THE HERSCHEL-PACS GRATING DRIVE MECHANISM : DESIGN STATUS AND PROTOTYPE RESULTS

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ABSTRACT

The Photodetector Array Camera and Spectrometer (PACS) is an imaging spectrometer-photometer which forms part of the science payload of the Herschel Space Observatory (formerly called FIRST), an ESA cornerstone mission (CS4) to be launched in 2007 on Ariane 5. This paper reports the present design of the motorised grating assembly for the PACS spectrometer. The PACS grating shall be capable of accurate positioning (4 arcsec) within a large angular throw (40 arcdeg) in cryogenic environment (4 K). The drive mechanism is remotely controlled from the "Detector and Mechanism Controller" (DEC/MEC). Technologies of actuators, position sensors, pivots, lubricants, servo-control and cryogenic test set-up are discussed in this paper.

Keywords : Herschel, PACS, cryogenics, cryogenic mechanisms, dry lubricants, servo-control

1. INTRODUCTION

The Herschel Space Observatory will have a passively cooled ∅3.5 m Cassegrain telescope and a science payload of three instruments: HIFI, PACS and SPIRE. The focal plane units of these instruments will be housed inside the payload module, which provides a cryogenically cooled environment using the superfluid cryostat technology developed for the Infrared Space Observatory (ISO) mission.

The PACS instrument [1] is designed for imaging photometry, low- and medium-resolution spectroscopy in the wavelength region ranging from 60 to 210 µm. This instrument will enable the scientific community to deepen the researches on circumstellar physics, on star and galaxy formation, and more generally on the distant universe as a continuation of the ISO mission. PACS Focal Plane Unit (Fig. 1) employs two Ge:Ga photoconductor arrays (spectroscopy mode) and two bolometer arrays (photometry mode).

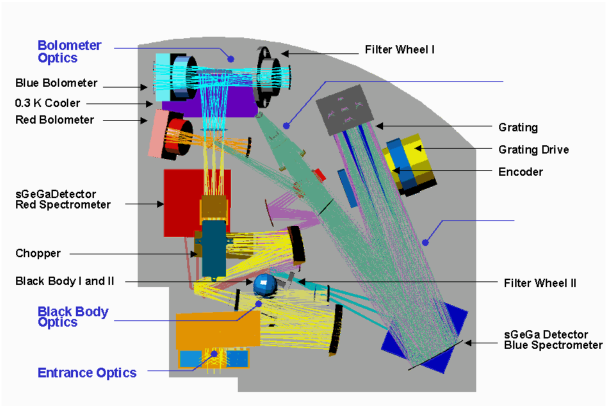

Fig. 1. PACS Focal Plane Unit.

Within the PACS Consortium, the *Centre Spatial de Liège* (CSL, Belgium) is responsible for the design, production and verification of the focal plane "Grating Assembly" and the "Detector and Mechanism Control Electronics" (DEC/MEC) located on the Herschel service module.

The Grating Assembly is the spectral dispersing element for the PACS integral-field spectrometer. The Grating is designed to cover the full PACS wavelength range and is operated in Littrow configuration. The first three orders are used simultaneously. The grating is actuated by a cryogenic motor with a resolution of a few arcsec which allow scanning/stepping for improved spectral flatfielding and for coverage of extended wavelength ranges. Anamorphic collimating optics expands the beam to an elliptical-shaped cross section to illuminate the grating over a length of ~300 mm required to reach the desired spectral resolution. The radiation from the 1st diffraction order vs. radiation from the other two orders is separated by a dichroic beam splitter and passed on into two optical trains feeding the respective detector arrays for the wavelength ranges 105 - 210µm and 57 - 105µm.

2. MECHANISM DESCRIPTION

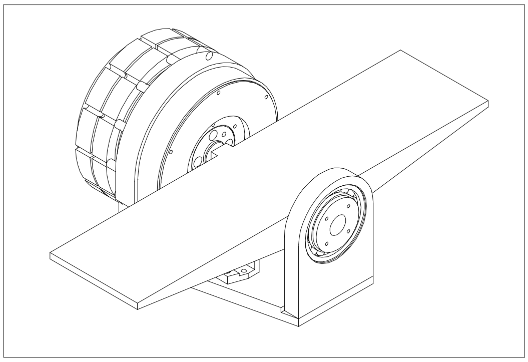

Fig. 2. - PACS Grating Assembly overview.

The Grating Assembly consists of a flat 320 x 80 mm² ruled grating with groove profile as shown on Fig. 3; its positioning mechanism; and launch-lock. Its main constituents are described in the following sections.

2.1 Diffraction Grating

The grating is made of aluminium alloy 6061. This alloy - which is also the structure material - features a flat coefficient of thermal expansion and a high thermal conductivity in the range 4 - 15 K that tolerates temperature gradients.

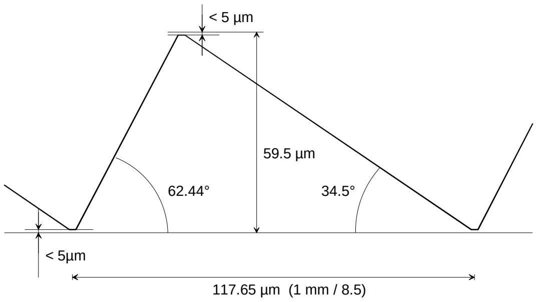

Fig. 3. Grating groove profile.

The grating blank is binded to an aluminium shaft with athermal conical connections to the stainless steel bearings.

2.2 Structure

The structure connects all elements together and ensures stability/alignment of the assembly after vibrations and thermal excursions. It consists of a monolithic bracket made of aluminium alloy 6061-T6 for thermal compatibility with PACS structure. The grating bracket is optimised for mass and stiffness. The total mass of the assembly is estimated ~3.5 kg. The first natural mode (twisting of grating) is evaluated in launch configuration (rotation locked) by finite element method and occurs at around 274 Hz.

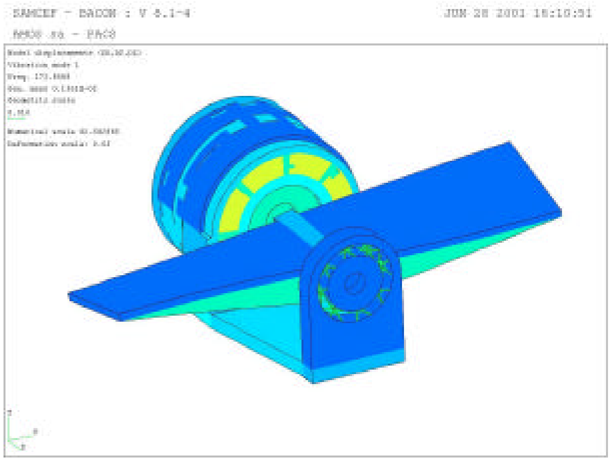

Fig. 4 - Finite-element results (1st eigen frequency)

2.3 Bearings

The rotor assembly is sustained by a set of three oblique-contact ball bearings (∅55 x 10 mm). On the actuator side a pair of bearings is mounted in opposition whereas a single bearing is mounted on the other side of the bracket. A preload of 650 N (Hertz pressure ~2 GPa) is applied to the double bearing to prevent shocks during vibrations, at the expense of an increased mechanical torque.

Bearings are made of stainless steel AISI 440C. Balls are TiC coated to prevent cold welding. A dry lubricant (MoS_2 or WS_2 -based) is applied on races. The final selection of this coating will be performed after environmental and life testing of different candidate materials: Microslide (Vilab, CH), Wolfratherm (Klüber, D), Dicronite (Dicronite, D)…

Tolerances on the outer and inner bore diameters have been calculated accurately to ensure a tight fittings at liquid helium temperature. The axial mounting includes a spring washer to compensate differential contraction between steel (bearing) and aluminium (bracket).

2.4 Actuator

The selected actuator is an axial brushless DC torquer (pancake type) herited from the German InfraRed Laboratory (GIRL). The stator is ironless and comprises two phase windings and Hall probes for generation of signals for electronic commutation. The rotor carries SmCo magnets and is made of magnetic stainless steel to form a magnetic loop. The winding of each phase is split into two separate coils to allow redundant operation. The Hall probes are redundant as well. In the present application an average dissipation of 3mW is tolerated to the 4.2K level.

2.5 Position Sensor

The position sensor is an inductive rotary transducer consisting of two non-contacting elements (stator and rotor). The rotor disk bears a periodic "printed circuit" pattern, with accurately known pitch interval (256/360°). The stator disk carries two periodic patterns of same pitch. The second winding pattern is displaced a quarter of period from the first winding pattern. An AC excitation signal applied to the rotor results in two output signals from the stator, which vary as sine and cosine functions based on the relative position in the pitch cycle. There is a unique pair of sine and cosine output amplitudes for every position within one cycle of the pitch. The accurately known pitch interval may be subdivided with high precision by measuring and processing the sine and cosine amplitudes in the DEC/MEC electronics (or ground control electronics). For redundancy purpose, dual redundant winding patterns are printed on both the rotor and stator substrates. In order to reduce ohmic losses in the instrument cryoharness the rotor is equipped with a 10:1 transformer.

2.6 Launch-lock

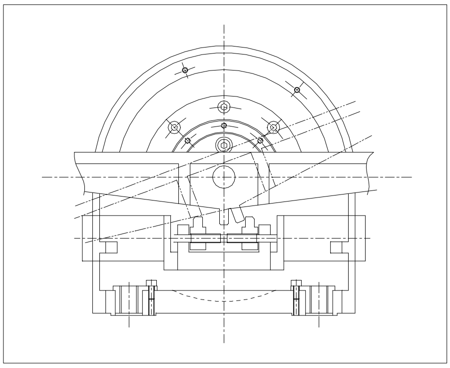

Fig. 5. Launch-lock.

Launch locking of the grating is required due to the high accelerations expected during launch and the impossibility to ensure a perfect balance of the rotor. Estimations lead to a possible resulting torque of 0.2 N.m under 100 g. Additional requirements apply to the launch-lock device : the grating locked position must fall within the useful angular range ; the device must be bi-stable (no energy required in locked or unlocked position) ; it must be remotely lockable-unlockable ; it must be electrically redundant. Moreover, as a safety feature, we want it to reset the grating at its central position without using the main actuator.

The proposed design is illustrated on Fig. 5. It consists of screw-driven tongs that are clipping a lug arranged at the backface of the grating. The screw is coupled to a small rotary motor that is duplicated for redundancy. The device is also provided with Hall probes for detecting the tongs position.

2.7 Temperature Sensors and limit Switches

The grating is provided with two cryogenic temperature sensors (nominal and redundant) that are bolted onto the back face of the grating in two symmetrical positions.

Mechanical limit switches with a reproducibility of 1 µm are installed. They are located at ~100 mm from the rotation axis to obtain an absolute reference within 2 arcsec.

3. MECHANISM CONTROL

3.1 Control Loop

The grating position is controlled in closed loop between the position sensor signal and the actuator command. The resulting torque of the actuator is proportional to the current command, which is determined by comparison between the current position signal and the position set point. The controller is based on a PID regulator that is implemented in the DEC/MEC CPU. Input/output signals are properly converted in a specific Mechanism Interface Circuit.

3.2 Control Hardware

During ground operations the grating is controlled through specific ground support equipment that simulate the DEC/MEC interface. This equipment implements specific control softwares, parallel interface to the processor, D/A converters and output amplifiers for the motor coils, read-out circuits and A/D converters for the position resolver and Hall probes.

4. PROTOTYPE AND TESTS

4.1 Cryogenic Prototype

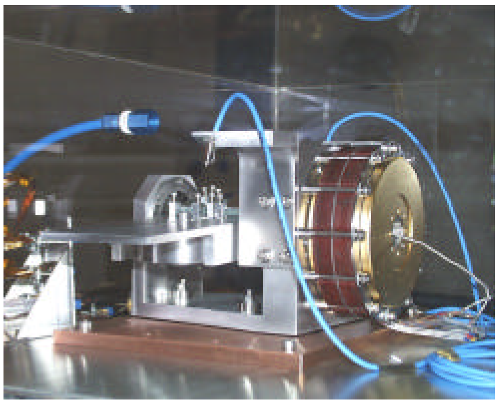

Fig. 6. Cryogenic prototype.

4.2 Test Plan and Set-up

The prototype is and will be submitted to an extensive test programme that is carried out in parallel with the design of the flight mechanism. This model is especially valuable for designing the control electronics because electrical and mechanical characteristics of the system are very different when it is cooled down to liquid helium temperature.

Tests at room temperature include balancing of rotor assembly, measurements of rotor inertia, electrical parameters, resolver precision…

Tests at low temperature are performed in a specific liquid helium cryostat that provides a cryogenic environment < 5 K. As shown on Fig. 7, the grating assembly is bolted upside down onto the bottom plate of a liquid helium tank, which ensures a conductive interface at 4.2 K and a radiative environment at ~4.8 K. Performances and operations of the test cryostat were described in a previous paper [3].

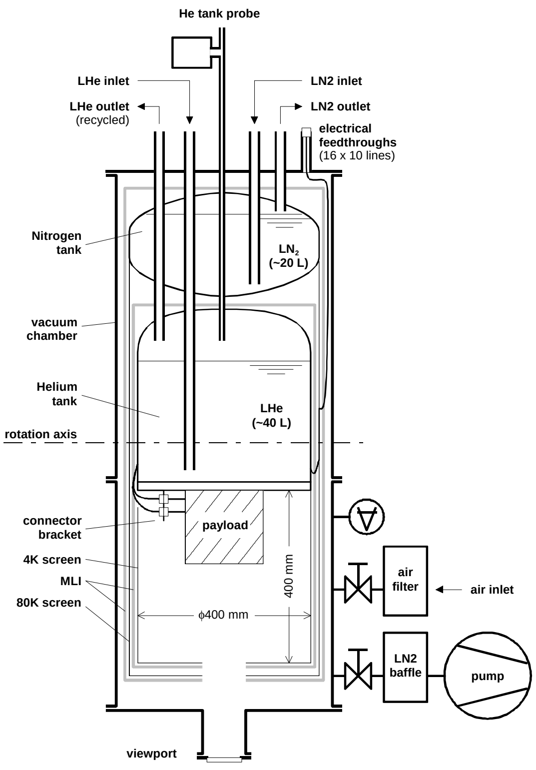

Fig. 7. Cryogenic set-up.

Tests at low temperature include :

- measurement of electrical parameters
- measurement of position resolver precision
- measurement of mechanical torque
- measurement of thermal characteristics
- qualification of actuator, resolver, limit switches
- selection of bearing lubricant
- life test of the mechanism
- adjustment of control hardware and software

4.3 Current Status

So far a complete blank test of the test cryostat was performed and it was shown that it fulfils all the operational and performance requirements for testing the grating prototype and subsequent models.

The prototype is currently installed in the cryostat and the bearings are running in at room temperature while the last control tools are implemented in preparation to the first cryogenic test planned early July 2001.

5. CONCLUSIONS

CSL has developed a prototype, a cryogenic test set-up and ground control equipement for evaluating the PACS Grating Assembly. The complete test bench is presently assembled and standing by starting an extensive test programme.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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