DESIGN AND TEST OF A SCAN MECHANISM FOR MICROWAVE IMAGING INSTRUMENTS

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Abstract

In frame of an ESA development contract, AIRBUS DS Friedrichshafen was selected to design, develop, build and test a pre-development model of a scan mechanism for microwave imaging instruments.

This paper will present the derivation of precursor mechanisms already flying in-orbit adapted to the new requirements of the actual scan mechanism. The development was facing new challenges as long term storage issue, as well as new features to be implemented onto the scanner to fulfil the present specification.

The project life cycles, from design phase over manufacturing and testing of the scan mechanism, will be presented. Results of the life test might be partially available and will be compared with in-orbit data of the precursor mechanisms. The paper will also detail some issues with long term storage of the mechanism and its components on the satellite as well as the lesson learnt throughout the project life cycle.

1 Overview

The pre-development of a scanning mechanism for two different microwave imaging instruments should demonstrate the feasibility of the used technologies considering the long term storage of 19 years and a nominal in-orbit lifetime of 7.5 years with a total number of about 250.000.000 revolutions.

Based on already existing scanning mechanisms with flight heritage developed for the Chinese FY3 weather satellites, the major components should be reused and improved to fulfil the challenging requirements of this development.

The scanner shall be compatible for the 2 different instruments in different configurations. While the first instrument holds an on-board calibration assembly outside of the rotating part fixed to the instrument baseplate, the second instrument requires a mechanical and electrical interface above the scan mechanism supporting a fixed, non-rotating 15 kg heavy on-board calibration assembly (CA). The CA interface is provided by the scan mechanism by means of a hollow mast through the rotating shaft, which routes the harness for the power and data lines to the CA.

A new developed Roll-Ring configuration transfers power and data including LVDS between the fixed and rotating part.

One of the main challenges is the long lifetime in-orbit with its huge number of revolutions. A suitable lubrication system has to be defined and used.

Figure 1: Assembled Scanner

2 Design Description

The design of the scanner is composed of the following subassemblies. The Drive Unit which provides the bearings assemblies, the motor and the encoder flanged at one side. Both bearings are assembled on membranes in order to cope with the thermal expansion in orbit and to provide the required stiffness in axial direction during launch. Attached as cantilever below the drive, the Roll-Ring is located in a housing cone where the roll-ring inner part is attached to the rotating shaft and the outer stator fixed to the housing of drive and baseplate. The rotating harness is routed through the drive unit and encoder, and is attached finally to the rotating instrument.

A double coupling is attached on top of the scan mechanism. One coupling is responsible for bearing offloading during launch. This patented Launch Offloading Device (LOD) (Figure 2) detaches the instrument from the scanning shaft during launch. The other coupling is responsible for a primary load path between the heavy CA and the rotating part during launch for sufficient stiffness supporting the CA mass. Due to the high load transfer of forces and moments in each direction, a Hirth Coupling (HC) has been selected. This type coupling is robust enough also for a lower preload as tested on this breadboard.

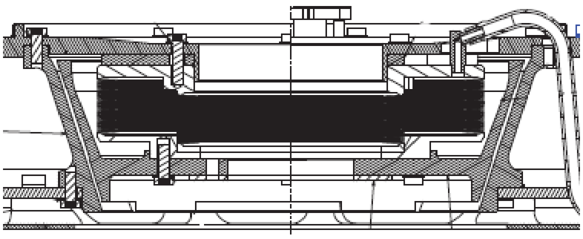

Figure **3***: LOD disengaged*

In-orbit, the cones of the LOD are engaged while the HC is disengaged. A bellows is acting as an actuator to close the LOD after launch and to disengage the HC. The bellows also provides the connection transferring the rotation. The other side of the LOD is attached to an interface cone which supports the rotating instrument parts.

2.1 Main modifications with respect to heritage design

A Roll-Ring is implemented instead of a slip-ring because of the required life time and the required transfer of the LVDS Signal. A new subsystem is the mast with the CA Interface and the hirth coupling (HC). The LOD load capacity is improved in order to cope with the METOP Spacecraft manoeuvres. A pneumatic feature is implemented to lift up and down the instrument by air during ground operations.

The bearing has exceeded the required in-orbit life on several precursor scan mechanism, which is a good indication for the bearings and used lubrication system. Based on these good in-obit experiences, only mandatory and minor modifications were implemented within the drive system.

2.2 PDTD

The **p**ower and **d**ata **t**ransfer **d**evice (PDTD) to route to power and data from the static to the rotating part is made of an improved Roll-Ring provided by Diamond Rolltrans. During first discussions with the supplier, it turned out that LVDS signals were never transferred via the Roll-Ring. Experience is available only with power and analogue data transfer. In order to transfer safely the LVDS signal, additional separators between the tracks were added. Before procuring a complete Roll-Ring, a development model was built and tested to demonstrate the capability. Diamond itself tested successfully the signal transfer. Additional tests were performed at AIRBUS premise, which also showed the capability to transfer the signal according to the requirements.

2.3 Bearing lubrication

The bearings are lubricated with the same grease used on former scanning mechanisms flying on the Chinese FY3 satellites which provides full life flight heritage.
Further considerations at begin of the study was the long term storage requirement of 19 years. Using oil as only lubricant was considered critical as this would

result in oil creep along the gravity vector downwards during the storage time and was early abandoned.

Further investigations were initiated since the heritage grease is no longer produced (due to REACH regulation). Grease based on PTPE oils were discarded due to well-known interaction between the iron in 440C bearings and the cracked oil molecules chains of the base oil. Remaining greases were the new Maplub formulations and the Rheolube pendant. Early after program start, an alert was raised that the Maplub (b) formulation was prone to separation at temperatures above 40°C.

The Rheolube grease contained additive which might create corrosion effect using the long term storage and was discarded during the development phase.

Some amount of the old grease Mapblub (a) formulation was available on stock at the bearing supplier. The disadvantage of the old Maplub (a) formulation was that it was on stock since its first use in 1999. The available grease was from the same batch as used for the scanners already in-obit. How could it be proved that this grease can still be used?

Two SOT tests were performed at ESTL to check its tribological properties. The result of the first test showed a larger dispersion of the orbit life time w.r.t. to a new manufactured batch tested in the past. While a second SOT test showed much better results than a new manufactured grease batch t.

In addition, a chemical test performed at ESA showed small change but no deterioration such that the grease could be used. Eventually, it was concluded that the grease can still be used.

3 Testing

3.1 Functional Performance Test

During the functional performance test, the constant speed requirement, micro vibration emission and susceptibility have been verified for 2 different configurations. Two different inertia wheels were used to represent the different instrument inertias of 5 kgm^2 and 25 kgm². During tests, the exported torques and forces are recorded by means of a ground mounted force table. Further torque margins were verified through measurements of the current.

Figure 4 shows the configuration of the functional performance test with the small inertia. The mechanism assembled with the small rotating inertia was mounted on a Kistler plate to record forces and moments. Additionally, an autocollimator was mounted to measure the wobble, as a contributor to the pointing budget, during rotation.

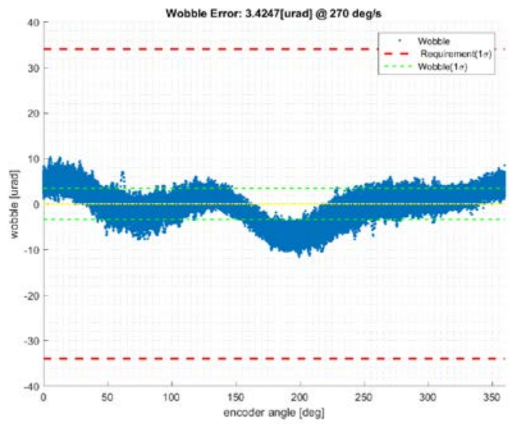

Figure 4: Rotor bearing wobble at 45 rpm

Different speed profiles (common test profile, rundown, pointing) were executed. PDTD (power data transfer device) power and signal transfer was tested.

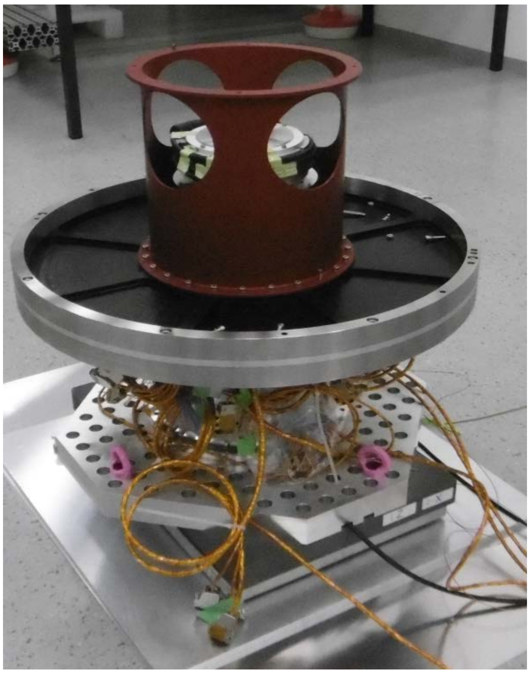

Figure 5: Performance Test with the small inertia

A defined common test profile with representative velocity plateaus was reached and held for evaluation. Full performance in different instrument configurations, PDTD power and signal transfer as well as torque and motorization margins could be verified successfully using this profile.

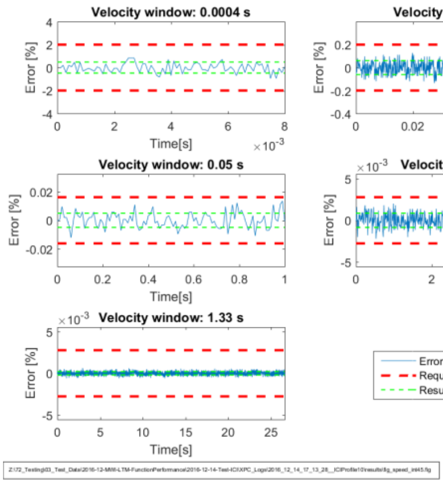

Figure 6: Velocity window errors at 45 rpm

The velocity mean window error, speed stability, accumulated pointing error, are evaluated using the internal and an external encoder. The velocity window error evaluates the mean error over different sampling window lengths. The pointing error compares the actual position to an ideal position at reference speed.
A specific rundown profile is performed to simulate an error case in which the motor becomes unpowered during rotation. The measured failure torque gives insight into the total friction of the system.

3.2 Microvibration

During all tests, the micro vibration emissioned force and torque were recorded and evaluated. Figure 6 shows the level of torque emissions (z=rotation axis) compared with the allowable torque spectrum (red curve). The reaction torque levels are within specification. At 0.75 Hz the required level of unbalance (customer's requirement) can be observed.

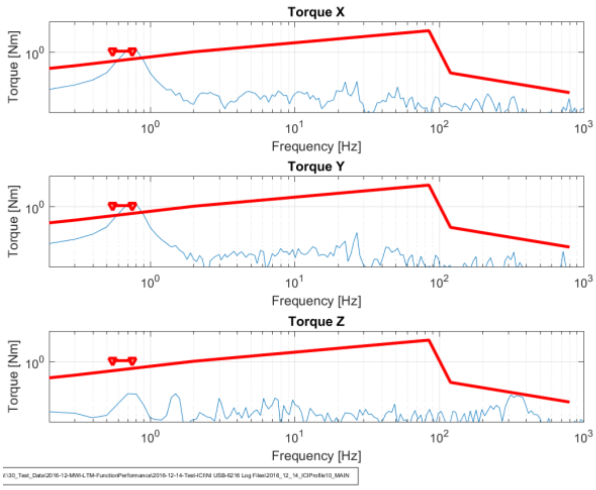

Figure 7: Micro vibration: Torque emission

3.3 LVDS testing

The PDTD is tested using representative signals on the power, heater, LVDS and thermistor lines. Voltage drop (max. 0.5V) is evaluated for the power lines. Eye-diagrams are used to evaluate the signal quality at the receiver end after passing the PDTD against overshot, delay and voltage level requirements. The bit error rate was successfully measured during rotation, passing the PDTD twice stator to rotor and back to stator without bit recovery on the rotor side.

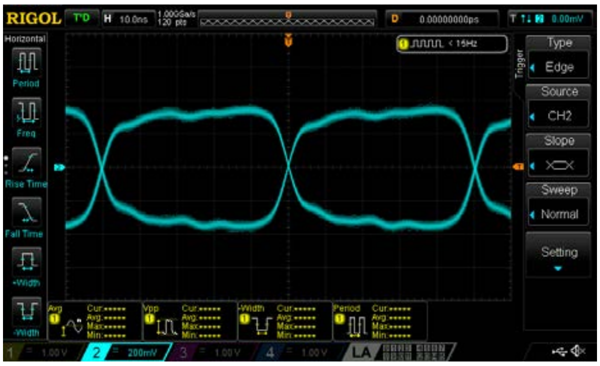

Figure 8: Eye-diagram of LVDS signal after PDTD

To further characterize the PDTD, the S_{11}-Parameter (reflections) measurements where performed on the rotating PDTD showing that up to 20MHz the PDTD can be used without restrictions, and the position of the flexure lead to a S_{11} delta of max ± 0.4 dB between 1 and 10 MHz.

3.4 TV test

During TV testing the setup, except the exported force/torque measurement, reference encoder and axial wobble measurement, was used to successfully verify proper function under thermal and vacuum conditions.
The functional test under thermal vacuum condition showed that the requirements were met. During a magnetic switching of the TV, an EMC impulse caused a wrong reading from the encoder to the controller. The controller simulation running on a PC could not handle the error and became unstable. This gave important hints to improve the controller being now robust against these errors.

3.5 Vibration Test

The vibration test was executed with a 15 kg mass on top (at CA I/F) and a preload of 12 kN which was applied to prevent opening of the HC. The first eigenfrequency of this heavy mass was slightly above the predicted value and well within the requirement.

Figure 9: Vibration Test with simulated central mast load (CA dummy)

3.6 EMC testing

For the pre-development mechanism, the drive electronic was not part of the contract and operation was performed with an EGSE only. Therefore, only a radiated emission test was performed.

During the sweep over the frequency band, it became obvious that in a certain frequency range the required deep notch of -21dbµV/m created issues as measured spikes violate an important requirement. Discussions with the supplier of this component were initiated and improvements identified to reduce the spikes. The evaluation and testing is ongoing.

Cross talk between the LVDS lines could not be identified thanks to the discussion and implementations of separators with Diamond at begin of the development.

4 Lessons Learned

LOD transmittable moment:

The geometry of the LOD is optimized for the required transmittable moment. A higher friction coefficient is increasing the transmittable moment whereby the friction coefficient must be below the self-locking value.

However, the test showed that, although the friction was below the self-locking value, a higher friction coefficient is contra productive with respect to pointing repeatability, since the final engagement position was affected. Therefore, the final selection is a LOD with low friction surfaces.

Motor Magnets:

Magnet alloy with high corrosion resistance but lower remanence are strongly preferred w.r.t. to magnet alloy with higher remanence and surface corrosion protection due to lower corrosion resistance of the magnet alloy. This aspect is mandatory regarding the need to long term storage.

Bearing lubrication:

It was sadly recognized that excellent working lubricants for space application are no longer available. The investigation in other lubricants showed that deficits are present and would have been created issue for the project. It is inevitable to develop and test new lubricants which are suitable for long running application in space and also for long term storage on ground.

Breadboard:

It is worth to build a breadboard before starting with the flight hardware in order to learn about the difficulties which would lengthen the development time. This breadboard allows to try different new technologies in order to provide good basic technology which can be used for flight.

5 Outlook

The qualification test campaign (w/o life) of the scanning mechanism was successful, confirming a good performance and compliant requirements. The difficulties which occurred during its development were flown down into the development of the follow-on MetOp-SG scanning mechanism.

The pre-development model is now within the life test. The on ground life time with instrument mass has been performed at nominal speed and it will now be operated in vacuum for 2 years with an acceleration factor of 5 (5x nominal speed) until its life test time end in 2019.