of two twin Korsch telescopes; each one composed of three on-axis aspherical mirrors and a flat folding mirror that direct the image to the focal plane (FP).



Fig. 1. 3D view of SEOSAT satellite [1]

Figure 2 illustrates the optical set-up and ray-tracing of the Ingenio/SEOSAT Korsch Telescope, which has the advantage to provide a flat image on the focal plane with very low stray light.

M1 is the primary concave asphere mirror. M2 is the secondary asphere and convex mirror. M1 & M2 is a stigmatic telescope at the centre of field. M3 is the tertiary and concave mirror, a field corrector. MF is the folding mirror.

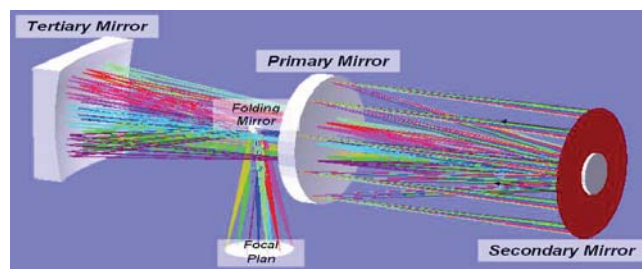


Fig. 2. Ingenio/SEOSAT Telescope Set-Up and Optical ray-tracing [1]

The system is designed with four all-reflective mirrors, enabling a spanning from blue to near infrared without chromatic aberration.

One constraint of a Korsch telescope is the limited field angle. The SEOSAT required a field angle of $\pm 5^\circ$ whereas one of the SEOSAT telescope could only cover a field angle close to $\pm 3^\circ$. It has been decided to split the coverage onto two identical telescopes [1].

Sagem is in charge of manufacturing for these twin telescopes the optical mirrors equipped with Mechanical devices, as illustrated by Figure 3.

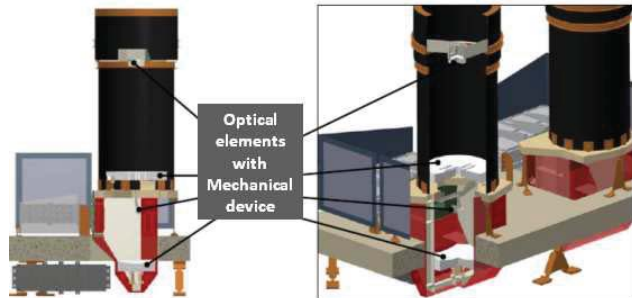


Fig. 3. Zoom on the optical elements with mechanical devices of SEOSAT

In space telescopes, the mirror assemblies are subjected to extreme vibration and thermal conditions, imposing challenging opto-mechanical design and manufacturing requirements.

In order to fulfil these requirements, once the opto-mechanical design is completed and accepted by customers, Sagem defines and applies adequate manufacturing flowchart to deliver to the customer within some months compliant and qualified space equipped mirror.

The flowchart of each mirror is sequenced as follows: the Zerodur substrates are lightweighted. The Zerodur substrates are then grinded and polished. The polished mirrors are then bonded to their pads and Mirror Fixation Devices (MFDs) on the mirror interfaces. Once the mirrors are bonded, a final polishing step is necessary to remove the bonding effects. Then, the equipped mirrors, polished to the specification, are coated and grounding straps are bonded on some specific areas of the coated surface. Finally, each mirror is qualified through dynamic and thermal testing, together with recurrent geometrical and interferometric tests all along the manufacturing process.

Figure 4 illustrates the chosen manufacturing flow chart. In the next paragraphs all these steps will be detailed.

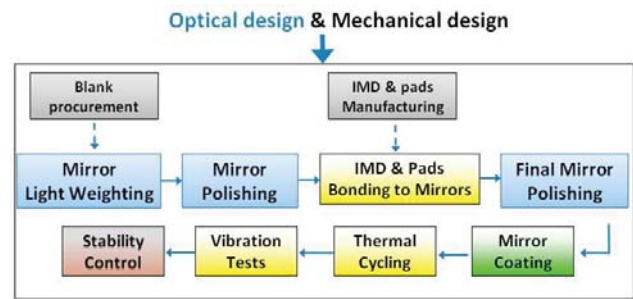


Fig. 4. SEOSAT Manufacturing Flow Chart

II. DESIGN AND MANUFACTURING STEPS

A. SEOSAT Optical design analysis

The optical design of the SEOSAT telescope is straight forward since it is defined as a Korsch telescope. The Primary, the Secondary and the Tertiary mirrors are aspherical mirrors and the Folding mirror is a flat mirror.

However, except for the optical design itself, one important design work is to define individual wavefront error specification for each of the four mirrors to finally verify that the wavefront error specification of the full telescope over the field angle of 35nm RMS is fully met.

The tolerancing of the system plays an important role. Sagem work is to tolerance the system to find the best compromise taking into account the manufacturing difficulties of each particular mirror. To do that, Sagem has separated the High frequency and the Low Frequency contributors and has built a budget for each mirror to remain compliant at the scale of the telescope and being coherent with the manufacturing flow chart.

Table 1 summarizes the final specifications for each mirror that have been agreed with customers.

TABLE 1: HF and LF budget

Mirrors	Specification Proposal for Surface Error	Final Agreed Specification For Surface Error
Primary	11,5nm RMS	12nm RMS LF / 8nm RMS HF 14,4nm RMS
Secondary	7,5nm RMS	10,4nm RMS LF / 8nm RMS HF 13,1nm RMS
Tertiary	15nm RMS	17,3nm RMS LF / 8nm RMS HF 19,1nm RMS
Folding	5nm RMS	5,4nm RMS LF / 5nm RMS HF 7,3nm RMS
Global WFE	35nm RMS WFE	35nm RMS WFE

Sagem capabilities proved that better Surface Errors can be achieved; however the aim for the SEOSAT mirror manufacturing was to perform a trade-off between Sagem best capacities and Sagem best delivery time. Thus, the choices for the mirror specification distribution have to be coherent also with the manufacturing time allowed.

B. Lightweighting

Individual Zerodur mirror lightweight structure design consists in balancing mirror substrate stiffness under its own weight and 0g sag release, strength under launch conditions, optical surface quilting under polishing pressure, and milling operation complexity.

A 72% lightweighting was achieved for the primary M1 and tertiary M3 mirrors. Figure 5 illustrates the lightweighting of the back side of the primary mirror.

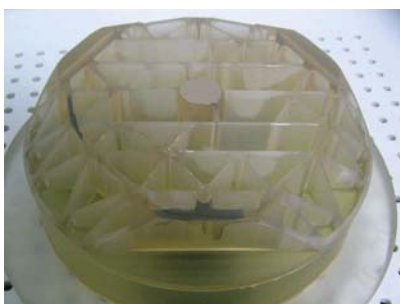


Fig. 5. Primary mirror back light-weighted surface

The second step of the ‘Light-weighting process’ is applied on the Primary mirror and has been named by Sagem ‘slots opening’. Indeed, for the light to go from the Secondary to the Tertiary mirror, holes must be done on the optical surface of the Primary mirror. The openings consist in four slots as illustrated in Figure 6.

The ‘slot opening process’ is realised once the Primary mirror is polished up to the specification. Indeed, it is always preferable to polish an optical surface without holes to prevent from any edge effect or fragility of edges. The process used by Sagem to perform these slots after the mirror is polished prevents from edge or quilting effect on the substrate optical surface. Figure 6 illustrates the slots opening realised on the first flight model of the primary mirror M1.

Note that the central hole that is visible in Figure 6 has been manufactured only for alignment reason and not for the Telescope purpose.

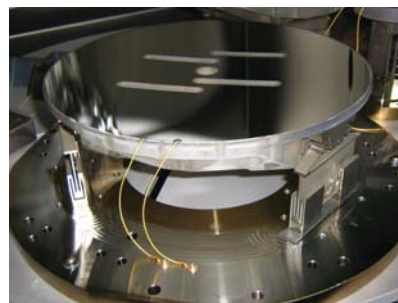


Fig. 6. Slots opening for the SEOSAT Primary Payload Primary mirror

C. Polishing

All mirrors, except for the folding flat mirror MF, are polished to be aspherical with an edge margin of 4mm only between the mechanical and useful optical areas. Thanks to our latest progresses in precision optics polishing technology, no edge effects are occurring.

Traditional polishing, Robot and Ion Beam figuring techniques are used to achieve surface quality in the range of 3-14nm RMS for diameter up to 325mm. Table 2 summarizes the obtained Surface Errors compared to the agreed surface errors specification.

TABLE 2: Surface error budget compared to results

Mirrors	Final Agreed Specification For Surface Error	Surface Error measured on mirror
Primary	14.4nm RMS	14nm RMS
Secondary	13.1nm RMS	8nm RMS
Tertiary	19.1nm RMS	7nm RMS
Folding	7.3nm RMS	3nm RMS

Figure 7 gives the Surface Error Maps of the first model of the SEOSAT telescope.

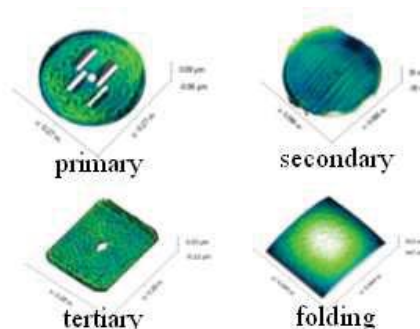


Fig. 7. Surface Error Map of the first model of the SEOSAT mirrors

The level of surface quality is in line with the constructed error budget of the full telescope transmission level.

Indeed, Sagem verified with simulation that the full telescope budget of 35nm RMS is well met all over the field. This has been simulated for the first telescope taking account the four measured surface errors of the Primary, Secondary, Tertiary and Folding mirrors.

Figure 8 illustrates the results all over the field. It confirms Sagem tolerancing skills and assumptions.

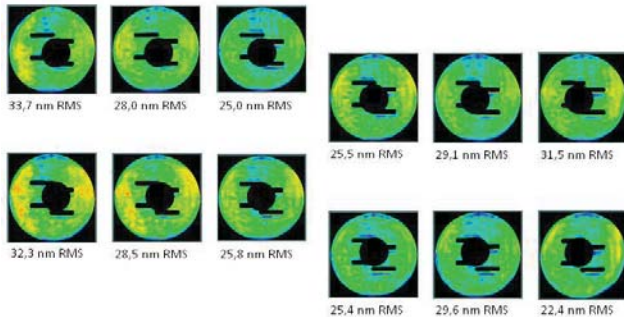


Fig. 8. Simulated transmitted wavefront of the first model of the SEOSAT telescope

D. MFD bonding

During the mechanical design, the Pad and Mirror Fixation Devices (MFD) were optimized for each mirror taking into account the weight, the mirror geometry, the mechanical specification and the Zerodur material specificity. They were designed to withstand tight mechanical requirements (first eigenfrequency higher than 250Hz, 20°C ±10° operational temperature, up to 75g quasi-static load level, 88g random acceleration).

The high request on random acceleration led Sagem to design and manufacture MFDs in combination with Pads in Titanium and Super Invar with very high precision and stress tolerance. Figure 9 gives an illustration of the SEOSAT MFD choice.

During the mechanical design, it is also taken into account the strict request of interface between Sagem and the customer instruments. Indeed, the SEOSAT mirrors have to be implemented in the telescope structure without interface re-adjustment which led to very strict mechanical manufacturing tolerances.

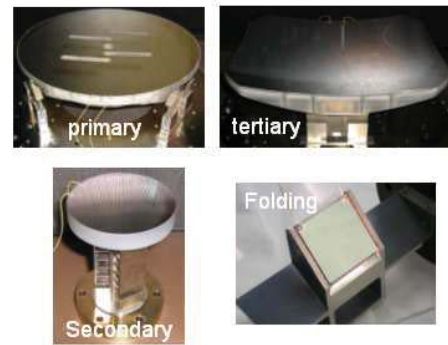


Fig. 9 SEOSAT mirror illustrations of MFDs

E. Reflective coating

An enhanced silver coating was deposited ensuring highest reflectivity over the 0.45 – 2.5µm spectral domain. The silver coating specific deposition also enables the bonding of grounding straps on each of the SEOSAT mirrors, so that resistivity and conductivity requirements are fully addressed. Figure 10 gives a picture of the grounding strap on the Primary mirror.

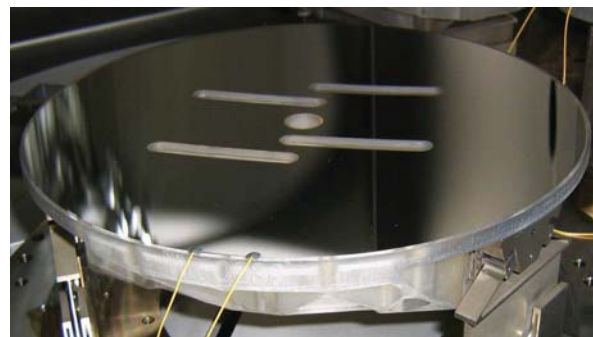


Fig. 10 Grounding straps on the Primary mirror

F. Environmental tests

Once the mirrors are polished, bonded and coated with grounding straps, the equipped mirrors are thermally and mechanically tested to verify that before and after tests the mirrors are fully stable mechanically at ±3µm and interferometrically at ±2nm RMS.

The mechanical tests are performed on shakers for all axes to verify all their mechanical properties. First eigenfrequencies are typically found around 400Hz, with a discrepancy lower than 10% with respect to the design value and stability lower than 4%. Strength was checked up to a level of 30g specified value in sinus and random vibration. Figure 11 illustrates one of the SEOSAT mirror on a shaker.

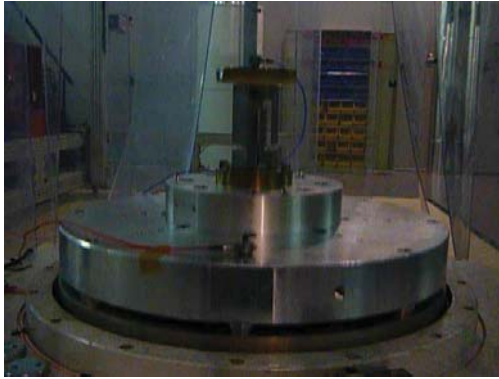


Fig. 11 Secondary mirror tested on a shaker

The thermal tests are performed in a thermal chamber. The equipped mirrors go through 10 thermal cycles between -25°C to $+60^{\circ}\text{C}$.

After each test, the mechanical stability at $\pm 3\mu\text{m}$ and the stability of the WFE at $\pm 2\text{nm}$ RMS are verified.

G. Primary & Secondary Sub-assembly testing

Finally, once all equipped mirrors are completed and qualified prior to customer delivery, Sagem performs an optical interferometric test of the sub-assembly composed of the Primary and the Secondary mirrors to evaluate the sub-assembly optical performance specified at 24nm RMS in transmission. The entire set-up is installed in clean room in order to preserve the cleanliness level of the freshly coated mirrors and their MFD's. The first Primary and secondary mirror optical test proved that the 24nm RMS was achieved.

III. CONCLUSION

Following this specific flow chart, Sagem could complete the delivery to SENER of the first telescope mirrors in February 2012. The second twin telescope mirror assemblies are currently under manufacturing in Sagem premises. The delivery is expected in September 2012.

The successful implementation of the first twin mirror assemblies enabled Sagem to consolidate its experience and choices for space mirror application. Indeed, Sagem has enhanced its strong experience and capacity in the domain of light-weighted, aspheric optic assemblies to pass loads up to 88g .

ACKNOWLEDGMENT

I would like to thank personally all Sagem SEOSAT team for the great work that has been done so far.

I also would like to thank the SENER SEOSAT team for their collaboration and their reactivity, as well as the INTA, EADS Spain and ESA for their support. We hope Sagem has contributed to the successful launch in 2015 of the first Spanish Earth Observatory Satellite.

REFERENCES

- [1] C.Miravet, "Development status of the telescope for the Ingenio/SEOSAT mission primary payload", SENER presentation, SPIE (2011)