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FILTER WHEEL MECHANISM DESIGN

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A TECHNICAL DESCRIPTION OF THE FILTER WHEEL MECHANISM (XMM-OM)
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Introduction

A filter wheel is required for each of the two blue systems, to interpose any one of eleven optical elements between the dichroic and the appropriate detector.

Specification

The following specification relates to the blue system.

a) The transverse placement of the optical elements should be repeatable to ±100 μm, and should be initially adjusted to ±50 μm of the optical centre.

b) The position of the optical elements along the optical axis should be ±20 μm for the magnifier, but is less critical for the other elements.

c) The transit time of the filter wheel from one optical element to another should be no more than 5 seconds for the longest traverse.

d) The system should be designed for 18,000 revolutions (i.e. 39,600 five aperture operations) in orbit, preceded by 1,000 revolutions (i.e. 2,200 five aperture operations) before launch.
Note : It was later learnt that the mode of operation of the wheel would be one aperture at a time.

General description

The general arrangement of the filter wheel assembly is shown in figure 1. The eleven optical elements, each in its own mount, are equispaced around the wheel. The wheel is mounted in precision ball bearings, and has a gear cut on its periphery. It is driven by a pinion on the motor shaft, with a ratio of exactly 11:1. Thus one revolution of the motor moves the wheel from one optical position to the next. The wheel is rotated in one direction only.

Optical sensing on the motor and the wheel, enables the accuracy of the wheel position to be checked after each traverse, and for the datum position to be checked on every complete revolution. The datum can also be reset if the position is for any reason lost.

Wheel

The wheel material has been chosen to minimise the possibility of distortion due to locked in stresses and creep. The non heat treatable aluminium alloy 5083 has been selected, and this will be stabilised as necessary during the fabrication process.

The mounts for the optical components are located in bores in the wheel with a worst case transverse error of ±25 µm. Provision is made to adjust the position of the magnifier along the optical axis with shims.

Bearings

The wheel is mounted on Barden Bartemp deep groove instrument bearings which have some history of space use. These are dry lubricated by material deposited on to the balls from the Duroid cage. The bearings have covers on both sides, and the bearing enclosure has further covers to minimise debris exchange in either direction.

Two sizes are used. The larger (SR8 SS TB) is firmly clamped into the bore of the wheel, and onto the stub shaft. The smaller (SR6 SS TB) is clamped to the wheel but is free to slide on the shaft. The internal clearance of the bearings is taken up by a low rate coil spring exerting an axial force of 10 N on the free inner raceway. This force was determined to be acceptable from an analysis by ESTL Risley.

The axial vibration force, clearly exceeds this preload and the larger bearing has to support this force alone. The radial vibration forces are shared between the two bearings. The inertial force of the 0.762 kg wheel at 100g acceleration (considered a reasonable design figure allowing for resonant amplification) is 747 N. The larger bearing has a static load capacity of 1023 N, and the radial capacities of the two bearings are 1543 N and 1081 N.

There is a problem with the fit of the bearings in their housings and on the shaft. The maximum clearance necessary to ensure that the bearing shells are not unduly radially strained, using reasonable manufacturing tolerances and over the design temperature range, is unacceptably large in terms of the specified positional accuracy. It has been decided that the design temperature range will have to be limited to 10°C to 30°C, and that some radial strain will have to be accepted. This is however comfortably within the 12μm radial clearance of the races. The bearing which must slide on the shaft must clearly have some clearance in all circumstances, but this is easier to achieve on the smallest diameter in the system, and with materials of similar expansion coefficient. This sliding joint may be burnished or sputtered with MoS_2.

In order to avoid problems with bearing “blocking” by the cage, the wheel will be rotated in one direction only.

Gears

The material of the pinion is stainless steel to BS 970 321 S31. The pinion is splined and axially clamped on to the motor shaft.

The surface of the gear cut on the aluminium alloy wheel is hardened by anodising. The teeth of both the wheel and the pinion are sputter coated with molybdenum disulphide (MoS_2).

Motor

The drive motor is a size 23, four phase, 200 step motor made by Norcroft Dynamics Ltd. Redundant windings are not included, because redundancy is provided by the second blue system. One step of the motor, with an 11:1 gear ratio gives a movement of 203 μm at the radius of the optical components. The positional resolution of the motor is expected to be better than 10% of a step, and the optical elements should therefore be placed by the system to 20μm plus an allowance for gear backlash.

The mean friction torque (upper limit 0.6 mNm) of the wheel is insignificant compared with the available torque of the motor, and the design of the motor windings and power circuits is driven by inertial considerations (wheel inertia 0.006 kgm^2 or 0.00005 kgm^2 at the motor).

Tests have been carried out to determine the limiting pull in and pull out speeds and acceleration of the system, using a wheel inertia increased by a total factor of 2.2 on nominal. A series resistor equal in value to the winding resistance was used in the drive circuit, and this will be a standard flight feature, giving an approximation to a current sourced drive. It was decided from these tests that the following drive parameters should be used, all of which are less than 67% of the critical (synchronisation loss) values, even with the factored inertia.

Pull in speed	200Hz
Acceleration	2000Hz/s
Cruise speed	420Hz

This gives a traverse time over ten filters of 4.82 seconds.

It is being recommended that alternative, slower, stepping rates can be commanded to overcome operational problems, such as step loss, should they should arise.

<u>Sensors</u>

The wheel position will normally be determined in open loop mode by step counting from a known datum position. The datum position is when the blank is placed in the blue beam.

A system of position sensors is provided to relocate the datum position, should it be lost, and to verify the wheel position after every traverse. This system also confirms that the centre of any optical element has been found, although the element is not identified.

A reflective infra red position sensor is fitted to the wheel which gives a true output when the blank is within about $\pm 15^\circ$ of its correct operational position. The resolution required of this sensor is not great.

A further infra red position sensor, this time used in transmissive mode, is fitted to the rear end of the motor. An occulting disk with a small aperture, through which the sensor looks, is fitted to the rear extension of the motor shaft. This is used to determine the motor position to a single step.

If the two sensor outputs are true then the wheel must be in the datum (blank) position. If the motor sensor is true, but the wheel sensor false, then one of the other optical elements is in place. Which one, is determined from the step count. Various other operating methods are possible in the case of sensor failure, and it may even be possible to locate the wheel, albeit slowly, using the information from the detector.

Positional adjustment

The gearing backlash is determined by adjusters at the motor. The motor casing is still free to rotate, and can be adjusted and locked to set the circumferential position of the optical elements. Radial adjustment of the optical elements is achieved by moving and locking the whole filter wheel assembly on its baseplate. The position of the filters along the optical axis can be adjusted by shimming between the stub shaft and the baseplate, and an individual fine adjustment of the magnifier is made by shimming between its mount and the wheel.

Electrical

Power supplies to the motor and sensors, and signals from the sensors will be terminated at a 15 way connector mounted on the main structure beam. The motor is operated with negative common connections, and excited with phase order 4,3,2,1,4 etc. Datum phase is phase 1.