MSG SCAN DRIVE UNIT – FM5 LESSONS LEARNT

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ABSTRACT

The Scan Drive Unit (SDU) is a linear actuator developed as a subassembly of the SEVIRI (Spinning Enhanced Visible and Infrared Imager) for Meteosat second generation program.
The qualification of the mechanism was performed end of 1999 with a delivery of 3 flight models. In 2004, a 4th flight model (FM4) initially ordered as a spare model, has been acceptance tested and provided for the MSG-4 mission. Despite the successful completion of acceptance tests at unit level and performance tests at instrument level, an anomaly occurred at satellite level after acoustic environment survey.
In 2008, the decision was taken to manufacture a new flight model (FM5). For stock, cost and planning reasons, the agreed baseline was to re-use to the maximum extend, after proper refurbishment, the key mechanical parts/components from the Engineering model (EM), like housing, stepper motor, roller screw and ball bearings. Only in case of available attrition (e.g. potentiometer, bellows), or in case of non-hirel parts (internal harness) or less complex parts, replacement by new parts has been considered.

This article aims to present :
- the way Thales Alenia Space Cannes has proceeded to prevent any risks during the assembly process, to guaranty the goodness of the old sub-assembly parts from EM or from attrition and to ensure the correct manufacturing of the new elements,
- the difficulties encountered during integration and testing,
- the lessons learnt linked to the re-manufacturing of a complex mechanism after a long period of inactivity (manufacturing stand by).

1. SCAN DRIVE UNIT TECHNICAL DESCRIPTION

1.1. MSG MISSION

The SDU is part of the MSG SEVIRI Imager that combines the East-West scan generated by the Satellite spin motion (at 100rpm) and the South-North scan motion of the mirror to generate a full-disc Earth image approximately every 15 minutes. The SDU is hermetically sealed and contains a linear actuator that moves the SCAN mirror through the Kinematic Link I/F (KL I/F) over a motion range of 1527 lines (1 line corresponds to a linear displacement of 40µm at SDU level). See the location of the SDU Figure 1. The initial SDU contract was set up to procure five models within the period of only 2 years:

- Engineering Model (EM)
- Qualification Model (QM)
- 3 Flight Models (FM1, FM2 & FM3) and **1 spare** (used as **FM4**).

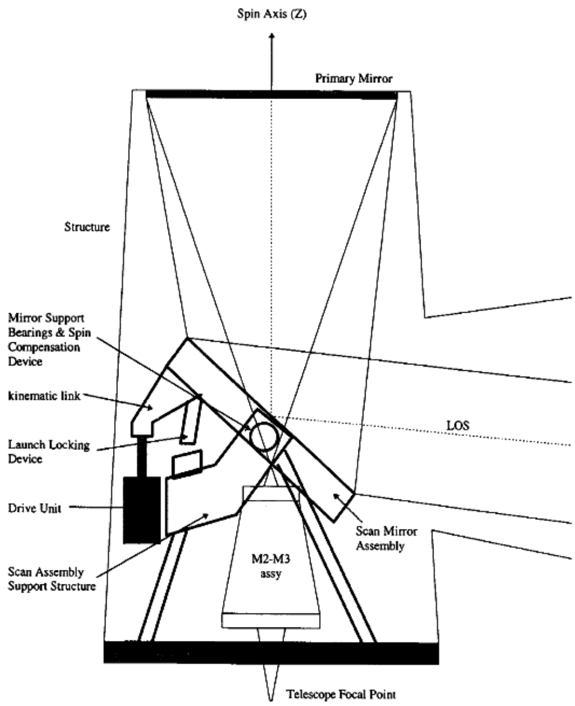

FIGURE 1: DRIVE UNIT LOCATION

'14th European Space Mechanisms & Tribology Symposium – ESMATS 2011'
Constance, Germany, 28–30 September 2011

1.2. CONCEPT DESCRIPTION

The main constraint on the mechanical lay out of the Scan Drive Unit is to minimise the length between the kinematics interface and the spindle nut in order to reduce the bending moment induced by the 4g in-orbit centrifugal loads. This bending moment directly dimensions the spindle internal preload which is linked to the main performances of the SDU.

The Direct Drive Concept associated to the drive functions is mainly composed of:

- a housing
- a roller screw device
- a stepper motor
- a ball bearing assembly

The association of the motor with the spindle described here-below leads to perform 12 motor steps per line which corresponds to 0.04 mm linear displacement.

- The scan read out function is performed by means of a redundant potentiometer.
- The temperature monitoring of the motor is achieved by thermistors mounted on the SDU housing close to the motor.
- The zero reference position and the end range status are given by means of redundant electrical switches.
- Two mechanical stops limit the travel range and prevent collision .
- An off loading device reduces the loads applied to the spindle during vibrations.
- A wet lubrication technology allows to reach the lifetime performance
- The hermiticity wrt the wet lubrication is based on:
  - the SDU housing
  - metallic sealing rings
  - two metallic bellows
  - a hermetically sealed connector

A guiding device limits the radial displacement of the kinematic link interface under in orbit loads.

The internal volume of the SDU is kept constant over the complete scan cycle in order to avoid any risk of over pressure inside the SDU. This is achieved , thanks to the use of two bellows (one on each side of the housing).

The design of this mechanism allows for a quick and relatively easy and straight forward dismantling of the unit in case necessary, e.g. in case of an anomaly detection.

2. SCAN DRIVE UNIT MAIN PERFORMANCES

- The SDU operates in 2 modes:
  - **Scan Mode:** Consists in performing successive lines of 12 motor steps followed by a waiting time to permit the imaging.

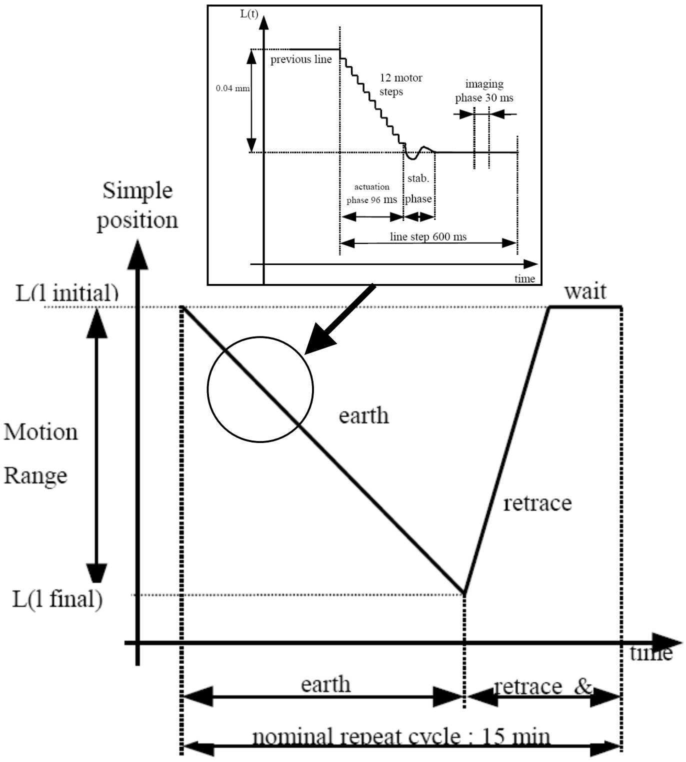

FIGURE 2: OPERATION CYCLE

  - **Retrace Mode:** consists in performing full actuations of the motor without any waiting time.
- **Range definition /stops location:** the SDU is equipped with electrical and mechanical end stops to prevent collision of the scan mirror with the structure.
- The SDU provide its **motor temperature monitoring**.
- The SDU provides the line **increment monitoring** with an accuracy better than 1/3 line.
- **Outgassing**: the limit for material out gassing is:

  TML < 1%

  CVCM < 0,1%

  The leak rate of hermetically sealed DU housing is less than 2.10^{-9} bar.$cm^{3}.s^{-1}$.
- **Lifetime:**

The SDU is designed to withstand the following lifetime:

  - 12 years on ground storage
  - 7 years in orbit with repeated cycle, SDU submitted to **4g radial acceleration.**

3. SCAN DRIVE UNIT : DEVELOPMENT

3.1. QUALIFICATION

- **Mass**

Measured mass = 4.5Kg.

- **Motorization margin**

The minimum voltage to perform one motor step is 2.2V which corresponds to a static starting resistive torque of 0.1 Nm, to be compared to a motorization torque given by the stepper motor with a constant torque of 3.2 Nm/A and a resistance winding of 29.3 Ω.

- **Power consumption**

The power consumption measured during retrace mode is 8.8 W, the driven parameters characterising the retrace mode are: 24.5 V and 125 Hz command.

- **Tightness**

Lower than 2.10^{-9} $bar.cm^{3.}s^{-1}$.

- **Opto-mechanical performances**

The measured error between two lines is characterised by the plot Figure 3:

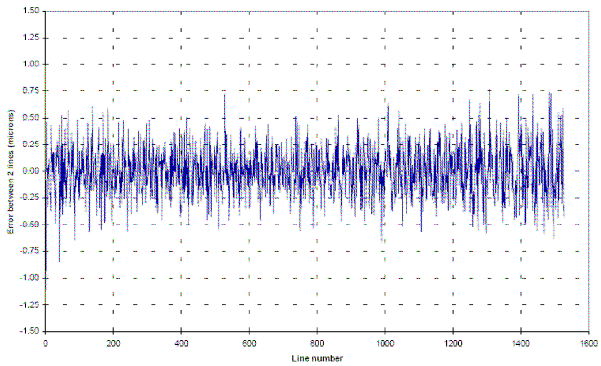

FIGURE 3: SDU QM OPTO-MECHANICAL PERFORMANCES

The line to line error being defined by $E=E_L-E_{L+1}$ with E_L the difference between the actual position and the theoretical one given by the regression line over one image.

- **Lifetime**

400 000 cycles (ie $1.2\ 10^{12}$ motor steps or 34 million of motor revolutions) have been successfully performed:

  - Without resistive torque increase.
  - Without opto-mechanical performance degradation.
  - Without wear or deterioration after inspection.

3.2. FLIGHT MODEL DELIVERY

4 Flight Models (FM) have been successfully delivered:

- FM1:
  - delivered in **1998 for MSG1 (launched in August 2002).**
  - 9 years of operational time in orbit .
- FM2:
  - delivered in **1998 for MSG2 (launched in December 2005).**
  - 6 years of operational time in orbit.
- FM3:
  - delivered in **1999 for MSG3 (launch planned in June 2012)**.
  - On storage since 2004.
- FM4 (spare):
  - delivered in **2004 for MSG4.**
  - integrated on satellite since 2006.

3.2.1. FM5 : Manufacturing Circumstances

3.2.1.1. FM4 Misbehaviour

The decision to use the spare model as a flight model took place in 2004 in order to comply with the MSG 4 additional contract. The model has been **nominally assembled** (applying the integration procedures from previous models) and subjected to the Acceptance sequence, which has been **successfully completed at mechanism level and at instrument level.**
A misbehaviour occurred during the MSG 4 acceptance test campaign, after **acoustic test environment**. During the nominal scan health check, it was discovered that the scan mechanism **did not execute all scan lines** properly and that over a certain angular range only partial lines were repetitively performed, which resulted into an overall **loss of 10 scan lines** over the full image(1247 lines). The phenomena appeared to be **non reproducible**.

3.2.1.2. Technical and programmatic choice for FM5 manufacturing

Considering the criticity of the mechanism for MSG mission, for conservative and programmatic reasons, all parties agreed on the **remanufacturing of a new model (FM5)** with the objective to replace the FM4 unit onboard MSG4.

<u>FM5 strategy:</u>

- **Tight schedule**: contractual, delay and cost constrains did not allow to implement a new procurement.
- **Engineering Model (EM) healthiness status**: all performance requirements were within specification and well within family if compared to other units. Large margins were present compared to qualification requirements.

As an outcome of this situation, the choice was made to built the SDU FM5 based on **components/pieces from the EM**.

4. SCAN DRIVE UNIT FM5 : WORKING PLAN TO SECURE FM5 ASSEMBLY, INTEGRATION AND TEST

4.1. ACCEPTANCE CRITERION FOR THE EM RE-USE

As a flight model, the SDU FM5 will be submitted to several acceptance environmental tests (Thermal & Vacuum, Vibration, Acoustic tests, etc…) at SDU, SEVIRI and satellite levels.
Since the SDU EM has been submitted to environmental tests already during its lifetime, **"Re-Use" of EM pieces** has been carefully assessed in order to be still covered by the **Qualification program**.

4.2. WARINESS MANAGEMENT FOR ENGINEERING DOCUMENTATION EVOLUTION

4.2.1. Mechanical Analysis report : Screw dimensioning evolution

Decision to Re-Use EM pieces was taken at the beginning of 2008, **11 years after design & dimensioning validation process**.
As the Internal standards at Thales Alenia Space are constantly optimized, an **overall review of the mechanical analysis** of the SDU has been performed to verify whether any criterion evolutions had occured.
The update of the screw tightening standard did show **negative margins** when analysing the minimum screw tightening criteria for 2 types of Rsat screws.
To overcome this inconvenience, the solution has been to **characterize a batch of screws** with an adequate torque angle sequence, in order to precisely limit the internal strain applied to these screws.

4.2.2. Assembly procedure

In order to prevent any assembly risks at assembly level, the Assembly procedure has been **reviewed and updated.** The goal was to be as thorough as possible.

4.2.3. Test procedure

TAS production management, team and tooling changes have resulted into more detailed test procedures taking into account **experience feedbacks fond in waking copies of previous models and operator change.**

4.3. WARINESS MANAGEMENT FOR HARDWARE

4.3.1. Design evolution

Since SDU EM corresponds to the **first design version** and the first model manufactured, certain design evolutions have taken place in the meantime and need to be considered for the built of FM5, such as:

- **Obsolescence dealing:** design evolution induces certain EM parts refurbishment or procurement of new pieces.
- **Design Processes change**: some processes as OAN coating are now prohibited and have been substituted.
- **Components prohibitions:** components used in 1997 are now prohibited, a direct change on thermistors was carried out.

4.3.2. Elementary Components : meticulous expertise and re-acceptance test

To follow the wariness management and the working plan, all functional components have been sent back to the manufacturer in order to perform **full inspection and acceptance test verification**. In this respect the following major elements have been re-checked and re-validated:

- Microcontact
- Roller screw
- Ball Bearings
- Stepper motor
- Potentiometer
- Bellows

5. HARD POINTS & LESSONS LEARNT

5.1. HARD POINTS AT ELEMENTARY PART LEVEL

Performing identical acceptance test on particular element 12 years after delivery implies **certain modifications on operations and toolings** at both sub-contractors and TAS facilities.

5.1.1. Ball bearing resistive torque

During Re-acceptance of the single ball bearing, the **mean torque value had increased** when compared with results from the first acceptance sequence. Investigations revealed that the measurement tooling has been improved at sub-contractor level resulting into more accurate values. Indeed, when applying the former resistive torque method, The former values were confirmed, therefore **no change in torque values observed since 1997**.

5.1.2. Potentiometer external diameter

A new potentiometer has been used (from attrition contingent), and **recurrent default** on potentiometer external diameter was observed again during FM5 assembly. Recurrent default on the potentiometer frame batch has not been taken into account by the subcontractor.

5.1.3. Roller screw device acceptance

Despite important investigations, several performance variations were observed in the acceptance test reports between 1997 and 2009. Since the observed disparities were **within the specification and the overall behaviour well within the family acceptance range**, the roller screw device has been accepted and released for integration within the SDU FM5.

5.2. HARD POINTS AT TEST LEVEL

5.2.1. Tests during assembly

SDU activities during assembly encountered difficulties at the time of:

- Resistive torque measurement
- Leak test measurement

Difficulties have been encountered since the test set up and measuring operation unwittingly vary over time and program context undeniably changed for this particular model.
Values were out of specification but **within family of the previous models** and have been accepted after explanations supported by analysis.

5.2.2. Opto-mechanical tests

Although, physical and electrical control checks, motorization margin and cartography were **successfully performed,** the opto-mechanical test sequence needed to be stopped since first results showed a partial non-compliance to the set of key performance requirements.

The opto-mechanical line to line error signature, Figure 4, has been subjected to a rewarding **NRB** and to a formal complete Root Cause Analysis applying the **ADEQUA process**.

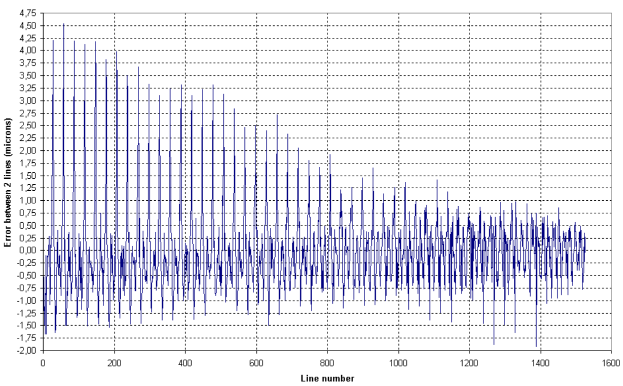

FIGURE 4 : SDU FM5 OPTO-MECHANICAL ABNORMAL PERFORMANCES

The investigations pointed to a malfunction within the **SDU translation parts** and more precisely to a potential problem at **roller screw device level**.
Indeed, data recorded by the potentiometers confirmed the motor and rotation parts nominal behaviour. Further, eventual tooling and measurement device discordances have been eliminated by appropriate tests elaborations.

The analysis of the parts involved in the translation process was then directly pointing to the:

- **Roller screw device**: performance and integration within the mechanism,
- **Guiding parts** in contact with translational elements,

as potential source for the observed anomaly.

Review of the acceptance data packages of the 5 roller screws procured and evaluation of the additional tests performed at subcontractor facilities with the SDU QM roller screw resulted into the conclusion that the **EM roller screw signature** was **singular,** when compared to the other units.
It was further noticed that the roller screw characterisation tests performed at sub-contractor level were not fully representative in terms of SDU kinematics and loads applied.

Mechanical analysis has highlighted the observed abnormal phenomenon as **an internal movement within the roller screw device.** In consequence of this finding, it has been agreed to authorize the FM5 dismounting process in order to confirm the root cause assumptions.
During the SDU FM5 dismounting, tests are foreseen to discriminate or incriminate the possible defective elements.

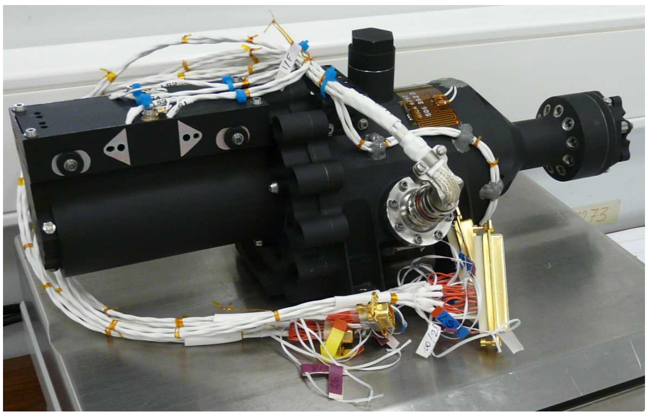

FIGURE 5: SDU FM5 AT TESTED STATE

5.3. LESSONS LEARNT

The consistent work carried out before the FM5 integration and test campaign has been rewarding to the TAS mechanism department in order to **familiarize AIT team with the SDU design and processes.**
However, all precautions taken by SDU team have not been sufficient to prevent the opto-mechanical abnormal behaviour despite:

- **Sub-assemblies and elements entire successful acceptance** wrt to appropriate specifications.
- **Assembly and test processes meticulous wariness**. Indeed, The assembly, integration and test team changing factor have been successfully treated.

This enriched experience led us through greater attitudes as:

- **Completion of a full review** of previous Non Conformance occurrences to acquire an heritage of:
  - Tests difficulties
  - Assembly troubles
  - Sub-contractor requirement non-compliances
- **Verification of procurement specification** wrt product requirement
- **Evaluation of results tendency** with trend charts following at:
  - Sub-System level
  - Mechanism level

The misbehaviour encountered on FM5 has also permitted to conclude on lessons learnt:

- **Replenishment of components might not be the best way to save schedule**. EM/FM evolutions check on parts took a lot of energy. The management alternative would have been to procure new elements with the same design, materials and processes.
- **Insist and Point on performances good attitude at assembly level**. We have consolidated the assembly procedure in order to ensure the correct staking of each mechanical part within the SDU assembly but no additional performance tests were implemented. Indeed, we have proceeded in many dimensioning controls which delayed the overall planning.
- **Restrain additional measurement and test interpretation**. During Assembly or MRB investigations, additional tests have been performed in order to fully understand and explain the behaviours. However, data recorded were assessed with difficulty since no comparisons with previous models could be done. The necessity of the tests was hard to appraise and some phenomena analysed were negligible to the second or third order to the performance needed.

CONCLUSION

Manufacture additional recurrent high-tech mechanism 5 years after the latest assembly activity and more than 10 years after its development is a difficult and delicate challenge.
In this particular case, for some anomaly or other, a high level of expertise is involved to fully comfort the product healthiness and performances good behaviour.
This substantial work carried out is hard to internally manage because:

- It needs a complete team working supported by approved analysis
- It unintentionally makes people reconsider structural choices while the design is largely qualified and is nominally functioning in orbit.

The work presented with its lessons learnt shows that the limit of resting in a long time working design without continuously manufacturing, is definitely difficult to determinate.