BALL BEARING TESTS TO EVALUATE DUROID REPLACEMENTS

M J Anderson,
ESTL, AEA Technology Space,
RD1/164
Birchwood Technology Park,
Warrington, UK
WA3 6AT
Tel: +44 1925 253087
Fax: +44 1925 252415
e-mail: mike.anderson@aeat.co.uk

ABSTRACT

ESTL has completed a programme to identify and qualify a self-lubricating material to replace RT/duroid 5813 ("Duroid"), for ball bearing cage applications in space mechanisms. Following literature reviews, material evaluations, friction and wear testing and a ball bearing screening test programme, PGM-HT (a PTFE/MoS_2/glass fibre composite) was selected for evaluation in ball bearings.

PGM-HT cages were tested extensively in conditions representative of that experienced by a selection of current mechanism applications. Different types (and sizes) of ball bearings and cages were tested over a range of operating speeds, loads (contact stresses) and under different environments.

From these tests, it was concluded that the torque behaviour of PGM-HT lubricated bearings was identical to that of Duroid. A design guide was then prepared to summarise the findings and assist designers with torque and lifetime predictions.

INTRODUCTION

In many space mechanism applications, precision ball bearings are used to provide low friction, high stiffness and rotary motion over long lifetimes. The simplest mode of lubrication of such bearings is by transfer from a self-lubricating cage. The cage, which separates the balls, transfers lubricant via intermittent contact between the balls and the cage, followed by transfer of lubricant from the balls to the races.

For 30 years, a self-lubricating polymeric cage material, RT/duroid 5813 (Duroid), manufactured by the Rogers Corporation, USA, was used extensively in precision bearing applications in space and vacuum, often in conjunction with sputtered MoS_2 films applied to bearing races and rolling elements. The friction, wear and lifetime characteristics of Duroid have been widely studied and quantified, and its use in space applications is well documented. The manufacture of Duroid has now ceased, remaining stocks are nearly exhausted, and an alternative material whose tribological performance is proven and documented is not currently available for space applications. There is therefore considerable concern in the space community regarding the identification and qualification of a suitable alternative self-lubricating cage material.

A programme of work was therefore carried out to identify and document the performance of a replacement material for existing Duroid cage applications and for use in future self-lubricated ball bearings used in space mechanisms.

BALL BEARING TEST PROGRAMME

Previous work [1, 2] involving tribometry tests and initial bearing tests had resulted in PGM-HT being down-selected for a comprehensive series of bearing tests. This test programme investigated the following:

Different bearing types/sizes
Different cage designs – e.g. snap-over and full ball pocket
Effect of contact stresses above and below the critical peak stress of 1200 MPa, for PTFE transfer films
Compatibility with sputtered MoS_2 films
Type of motion - oscillatory and unidirectional
Cage wear
Effect of temperature
Effect of speed
Environment
Bearing torque and torque noise as a function of preload
Running-in requirements

Based upon the findings, a performance guide was to be prepared, the aim being to summarise the results of the test programme and provide guidelines for torque and lifetime predictions.

Test Parameters

The bearing types, dimensional envelope, peak contact stresses and temperature ranges are summarised as follows:

Bearing, (ODxBxW, mm)	**Peak Stress (Outer, MPa)**	**Temp range (^{o}C)**
ED20 42x20x12	716-946	+20
SR3 12.7x4.76x 3.97	800-1460	-30 to +60
SR6 22.2x9.52x 7.14	800-1400	+20
SEA45 58x45x7	500-1100	-40 to +60

The test conditions were intended to simulate the operational conditions of a Metop deployment actuator and Earth Sensing Mechanisms, for SR3 and SEA45 bearings, respectively, or for comparisons with existing data.

SUMMARY OF RESULTS

The observations made were as follows:

- Baseline validation testing, under standardised test conditions, of PGM-HT cages fitted in ED20 bearings revealed that their torque characteristics were consistent with those of Duroid-lubricated bearings.

- Summaries showing the operational torque limits for the all the test bearings studied, in vacuum and at room temperature, are provided in Figures 1 to 3.

- The torque of PGM-lubricated bearings exhibit three distinct phases. These are:

  - an initial running-in phase during which lubricant transfer is established and in which the mean and peak torques can exceed the subsequent run-in torque levels by up to an order of magnitude.

  - a steady-state torque phase following running-in when and corresponding to the establishment of a transfer film on the bearing races.

  - failure, where the torque level increases due to cage wear-out or debris build up.

- The test data for bearings of different sizes and with different internal geometrical and cage parameters showed that the torque results for PGM-HT lubricated bearings could be predicted using CABARET bearing code and by extrapolating Duroid data from ED20 bearing test results.

- Testing PGM-HT lubricated bearings confirmed that a critical Hertzian contact stress limit exists. At stresses below 1200 MPa (peak), steel wear was not observed and transfer films proved to be effective lubricants. Above 1200 MPa, steel wear occurred.

Based upon the test results from this programme and from correlations with Duroid test data, it is concluded that PGM-HT will behave in an essentially identical manner to Duroid in self-lubricating ball bearings. From the findings of this programme the PGM-HT material is considered verified as being suitable for use in self-lubricating, ball-bearing (space) applications for which Duroid was formerly base-lined.

PEFORMANCE GUIDE

A performance guide (referred to as the “Guide”) was prepared as part of this programme. The objectives of the Guide are as follows:

- To summarise the as-measured torque characteristics of the ball bearings fitted with PGM-HT cages under conditions representative of space mechanism applications.

- To provide guidelines for estimating the mean torque, peak torque and torque noise characteristics for ball bearings fitted with PGM-HT cages (based on extrapolations of the bearing torque data obtained in this programme).

- To correlate lifetime predictions from an existing Duroid design guide [3] for bearings operating in air with the experimental lifetimes obtained in this programme.

Torque predictions

The performance guide allows prediction of bearing torque through utilisation of the experimental torque data obtained in this programme and ESTL’s CABARET bearing code. Essentially the method is as follows:

- Compute (using CABARET) the effective sliding friction coefficient (μ) from the steady-state torque values of run-in PGM-caged bearings.

- Use this value of μ to predict the steady-state torque of the design bearing at the intended operational load.
- Use the guideline data to predict from the computed steady-state mean torque the following:
  - the expected mean and peak torques during running-in
  - the expected range of mean torques during steady-state running
  - the expected maximum peak torque during steady-state running

Note that it will be necessary to carry out more detailed analyses using CABARET to take other factors, e.g. thermal and fit effects arising from the bearing housing, shaft and surrounding structure, into account.

Lifetime Predictions

We have devised a method for predicting the useful life of PGM–caged bearings. This method is based upon that used in a design guide [3] for Duroid-caged bearings. The method is currently applicable when the following conditions apply:

- The wear rate of PGM-HT is similar to that of Duroid (measurements have verified that this is the case, with the wear rate of PGM being slightly less than Duroid)

- The wear rates of PGM as measured in pin-on-disc measurements in air and vacuum are applicable to sliding interfaces within the bearing (i.e. ball-to-cage pocket; cage-to-land sliding) .

- For conditions where the peak contact stress is less than 1200 MPa, lifetime is defined as 15% loss of cage volume which corresponds to the wearing through of nominally two-thirds of the widths of the cage ball-pocket separators.

Given the above conditions, the method for predicting life is as follows:

1. Identify the following bearing parameters:
   Bearing size (bore, OD, PCD: in mm)
   Ball complement
   Rotation speed (revs/min)
   Operating temperature (deg.C)

2. Calculate the equivalent radial load, R_E from:

$$R_E = 2.9A + R$$

where,

A = axial load (MN)
R = radial load (MN)

3. Using R_E calculate a Bearing Factor, R_E /n.d2,

   where n = ball complement
   d = bearing bore (mm)

4. Calculate the bearing life from the charts provided within the guidelines.

The above method was used to estimate the lifetimes of the test bearings used in this programme. For example, for ball bearings operating below 1200 MPa peak stresses, lifetimes in excess of 5 x 10^8 revs are predicted for SR3 and SR6 bearings.

We are currently carrying out extended tests on PGM-caged bearings in order to generate additional life data with which to judge the accuracy and applicability of the lifetime model.

CONCLUSIONS

It is concluded that PGM-HT is an effective replacement for Duroid as a self-lubricating ball-bearing cage material for space applications. The torque data generated provide essential practical data for design engineers who intend using PGM-caged ball bearings. This data, when used in conjunction with the CABARET bearing code, can be extrapolated to allow torque predictions for ball bearings which are of a different size and geometry to the test bearings used in this study. Furthermore wear and life data has been obtained which will prove invaluable in the prediction of the useful life of PGM-caged bearings. A PGM-cage Performance Guide has been prepared to assist designers in the prediction of bearing torque and life.

ACKNOWLEDGEMENTS

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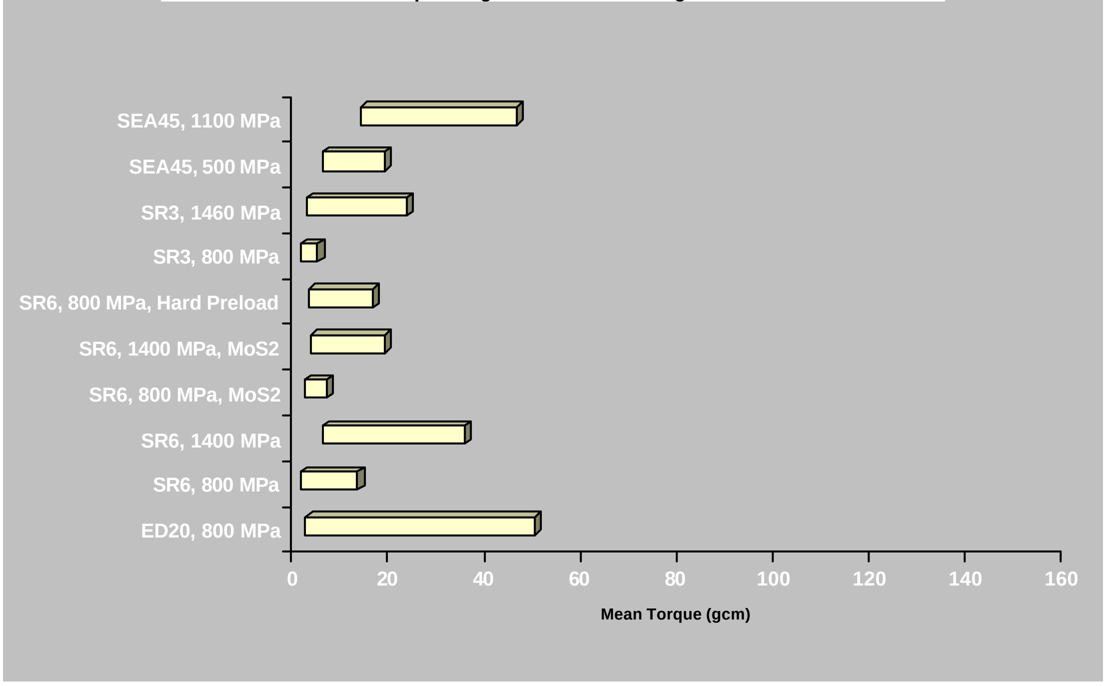
Fig. 1 Summary of mean Torque Limits for ED20, SR3, SR6 and SEA45 Ball Bearings Operating in Vacuum at 20 deg C



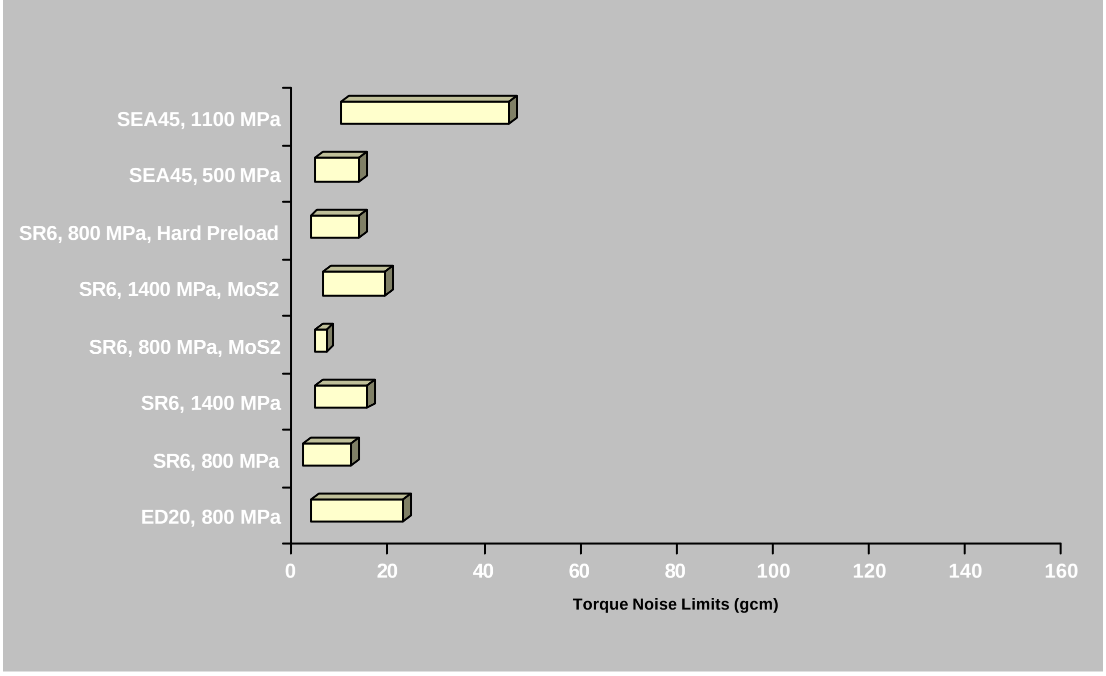


Fig.2 Summary of torque Noise Limits for ED20, SR3, SR6 and SEA45 Ball Bearings Operating in Vacuum at 20 deg C

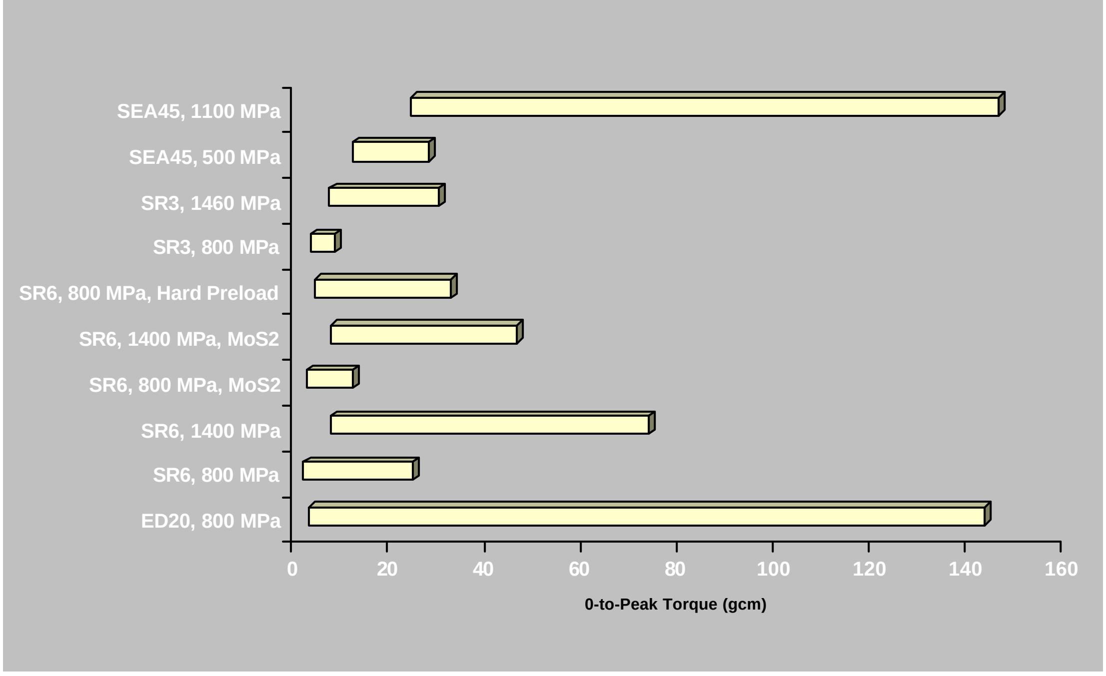


Fig.3 Summary of 0-to-Peak Torque Limits for ED20, SR3, SR6 and SEA45 Ball Bearings Operating in Vacuum at 20 deg C