

# A very accurate filter wheel for a large field IR imager

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## ABSTRACT

HAWK-I is a near-infrared imager with a relatively large field of view. Two filter wheels with 6 positions each offer a choice of 10 filters. The filters are directly in front of the detector, a mosaic of 2 x 2 HAWAII 2RG 2048x2048 pixels detectors. A rather high positioning reproducibility (< 6 arc sec) is required in order to avoid any disagreement caused by subtraction of eventual fix pattern on the filters.

The document describes various drive systems which have been tested in order to reach the specified positioning reproducibility. This includes an interesting dissipation free locking system combining electro magnet and permanent magnet. Every solution is discussed and the performances measured in the laboratory during a long campaign of test are exposed. We also address the choice of other critical components like the ball bearings, mounting of the filters and cooling of the wheels.

**Keywords:** Cryogenics, mechanisms

## 1. INTRODUCTION

In a traditional case a filter wheel cannot be considered as a very critical function as the goal is generally simply to position a filter inside the optical beam within the reasonable tolerances in order to avoid any vignetting. In the case of HAWK-I, where the filters are right in front of the detector, the quality of the data might depend on the repositioning of the filter. Any dust and un-homogeneity of the filter could only be canceled if there are well subtracted between science exposure and calibration exposure.

## 2. GENERAL DRIVE PRINCIPLE

### 2.1 Description

Figure 1 shows the drive mechanism of the wheel. The wheel is driven using a spur gear system with a gear ratio of 1/6. We can recognize the following components: A small pinion (**1**, made of Vespel SP3) is attached on the motor shaft (**2**). This pinion engages in a large teeth wheel which is made in three slices. The two extreme wheels (**4**, made of Stainless steel) are rotationally preloaded against the central one (**3**, made of aluminum). This creates an elastic teeth and then acts as a backlash compensation gear.

The large teeth wheel is mounted onto the filter wheel (**5**) it-self which is guided in rotation using a pair of pre-loaded ball bearings (**6**). The two ball bearings are mounted with the inner ring clamped on an extension of the heat exchanger (**7**). The heat exchanger is used for pre-cooling via circulation of liquid nitrogen in a labyrinth feed with two stainless steel tubes. A heater and a temperature sensor are used to control the temperature of the wheel.

In order to allow the wheel and the filter to cool deeper than the rest of the surrounding mechanics, the heat exchanger (**7**) is mounted onto the wheel housing (**9**) via the thermal insulating ring (**8**).

A magneto resistor (**10**) which is activated by a small arm (**11**) mounted on the rear extension of the motor axis is used to generate a pulse for every revolution of the motor and then every time a filter is in position in the optical beam.

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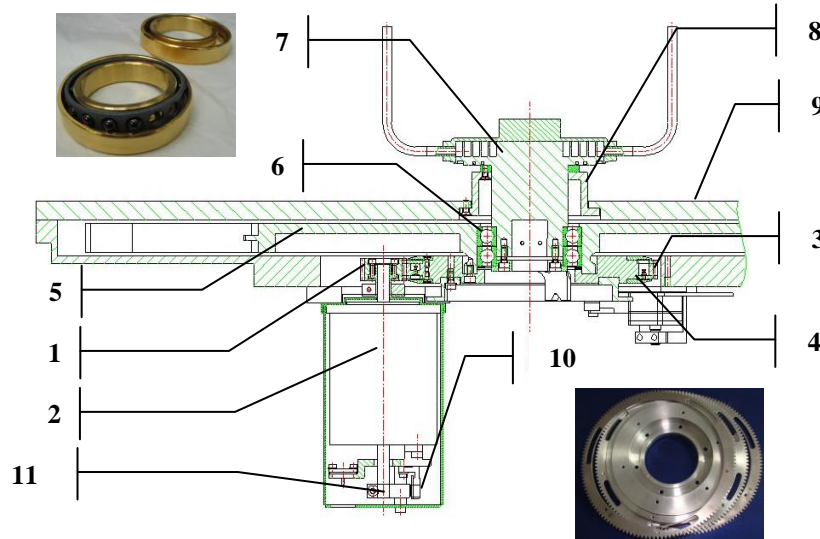


Figure 1: Wheel drive

## 2.2 Characteristic of the drive components

- Pinion:

Material: Vespel SP3

Number of teeth:  $Z_1 = 22$ , module  $m=1$

- Teeth Wheel:

Material: Main central wheel: Al 7075, MoS2 coated

Number of teeth:  $Z_2 = 132$ , module  $m=1$

Play between the teeth:  $15\ \mu\text{m}$ , corresponds to 50 arc sec on the wheel (1 motor step corresponds to 21.6 arc sec)

Ball bearing:

- Angular Contact dismountable ball bearing from IBC: 71907 ACD, races: gold coated, balls: Tungsten carbide

Bore diameter: 35 mm, Outer diameter: 55 mm

Axial pre load: 100 N

Running torque at cryogenic temperature (80 K):  $88\ \text{N}\cdot\text{mm}$

Thermal conductance at 80 K:  $0.170\ \text{W/K}$

- Motor

2 phase cryogenic motor from Phytron: VSS 57 500-2,5 UHV-Cryo

Torque at cryogenic temperature at 50 Hz:  $270\ \text{N}\cdot\text{mm}$

## 3. A FEW DESIGN ALTERNATIVES

During the pre-design phase a series of tests has been carried out to assess the reproducibility of this drive relying only on the motor step positioning and the anti-backlash gears. The performance of this drive has been compared to the one of different locking and indexing systems.

### 3.1 Spring locking system

This is the simplest indexing system. The angular position of the wheel is defined by a fixe cylinder which is pressed into reference Vee grooves machined on the periphery of the wheel. Practically the cylinder is a ball bearing mounted at the end of a rotating arm. A spring is used to press the bearing against the wheel. Between two locking positions the bearing is rolling with a minimum friction on the outer surface of the wheel.



Figure 2: Spring locking system

This system (shown in figure 2) has been intensively tested with various parameters. Different shapes have been used for the locking Vee and the influence of the pressing force has been assessed. Reproducibility of a few arc seconds ( $> 6$  arc sec) has been reached for some of the configurations. This system performs well when the wheel is driven from one position to the next one. Serious problems are encountered while passing over a locking position without stopping. The backlash which is necessary for the optimal operation has a side effect. Depending of the speed and inertia of the wheel different levels of oscillation are caused while the wheel is driven over one of the references. In some extreme cases this leads to a failure of the stepper control.

### 3.2 Additional motor locking

Figure 3 shows some technical drawings and a photography explaining the second configuration. The wheel is driven with the same mechanism. The backlash compensation wheel, like in the previous case, has been neutralized and the motor has been slightly pushed away from the large gear wheel. This ensures a significant play in the gear:  $\sim 10$  arc min. When the wheel arrives in position, a small ball bearing (1) mounted on the arm (2) is used to position the wheel accurately. For that an excenter (3) mounted on the shaft of the motor (4) is used to liberate the arm (2). The spring (7) rotates the arm such that the bearing (1) engaged in a reference Vee which is machined on the ring (6). The ring (6) is a part of the wheel (5).

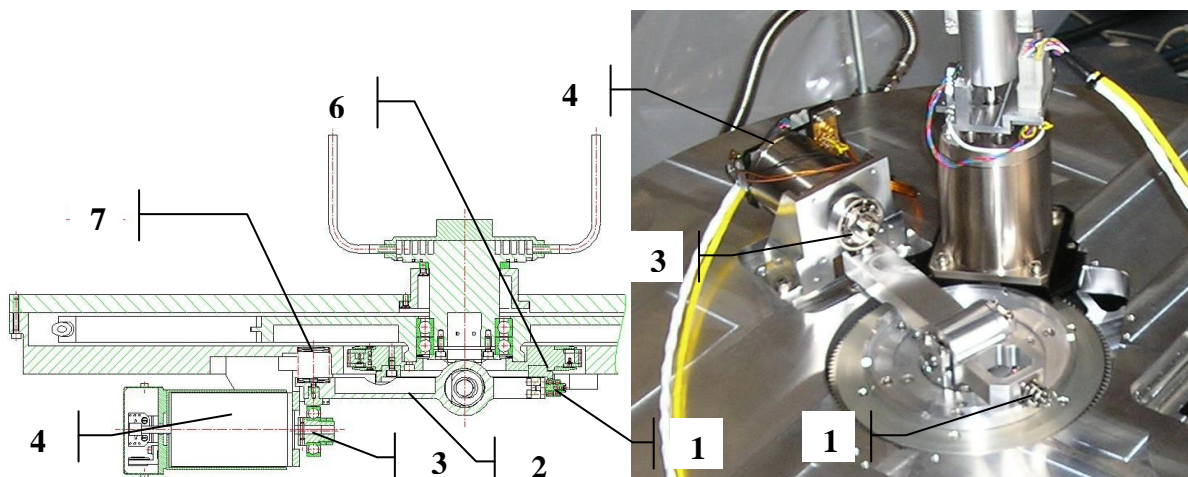


Figure 3: Motor locking

The intensive tests carried out on this system shows that it can reproduce with an accuracy of a few arc seconds ( $> 8$  arc sec). The main disadvantage is to have to control two motors in order to position one filter.

### 3.3 Retro-drive to a reference

Figure 4 shows a drawing and a photograph of the third solution which has been tested. The drive mechanism is in the original configuration with the backlash compensation gear. The wheel is rotated clockwise slightly further the position to be reached. During this part of the rotation the arm (3) falls into the lower part of the came (1).

Then the motor drives the wheel slowly back such that the special cam (1) is preloaded onto a small ball bearing (2). The final angular position is defined by the flanks of the cam. The ball bearing is mounted on a rotating arm (3), which escapes to leave the wheel rotating freely clockwise. A small spring (4) keeps it in the locking position. The main idea behind this design is to use the spring effect of the stepper motor to preload the wheel against a reference solution.

The test campaign has demonstrates clearly the limitation of this system. Some good reproducibility can be obtained if the wheel is driven extremely slowly back. The dynamic is very limited. Micro stepping is required for accurate positioning. As soon the elastic effect of the motor is over-passed the reaction degrades considerably the positioning accuracy. In a long term such a solution cannot guaranty better than 15 to 20 arc second positioning reproducibility.

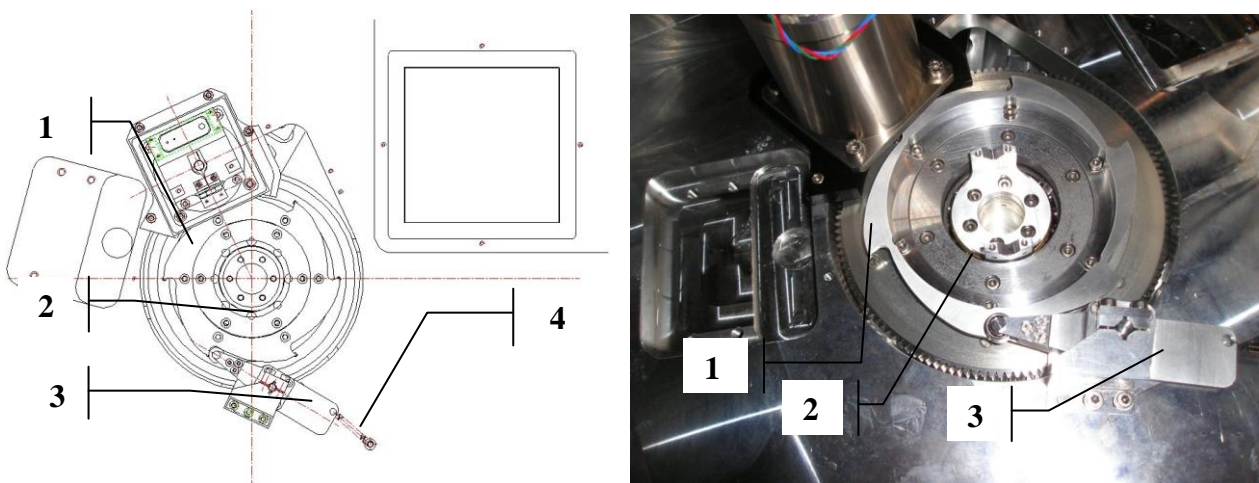


Figure 4: Retro drive

## 4. MAGNETIC LOCKING

### 4.1 Design

Basically this system (figure 5) is very similar to the one described before, it consists on a small ball bearing (1) mounted on a spring blade (2) and which is activated by a push/pull system. The push/pull system is an electro magnet (3) which either moves a cylinder (4) back onto a permanent magnet (unlock position) or remove it from the attraction field of this permanent magnet. In that case a spring (5) move the cylinder and such that the small ball bearing enter in a Vee groove manufacture on the circumference of the wheel (locked position). An additional intermediate articulation part (6) is used to avoid stress created by the conversion from translation to rotation.

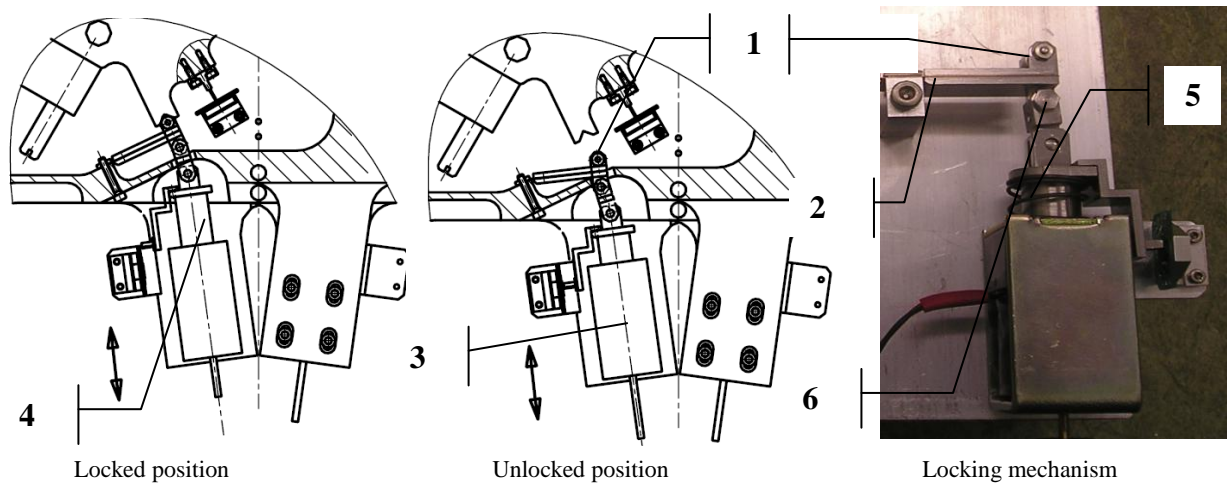


Figure 5: Magnetic locking system

## 4.2 Implementation

During the first validation only some 50 operations were done, this was enough to show the significant improvement introduced by this system. Unfortunately the permanent magnet used to block the activator in the unlocked position did not survive more than 100 operations. This part is simple part of magnetized iron and at low temperature it loses the magnetization under the hard shocks.

This magnet was replaced by extremely powerful magnet out of Neodymium Iron Boron (NdFeB). The disadvantage of this material is that the attraction force increases considerably at cryogenic temperature. It has been then necessary to reduce the contact surface in order to have an attraction force at cryogenic temperature such that the spring can extract it after the short electrical pulse.

Some other funny effects have also been discovered later in the testing. Most of the problems have been solved using a very well defined cylinder out of iron and all parts directly attached to it made from non magnetic material.

## 4.3 Test results

The reproducibility of the positioning is only one aspect of the final positioning. The wheel should also stay in position over the time of an exposure while the instrument is rotated to follow the field rotation. The position stability of the wheel has been measured for a residual un-balanced of 0.3N.m, which can correspond to a maximum difference of weight between two opposite filters.

The following table gives the information on the position measured on the two wheels before installation in the instrument.

	Wheel # 1		Wheel # 2	
	Reproducibility	Stability	Reproducibility	Stability
<b>Without locking</b> (With backlash compensation)	13 Arc sec	7.5 Arc sec	12 Arc sec	6 Arc sec
<b>With locking</b>	3 Arc sec	3 Arc sec	3 Arc sec	3 Arc sec

For a cryogenic instrument, the gain in performance should always be compared to the risks and the impact on the reliability. A life test has been performed in order to assess the reliability of the system. The results are not really convincing as it regularly failed after a few hundreds of settings. In most of the cases, it was not possible to detect any hardware failure. Re-starting a new sequence allowed to complete an additional series of a few hundreds of settings before a new failure occurred.

## **5. CONCLUSION**

Finally real test exposures have shown that the 12 to 13 arc seconds reproducibility reached by the base line system was largely enough to guaranty an optimal reduction of the data. It has been decided not to implement an extra complexity in the instrument and then to use the backlash compensation and no locking system.

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