HIGH THERMAL CONDUCTIVITY BALL BEARINGS FOR INFRARED INSTRUMENTS

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ABSTRACT

Infrared instruments need to be cooled to minimize thermal radiation. The cooling time of small instruments is directly dependent on the cooling time of the rotating components. Cooling of a wheel by contact with balls of the ball bearings is not efficient. One way of improving the cooling efficiency is to have a braid connection, but this leads to a restriction in rotation. Another way is to use a slip-ring, but this has the disadvantage of leading to a higher drag. A completely different approach is to increase the thermal conductivity of ball bearings. By using various materials to produce either solid or coated balls and experimenting with various race coatings, it is possible to increase the thermal conductivity by a factor greater than two. In the attached diagrams we give details of the tests carried out to evaluate thermal and mechanical performance.

INTRODUCTION

Cryogenically cooled infrared instruments become operational only after all optical components have reached a steady state temperature. It is often desirable to have the instruments in operation within the shortest possible delay even after adjustments which require intervention inside the cryostat. These two conditions make it necessary to keep the cooling time as short as possible.

In order to be remotely selectable, optical components are usually mounted on a wheel which ideally is cooled via its bearings. The thermal conductance of a ball bearing of a given size depends on three parameters: the material of the balls, the nature of the material at the point of contact and the contact pressure. As these parameters also affect the mechanical performance, it is necessary to carry out torque and reliability measurements while changing one of these parameters.

The aim of this work is to select a bearing solution which can be used universally for any rotating element of any future instrument.

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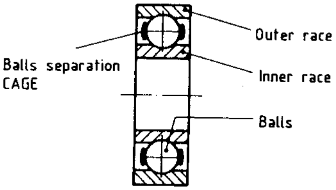
Table 1. Composition and reference of the different ball bearings (**R M B, Eckweg 8, CH-2500 Biel)

BALL BEARING :



Axis diameter: 8mm - outer
Diameter 19mm - 7 balls from R.M.B.
ST= Stainless Steel AISI 440 C
Composite: DQ 1 AN 1400 from IHG

REF. NUMBER	COATING	BALLS MATERIAL	COATING BALLS	CAGE MATERIAL
1	none	ST	none	ST
2	none	ST	none	Composite
3	none	Al_2O_3	none	Composite
4	none	Tungsten Carbide	none	Composite
5	none	Copper-Beryllium	none	Composite
6.	gold 2 um	ST	none	Composite
7	gold 2 um	Al_2O_3	none	Composite
8	Mo S_2 Sputtering	ST	none	Composite
9.	Microseal	ST	Microseal	ST+ Microseal
10	Silver	ST	gold 2 um	Composite
11	Titanium Nitride	ST	none	Composite

THERMAL EVALUATION

We are using deep groove ball bearings which are commercially available from the company R.M.B. They have a bore diameter of 8 mm, an outer diameter of 22 mm and are fitted with seven balls of 4/32 inches diameter. Each bearing has been dismounted and, after coating of the races, has been reassembled either with the original balls or with balls of a different material. Table 1 gives the composition and references of the different bearings for which thermal and mechanical performances have been measured. Figure 3 shows the set up used for the thermal measurement. A 300 g stainless steel wheel is mounted on an axle which is directly attached to the cold plate of a bath cryostat. The axial preload, produced

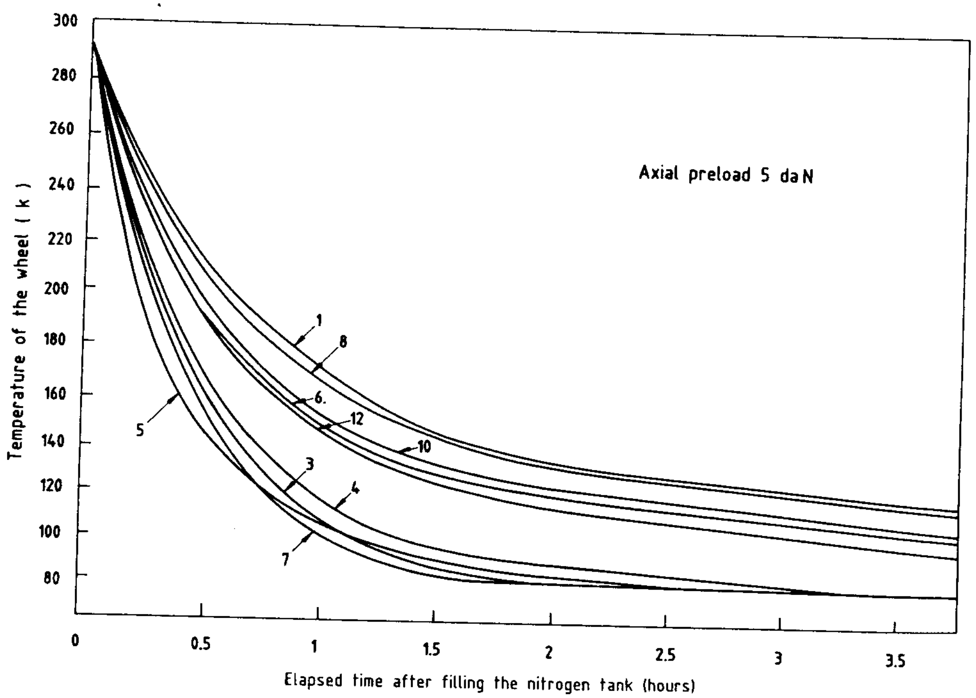


Fig. 1. Time variation temperature of a 300 g stainless steel wheel mounted with different ball bearing types

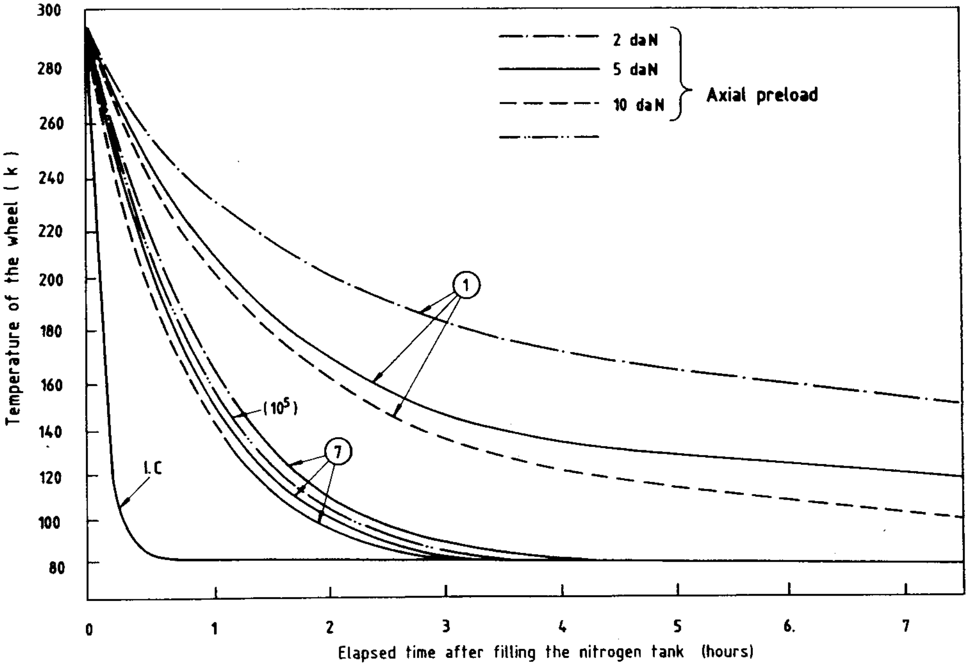


Fig. 2. Time variation temperature of a 300 g stainless steel wheel. The three curves No. 1 show the temperature evolution of the wheel mounted with ball bearings No. 1 using three diferent axial preloads.

The three curves No. 7 show the temperature evolution of the wheel mounted with ball bearings No. 7 using three different axial preloads.

The curve marked 10^5 shows the temperature evolution of the wheel mounted with ball bearings No. 7 using a 5 daN axial preload after 105 revolutions.

The curve marked I.C. shows the temperature evolution of the inner rings of the ball bearings.

by spring washers, can be adjusted by shimming. The temperature of the wheel is measured using the thermocouple T_1 while a second thermocouple T_2 is needed to measure the temperature of the inner ring of the ball bearing. The complete wheel is surrounded by a highly polished radiation shield and the residual pressure is lower than 10^{-6} mbar so that we can assume that thermal exchange by contact is largely dominant. The temperature records are shown in figures 1 and 2.

MECHANICAL EVALUATION

The experiment is set up in a dedicated cryostat fitted with a rotating axle. One end of this axle is a kind of mandrel which is cooled to the temperature of liquid nitrogen. A D.C. motor and a revolution counter mounted in air and at room temperature are attached at the other end. A wheel is mounted on a short axle in the way previously described in figure 3. This small assembly is installed in the cryostat so that the axle is rotated by the mandrel while the wheel is kept angularly fixed. This immobility is ensured by a thin wire which is at the other end attached to a load measuring device. In order to avoid possible calibration problems the load cell is mounted on the warm wall of the

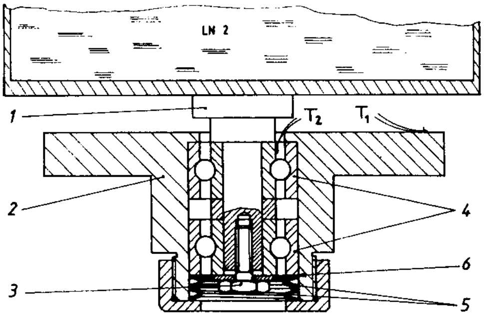


Fig. 3. Test set-up
(1) Axel. (2) Wheel. (3) Clamping screw. (4) Ball bearing under test. (5) Spring washers. (6) Shimms.

cryostat and the wire is made from a material which has a very low thermal conductance. The load cell measure the effort necessary to prevent the wheel from rotating. This force is directly proportional to the rolling resistance (torque) of the ball bearings.

Figure 4 shows the static torque of various ball bearings as a function of the axial preload.

Several pairs of ball bearings have been run until a failure occurred. The evolution of the torque against the number of revolutions is shown in figure 5. The small bar displayed peerpendicular to some of the curves indicates the torque noise.

DESIGN PROPOSAL

Cooling via the ball bearings means that one of the rings of the ball bearings is directly linked to the heat sink while the part which is to be cooled is mounted on the second ring. This method results in the building

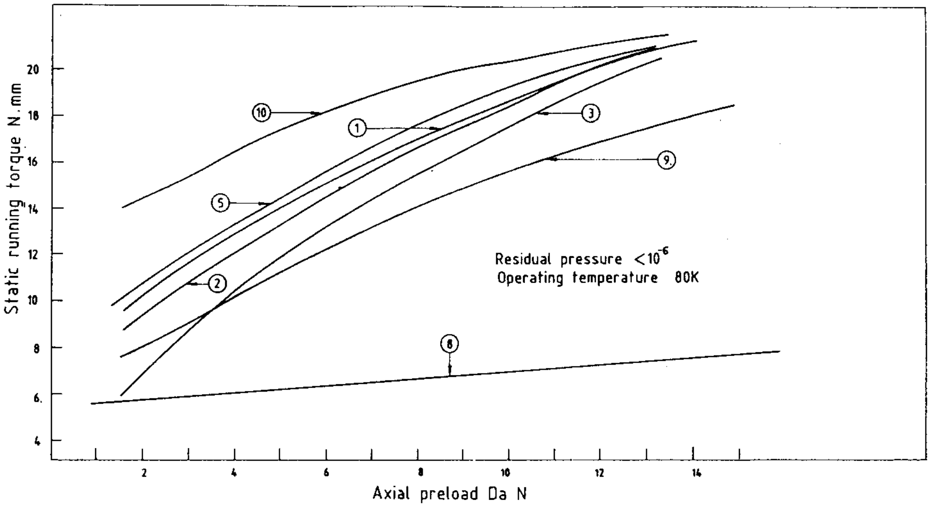


Fig. 4. Static running torque at 77K

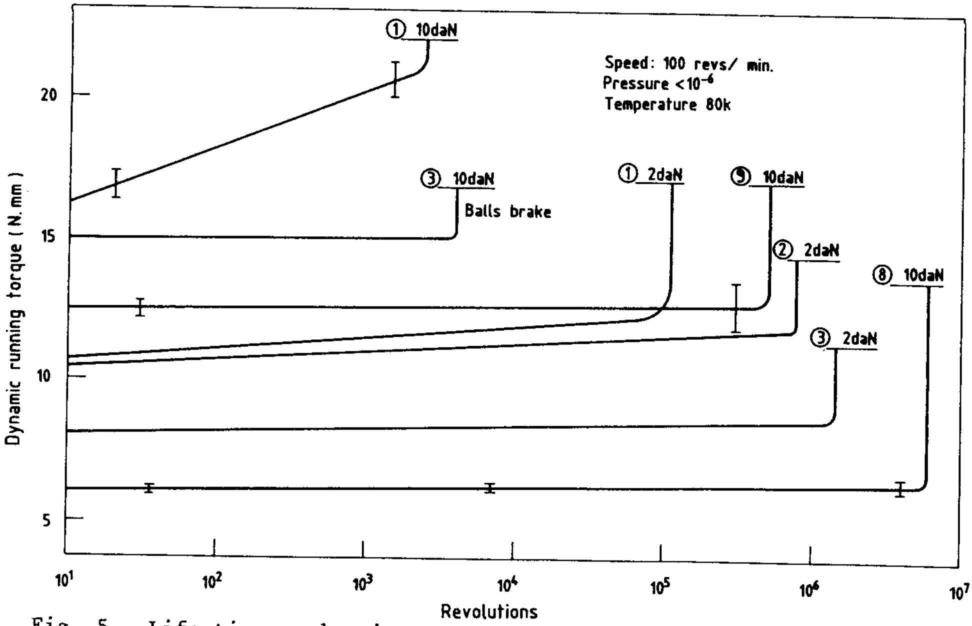


Fig. 5. Life time evaluation
The different curves show the evolution of the dynamic torque against the revolutions number at a temperature of 80 K. The small bars represent the torque noise

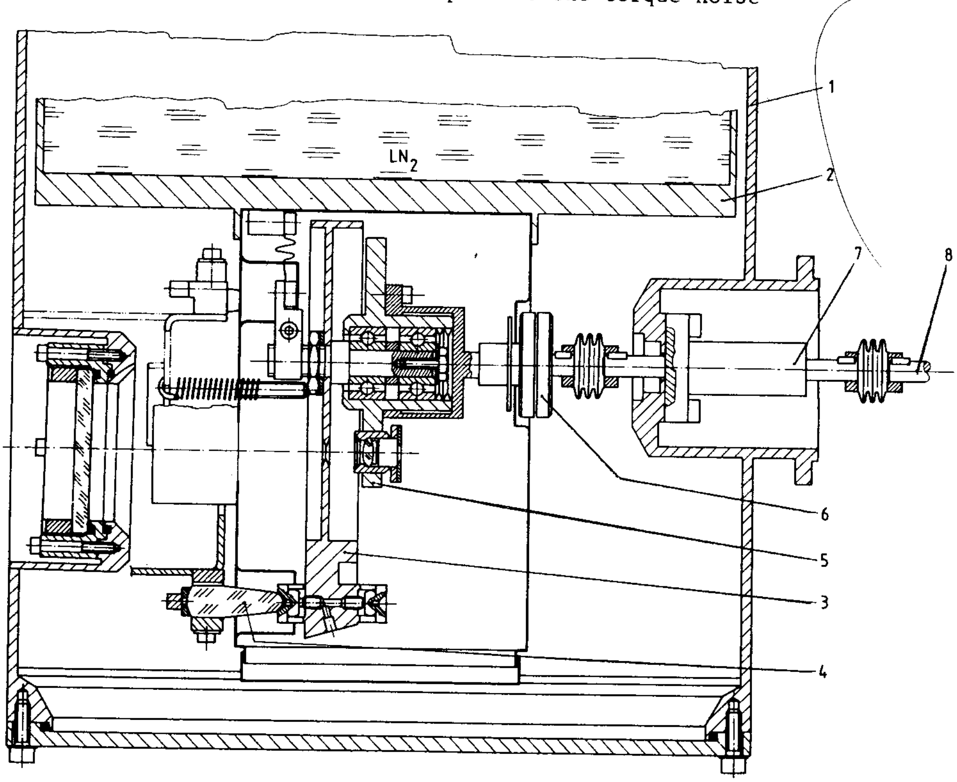


Fig. 6. Design proposal
(1) Vacuum vessel. (2) Nitrogen tank. (3) Structure. (4) Thermal insolated kinetic mount. (5) Lens wheel. (6) Rotary thermal insulator. (7) Rotating ferrofluidic seal. (8) Control unit.

up a large thermal gradiant between the two rings during the first minutes of cooldown (see curve I.C. and figure 3). In order to avoid that thermal shrinking of the coldest part causes any damage to the ball bearings we have adopted a construction which departs slightly from the conventional design: the rotating load is fixed to the outer rings of the ball bearings.

Figure 6 shows the design of a lens wheel in a cryostat. A cold structure which can be used for several purposes is positioned inside the vacuum tank on a thermally insulated kinetic mount. This structure is kept in position by a spring. The axle is fixed to this structure and is thermally linked to the cold plate of a bath cryostat. The inner rings of the ball bearings are rigidly fixed on the axle while the outer rings are spring loaded into the wheel. A control unit including motor, tacho, brake and high resolution encoder is mounted outside the vacuum vessel. A rotating ferrofluidic vacuum seal is used to transmit the rotation to the interior of the vessel. The wheel is brought in rotation via a coupling bellows and a low thermal conductance coupling. The coupling which is a flat universal joint using glass balls as pivots and a glass plate as cross piece has the extra advantage, in combination with the bellows, of being able to compensate for any mechanical misalignment.

CONCLUSION

The ball bearing No. 7 fitted with balls made from Al_2O_3 running in gold coated races gives the best thermal performance. The poor mechanical performance of the Al_2O_3 balls while increasing the axial preload should not be a reason to reject this bearing. A cooling solution as described here is only reasonable for relatively small moving masses. Therefore, the minimum axial preload which is required to ensure good mechanical accuracy and good mechanical stability can remain low.

No test was carried out at temperature lower than 80K but the thermal conductivity figure of Al_2O_3 makes this type of ball bearing also attractive for use at lower temperatures. The aforementioned performances could also be improved by using dismountable oblique contact ball bearings which can accommodate a larger number of balls.

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