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CRYOGENIC MECHANISMS FOR SCANNING AND INTERCHANGE OF THE FABRY-PEROT INTERFEROMETERS IN THE ISO LONG WAVELENGTH SPECTROMETER

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1. Introduction.

The Infrared Space Observatory (ISO) is an ESA cornerstone mission for infrared astronomy. Scheduled for launch in 1993, its four scientific instruments will provide unprecedented sensitivity and spectral resolution at wavelengths which are inaccessible using ground-based techniques. One of these, the Long Wavelength Spectrometer (LWS), will operate in the 45–180 μm region (Emery *et al.*, 1985) and features two Fabry-Perot interferometers mounted on an interchange mechanism. The entire payload module of the spacecraft, comprising the 60-cm telescope and the four focal plane instruments, is maintained at 2–4 K by an onboard supply of liquid helium. The mechanical design and testing of the cryogenic interferometer and interchange mechanisms are described in this paper.

2. Fabry-Perot Interferometers.

The LWS features two scanning interferometers, one each for the wavelength ranges 45–90 μm and 90–180 μm. These differ only in the spacing and characteristics of the reflectors. An exploded isometric view (fig. 1) shows the compact construction, mostly of Al 6061 alloy.

The interferometers consist of two metal mesh reflectors built into three plates, the middle of which is sandwiched between the outer two and suspended by three BeCu leaf springs. The springs are profiled to a sector of an annulus, anchored with a small screw and pin to the back plate, and fixed again with a screw to the moving plate. This arrangement is highly compliant in the direction of motion, but very stiff in the perpendicular direction.

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The plate motion is generated by three moving coil actuators, equispaced around the circumference to enable active control of the mesh parallelism. The coils, comprising 800 turns of 44 swg (0.081 mm) copper wire, are mounted on the moving plate and engage with shielded SaCo magnets which are fixed to the back plate. This arrangement minimises the moving mass.

The separation of the fixed and moving plates, which carry the two reflectors, is monitored by three capacitance micrometers, also equispaced around the circumference. A closed loop electronic circuit provides servo control of the plate position and operates as follows. The micrometers are excited at 10 kHz and the current through each is compared with that through a 100 pF reference capacitor (fig. 2). The micrometer excitation voltage can be controlled by digital command. At the balance point of the servo, we have:

$$KC_M = C_R, \tag{1}$$

where K is the digital multiplier, C_M is the capacitance of the micrometer, and C_R is the reference capacitance. Since the micrometer capacitance is simply related to the plate separation d, we have:

$$d = K\,\frac{\epsilon_0 A}{C_R} \tag{2}$$

(ignoring edge effects), where A is the area of the micrometer pads. The plate separation is linearly related to the digital command K and is independent of the amplitude and frequency of the driving voltage. In practice, the relationship is slightly nonlinear due to edge effects. This control system provides for plate motion over a range of $\sim 100\,\mu$m, with a step size of ~ 25 nm.

A block diagram of the complete servo control system is shown in fig. 3. One 12-bit command is applied to each channel to control the plate motion, while two 8-bit commands are applied to channels 2 and 3 to provide independent control of the parallelism. This adjustment has a range of $\pm 10\,\mu$m.

The coil current is limited to ± 15 mA by the resistance of the harness which connects the analogue electronics unit to the focal plane instrument. The power dissipation in each coil is typically $250\,\mu$W. This heat is efficiently conducted to the LHe reservoir through the leaf springs; tests have not revealed any significant heating effects due to dissipation in the drive coils.

The reflectors are precision nickel meshes, of thickness $3\,\mu$m, bar width $6\,\mu$m and pitch 15–19 μm. Each mesh is initially stretched over a titanium alloy ring and bonded to it by gold thermocompression. The rings are then attached, by 0-80 screws, to the aluminium alloy plates which feature rims for additional stretching. Such use of dissimilar materials demands prior characterisation of the mesh elasticity, enabling the tension in the meshes to be controlled such that they remain intact and taut at 4 K.

The stretching rims define the operating position of the meshes, and must be flat to ~0.1 μm rms to avoid degradation of the interferometer performance. This is achieved by precision diamond turning of the rims, the micrometer pads and associated reference surfaces. Finally, cleanliness is of paramount importance at the assembly stage, since particulate contamination can also degrade the mesh flatness.

3. Interchange Mechanism.

The LWS requirement for two interferometers, and also for a lower resolution operating mode with no interferometer in the beam, led to the development of an interchange mechanism. In the absence of suitable commercial devices for this application, we decided to develop a low power, long life mechanism for the cryogenic space environment (Patrick *et al.*, 1989). A brief summary of the mechanical and thermal design of the mechanism and its performance in vibration and life tests is given here.

The interchange mechanism is driven by a cryogenic stepping motor, which features a two-phase drive technique and is characterised by its rugged and simple construction. Magnetic materials were selected following evaluation of prospective materials under cryogenic conditions. In practice, two pairs of drive coils, eight wires and two drive circuits are employed for end-to-end redundancy, since the mechanism represents a critical single point failure for the LWS. The 440C stainless steel bearings and pinion are sputter coated with MoS_2 for lubrication.

The interferometers are attached to an aluminium alloy (6061) wheel using a three-point fixing, which allows for the introduction of shims as necessary to bring the alignment of the meshes with respect to the LWS beam within the 4 arc min tolerance. The wheel features a rim gear which engages the motor pinion with a gear ratio of 29. The form of the gear teeth was to the conventional involute (20° pressure angle) standard, and backlash was set to 0.1 mm at room temperature. The gear teeth were hard anodised for mechanical protection and sputter coated with MoS_2 to a nominal thickness of 0.2 μm. The angular contact ball bearings on which the wheel shaft was mounted were pre-loaded through a compressed Belleville washer to eliminate play up to ~100g vibration. The rings and balls were sputter coated with MoS_2 (Gould and Anderson, 1990) and fitted with a duroid ball cage.

A thermal model of the subsystem reveals that the interferometer springs and the wheel bearings represent the largest thermal impedances. In the former case, no action was taken since the power dissipation level was so small; in the latter case, however, initial cooldowns were unacceptably protracted. A clock-spring thermal strap was therefore introduced, consisting of high purity copper sheet coiled into a spiral, the inner end rotating with the shaft and the outer end anchored. The elasticity of this strap is one of the major sources of resistance in the interchange mechanism.

The other source of torsional resistance is the wiring bundle to the interferometers. The harness consists of a mixture of 24 stainless steel and copper wires, all coated with PTFE insulation, and is passed through the hollow shaft of the wheel en route from the interferometers to the fixed connectors on the LWS wall. To minimise wind-up in the harness, a guide tube is included which provides 20 cm of free length; nevertheless, the power requirement is substantially higher at the extremes of the wheel motion due to the stiffness of the PTFE insulation at 4 K.

The wheel has four operating positions: the two interferometers, an open aperture, and a blanking plate for reference measurements. The wheel position is detected by an inductive sensor, consisting of three fixed coils on one support bracket and magnetic markers at each of the four operating positions. The response is sharply peaked and of either polarity, enabling the wheel position to be set with an accuracy of $\pm 0.7°$; the 2-fold degeneracy is decoded by the drive software. Spring stops limit the rotation to 5° beyond the extreme positions.

The interchange mechanism is controlled by a 3-bit counter from the on-board computer. In a normal interchange, the motor is ramped up over the first 127 steps, driven at the slew speed of 250 Hz, and ramped down over the final 127 steps. The wheel is brought to a stop 7 steps before the intended position, and is then single stepped until the peak response from the position sensor is detected. A 90° interchange requires $\sim$2 s and dissipates only 150 mW, thereby minimising the boil-off of stored cryogen on the spacecraft.

A development model of the interchange mechanism was subjected to room temperature vibration to ISO qualification levels, on the basis of which the bearing pre-load and the thermal strap design were both revised. Cryogenic vibration of the LWS Engineering Qualification Model resulted in two broken wires at the interferometers; these led to small design changes, which were later proven by further cryogenic vibration in the convenient facility at F.U. Berlin.

The interchange mechanism is expected to undergo 10,000 operations during the ISO mission, depending on the scientific observations programme. Following vibration of the development model, an accelerated life test was undertaken at 4 K. The test was terminated after 40,000 interchanges, at which point the motor had begun to drop steps. The motor current (fig. 4), which is the indicator of bearing friction, was within operational limits throughout. No wear debris was found in the cryostat, and subsequent dismantling produced no evidence of end-of-life wear.

4. Conclusions.

The development of cryogenic mechanisms for the scanning and interchange of two Fabry-Perot interferometers has recently reached a successful conclusion. Following five years of design and test effort, the Flight Model instrument has been manufactured, tested and integrated into the LWS for launch by ESA in 1993.

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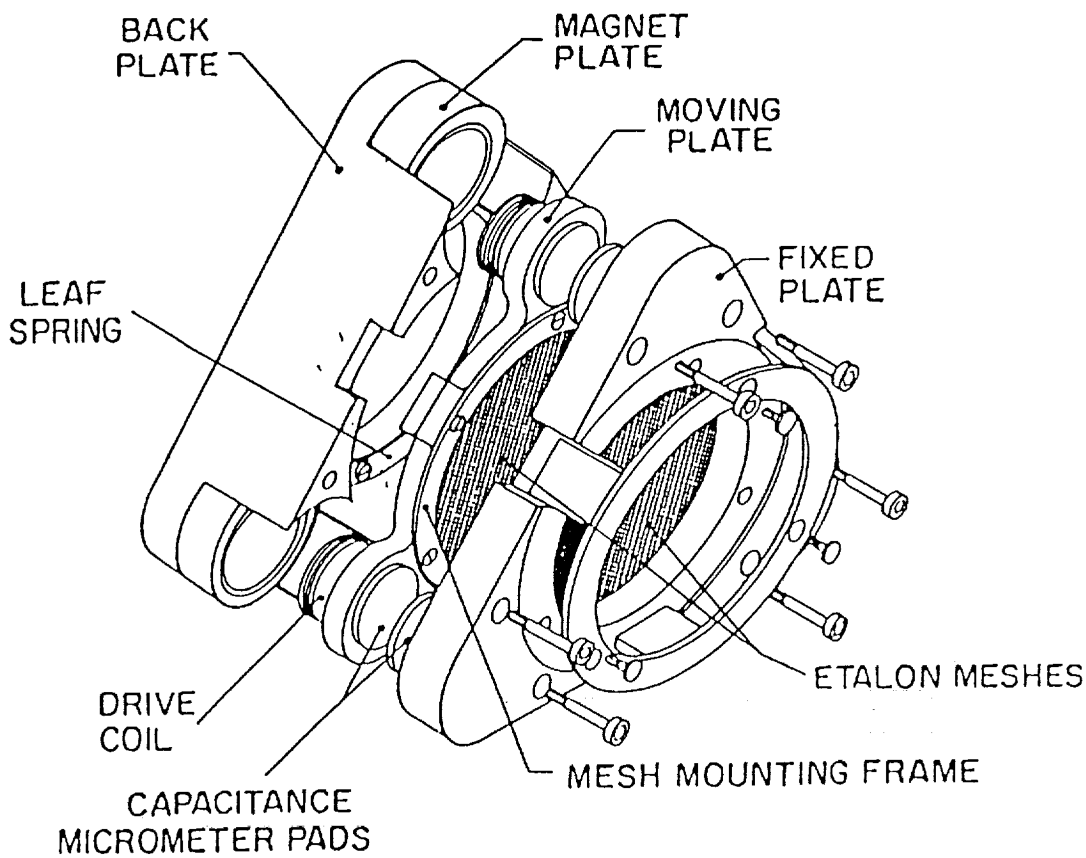

FIGURE 1

Exploded Isometric View of the Fabry-Perot Interferometer

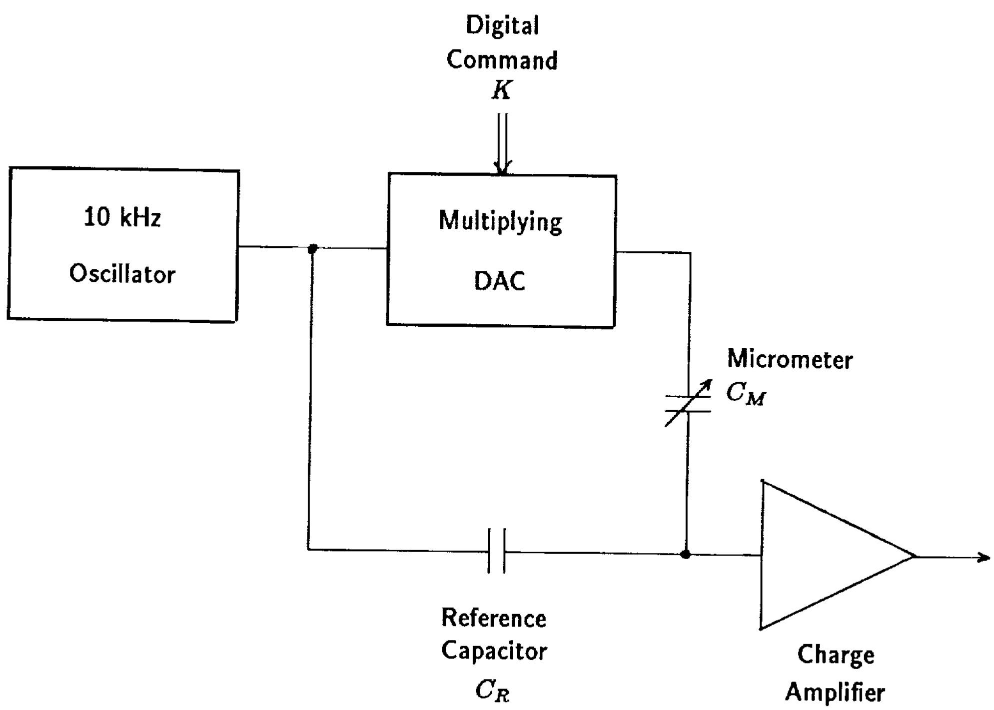

FIGURE 2

Schematic Representation of the Capacitance Micrometer

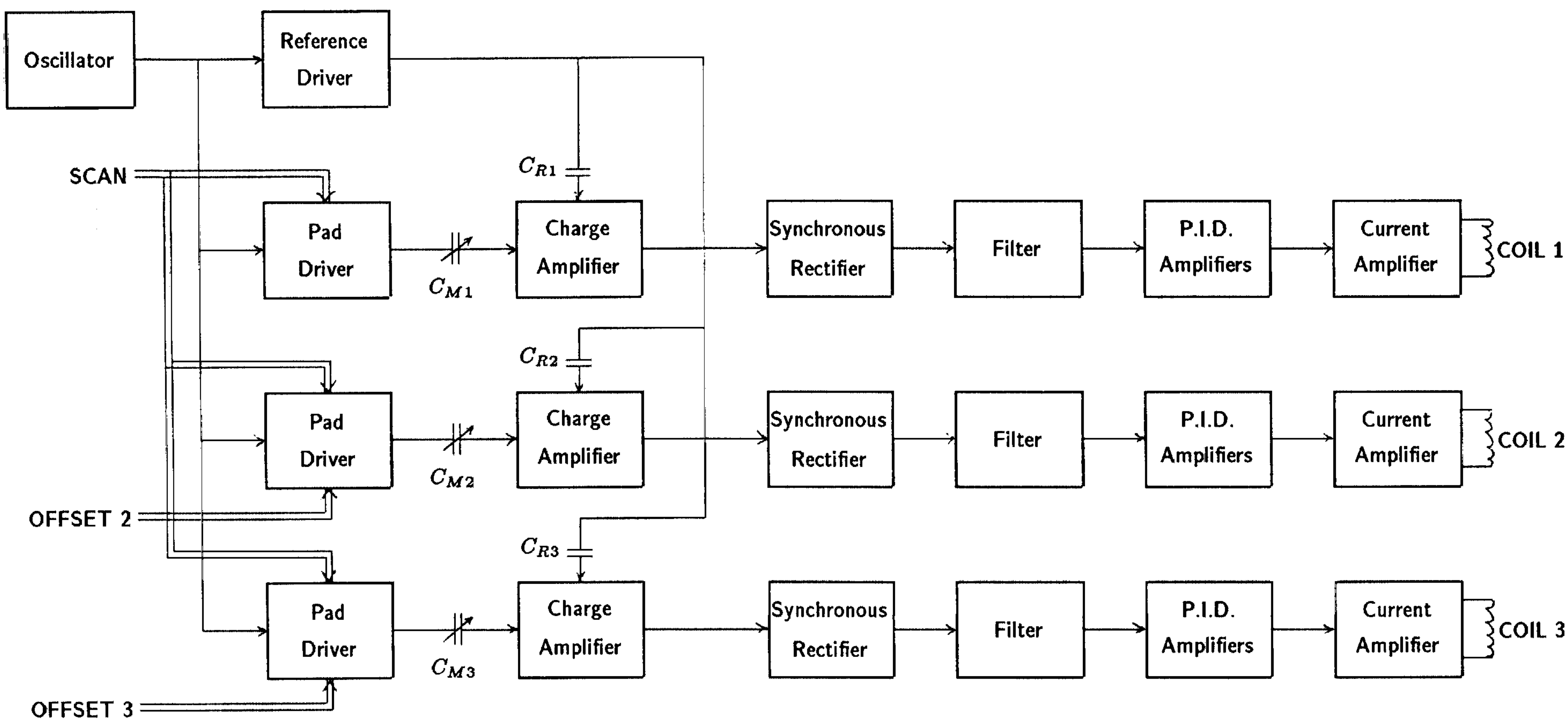

FIGURE 3

Block Diagram of Interferometer Servo Circuit

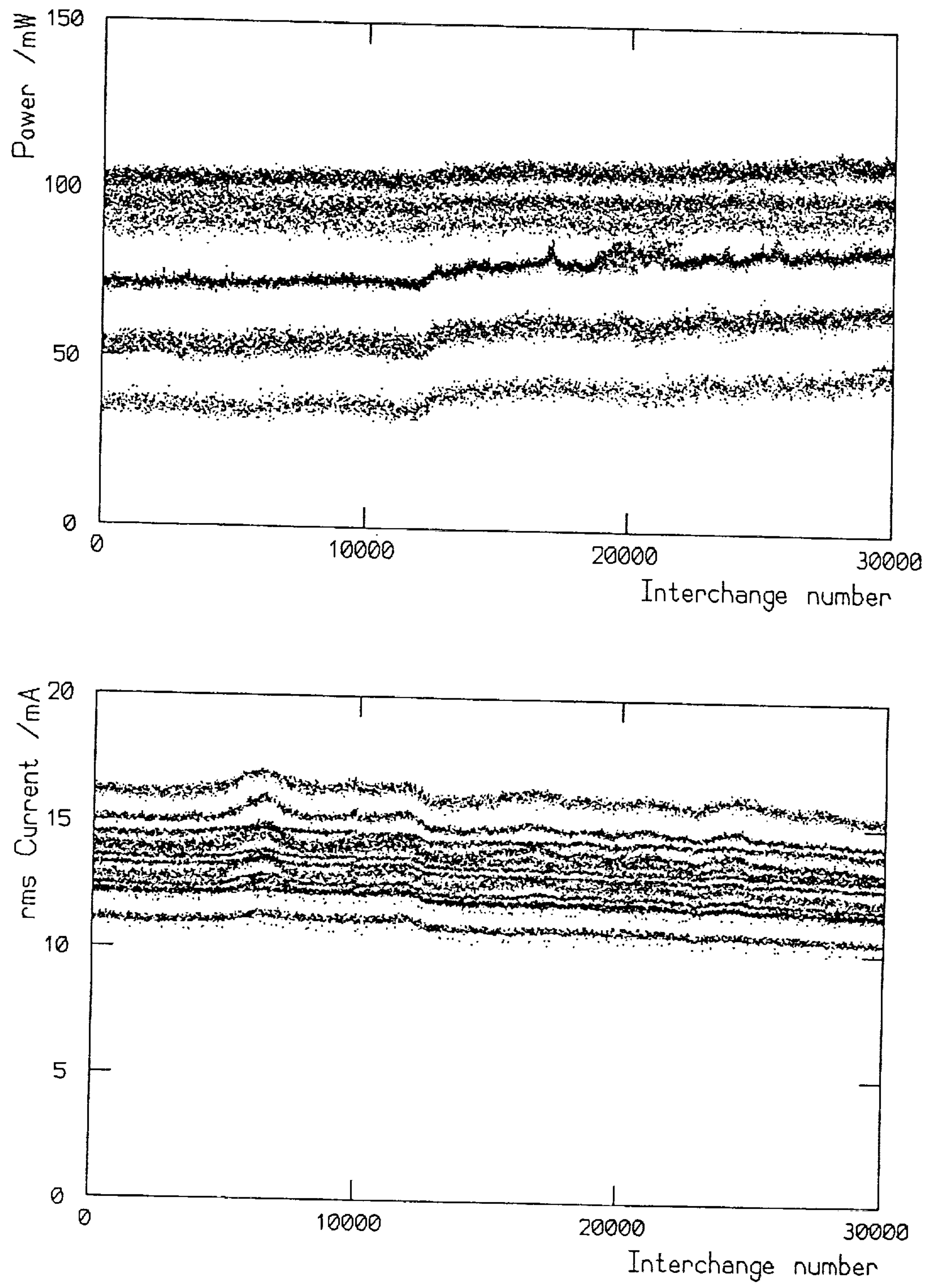

FIGURE 4

Measured power consumption and rms current (both per phase) during the cryogenic life test of a development model of the interchange mechanism. Each point represents one interchange. The bands correspond to interchanges between different combinations of the four wheel positions.