# Review of NOTCam Bearings

*Graham Cox*

August 20, 2004

## Introduction

The NOT infrared instrument, NOTCam, mechanically consists of a 60cm cube vacuum vessel which includes within it several wheels, two for filters, two for other optical components and a camera and aperture wheel that are held at -200$^{o}$C. These wheels are driven by cryogenically cold stepper motors through a worm-gear arrangement. The worm engages on the rim of the wheels and they have a turns ratio of about 200:1 i.e. the worm turns 200 times for one revolution of the wheel. With the nature of typical observations the two filter wheels, and especially the one containing the broadband filters, are used the most. The worm-gear is mounted in a housing and connected to the stepper motor by a flexible coupling. The worm shaft is supported by two small bearings and these bearings have been been causing problems, see figure 1.

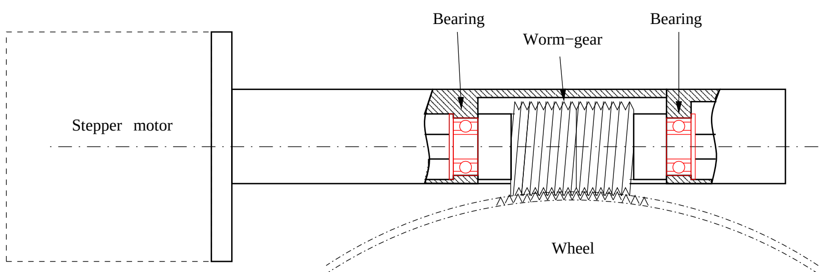


Figure 1: Schematic of Worm-wheel showing problem bearings

The bearing problem manifests itself by either you getting the wrong or no filter positioned in the optical beam when they are selected, or during initialisation of the instrument the filter wheel times out. What is happening is that one of the bearings is seizing up so causing the motor to miss steppers and so positioning the wheel incorrectly. There is no feedback from the motor or wheel to tell the controller where it. Once the wheels have been initialised, everything is done by dead reckoning based on the initialisation. So far we have had filter wheel #2 (defined as wheel C and which contains the broadband filter) fail twice and the other filter wheel once. Under normal operating conditions the bearings in the worm-gear of filter wheel two survived typically up to two years, this is equivalent to approximately 100 nights observing. The only solution once a bearing has failed is to open up NOTCam and replace it with a new one, this procedure takes almost two weeks due to the warming up and cooling down period for the instrument.

## Discussion

Originally the bearings using in the worm-gear were standard stainless steel flanged radial single row ball bearings supplied by SKF. The dimensions of the bearings are, internal diameter 6mm, external diameter 13mm and overall length 5mm including a 1mm thick, 15mm diameter flange. These bearings have been clean by NOT staff in acetone of all their lubricant and then coated (sprayed) with a $MoS_2$ (Molybdenum Disulphide) manufactured by Rocol and supplied by RS components (part number 196-3485), from an aerosol. The $MoS_2$ is described as OXYLUBE SPRAY (Formerly DFSM) Dry Film Anti-Scuffing Spray (-100$^o$C to +450$^o$C), inorganic bonded $MoS_2$ dry film lubricant, and suitable for use in vacuum environments. It is noted that this $MoS_2$ is only rated down to -100$^o$C. Later, after talking to the ING (Isaac Newton Group) we tried a different coating applied professionally. This second coating, though on the same SKF type bearings, was $WS_2$ tungsten disulphide, applied by WS2 Coatings Limited, England. $WS_2$ is generally considered a suitable material as an anti-seize lubricant in a vacuum. This choice proved to be a disaster with the bearings failing within six months of them been installed. This corresponded to less than 26 nights observing.

On inspecting the worm-gear bearings it is frequently found that at room temperature they will turn, though roughly, but we have had one that had completely seize such that even at room temperature it would not turn. A closer look at the bearings show that the ball and races look fine and this is consistent with the suspected problem and that is between the balls and the cage, also called the ball separator, where at this interface the balls slide where as for the race to ball interface they roll. This theory is enhanced since the stepper motor bearings, to date, have not failed and they turn as many times as the worm-gear bearings. The motor bearings are of another type supplied by RMB/Myonic[3] and have Duroid[1] cages. The exact material for the balls and races of the RMB bearings is unknown but believed to be either stainless steel of chrome steel.

Since it is found that even when a bearing refuses to move inside NOTCam at -200$^o$C it does turn when brought back to room temperature. This suggests that the bearing may be getting crushed by the aluminum housing. Aluminum has a temperature coefficient of thermal expansion twice that of stainless steel and thermal conductivity about five times. As a consequence it has been decided to remake the housing in stainless steel, this has been does by a local La Palma company.

Apart from the motor bearings all other bearings in the instrument are of the same type, standard stainless steel flanged radial single row ball bearings supplied by SKF and treated by NOT staff.

After our experiences it was decided to try and find a more suitable solution for the bearings. A paper written by Jean Louis Lizon[1] of ESO was referred to, RMB were asked if they could provide suitable cryogenic bearings and ESTL, who supply bearings for space application and other infrared instruments were consulted. Talking with people at the Glasgow SPIE meeting provided a reference and a web search was made.

# Lubricants

From a reference it has been found that $MoS_2$, $WS_2$ and $NbS2_2$, described as lamellar solids[2], and are known to be very good lubricants especially in vacuum. $MoS_2$ (and probably the others as well) is also known to have improved performance when used with PTFE cages, though has a limited lifetime. A warning regarding $MoS_2$, it is hydroscopic and as a consequence degrades if exposed to moisture.

As well as the lamellar solid lubricants soft metals[2] can also be used, these include lead, silver, gold and indium.

ESTL mentioned the possible use of lead as a lubricant which has many benefits for cryogenic applications. Using lead with cages made from dry machined self-lubricating bronze material is also an advantage. A minor disadvantage is when operating the bearings under normal atmospheric conditions they recommended you don't operate for >100,000 revs and at speeds less than 100rpm.

[1] Duroid is a trademark of Rogers Corporation and is believed to be PTFE

Ralf-Rainer Rohloff of the Max Planck Institute for Astronomy, Germany recommended (at SPIE Glasgow) the company Dicronite[6] who manufacture DL-5 which is a modified tungsten disulphide ($WS_2$). DL-2 is rated for vacuum down to a temperature of -185$^o$C. Max Planck's experience with this material has been very good with no apparent problems.

## Cage material

We were originally recommended by ROE (Royal Observatory Edinburgh) that we should obtain bearings from RMB with cages made of Duroid. ESO use cages made from cast nylon 6/6 and manufactured by Nylacast Ltd, Leicester. A potential idea cage material is Vespel SP3 from DuPont which is a $MoS_2$ filled polyamide, but is extremely expensive. Vespel is used in NOTCam as bush bearings for the shutter and as the material for the actual worm gears. ESTL have also proposed using self-lubricating bronze material and RMB have offered bearings with PGM-HT cages. PGM-HT, PTFE, Duroid, Vespel, Torlon and nylon are all polymers and are potential materials for cages.

One alternative material for cages, mentioned above, is dry machined self-lubricating bronze suggested by ESTL.

## Cryogenic Bearings Options

An example of a bearing using in cryogenic equipment is manufactured by RBC[4] Bearings. Their balls and roller bearings are made of AISI-440-C stainless steel, with special sub-zero treatment in liquid nitrogen. The bearing cages are made of fiberglass reinforced Teflon.

ESO[1] for their infrared imager spectrometer (ISAAC) use a cast nylon 6/6 cage and tungsten carbide balls, the race material is unknown but probably stainless or chrome steel. Their procedure for preparing the bearings is to disassemble and ultrasonic bath them in acetone. The bearings are then reassembled but initially with a 50% load and a generous application of $MoS_2$ on the cage, ran in, then repeated for increasing loads up to 110%. The bearings are then disassembled again wiped clean with paper and a final thin coating of $MoS_2$ is applied to the cage. The bearings are then finally assembled with tungsten carbide balls. The nylon cages are manufactured by Nylacast Ltd, Leicester.

RMB (or Myonic) supplied the bearings now fitted in the stepper motors. These bearings have Duroid cages and are no longer available but RMB have offered two possible alternatives for replacement bearings, one made of chrome steel with PGM-HT[2] cages with $MoS_2$ coated rings and the other, stainless steel rings with ceramic balls and PGM-HT cages. The prices for their two offers (June 2004) are for 20 pieces, €7880 and €5860 respectively. The details of these bearings are given in tables 1 and 2.

| RMB Part Number | Comments | Quantity | Unit price(€) |
|---|---|---|---|
| ULKZ 613-238PG-11/20-J739/5-Dry | $MoS_2$ on rings | 20 | 394 |
| ULKZ 613X-238PG-15/25-J858/7-Dry | Ceramic balls | 20 | 293 |

Table 1: Part number and Cost.

ESTL[5] have suggested taking the standard SKF stainless steel bearings disassembling them and coating with either lead, $MoS_2$ or silver. There is a question about manufacturing new cages or re-use the original one, since the space is tight. Their price was ∼£6500 for 15 pieces, (June 2004).

[2] PGM-HT is a polymer made by Barden Corp and is equivalent to PTFE

| Key | Description |
|---|---|
| ULKZ 613 | flanged bearing ID=6mm, OD=13mm, T=5mm |
| X | stainless steel (nothing chrome steel) |
| 238PG | 23 type comb or crown cage, 8 balls, ?PG = PGM-HT? |
| 11/20 | radial play Lower/Upper limits |
| J739/5-Dry | ? |
| J858/7-Dry | ? |
| MS | ?$MoS_2$? |
| PGM-HT | Polymer equivalent to PTFE made by The Barden Corp. |

Table 2: Key to RMB Part Numbers.

In addition to the companies mentioned above there is another called GRW (or ABIS Bearings) who manufacture miniature and instrument bearings that can be treated for arduous and hostile environments including high vacuum. These bearings are production items made from standard parts.

Another approach, rather than buying expensive specialized components, is to use standard SKF stainless steel bearings and clean then ourselves and treat then with $MoS_2$ spray. This is known to only have a limited life, estimated to be around two years for our most critical bearings, though since we will expect to be opening the instrument at least once a year we can take these opportunity to do some preventive maintenance on the bearings i.e. replace them. We now have an alternative $MoS_2$ spray made by Dow Corning called MOLYKOTE(R) D-321-R and is rated to -185$^o$C. The Spanish suppliers are Univar Iberia SA, Barcelona. Tel 93 229 10 05, Fax 93 229 03 35 email gilles.dumont@univareurope.com. This is also by far the cheapest option, costing only a couple of hundred Euros for the bearings and less than a day to do a complete change of all the critical bearings, twelve in total, but not an ideal solution due to the constant maintenance required and question mark over the exact life time!

A suggested recipe for treating the bearings in-house has been provide to use by Peter Hastings at the ATC (Astronomy Technology Centre), Edinburgh, and is given below, though this is not the procedure we have used up to now.

1. Clean bearings thoroughly by flooding with iso-propyl alcohol - do not use an ultrasonic cleaner.
2. Air dry the bearings.
3. Mount them on a spigot in a lathe.
4. Rotate the whole bearing slowly and spray them sparingly with $MoS_2$ (or equivalent).
5. While they are rotating, bring the outer race to a halt (a gloved finger is ideal for this) so that the balls and retainer rotate differentially to the inner race. Continue a light spray of lubricant.
6. Stop spraying.
7. Continue to run the bearings slowly until all the carrier for the $MoS_2$ has evaporated.
8. Clean bearings thoroughly by flooding with iso-propyl alcohol - do not use an ultrasonic cleaner.

There should be an even, slightly shiny, light gray coat of $MoS_2$ on the tracks and the balls. If not, then repeat steps 4-8.

Once the bearings have been treated, and before they are mounted in their assembles, they should not be subjected to high impact loads because there is no oil film between the balls and the races or cages to cushion the force.

## References

[1] Lizon, Jean Louis, *Selection, preparation and lubrication of middle size ball bearings for infrared instruments*

[2] *Barden Corporation, FAG Aerospace and Super Precision Bearings Division*

[3] *www.myonic.com, RMB Catalogue*

[4] *www.rbcbearings.com, RBC Aerospace Specialty Bearings*

[5] *www.solutionsinengineering.com/ESTL, AEA Technology - ESTL*

[6] *www.dicronite.com*