DEVELOPMENT OF MOTOR BEARINGS FOR A NEW SADA (BEPI COLOMBO)

J. Kreuser [(1)], R. Bachmann [(1)], B. Bergrath [(1)], B. Heinrich[(2)], J. Zemann [(2)]

[(1)] CEROBEAR GmbH, Kaiserstrasse 100, 5134 Herzogenrath, Germany
E-Mail: cb-sales@cerobear.de;
[(2)] RUAG Schweiz AG,RUAG Space, Schaffhauserstrasse 580, 8052 Zürich-Seebach
Email: Josef.Zemann@ruag.com

ABSTRACT

The special requirements of the new MPO Solar Array Drive Assembly (SADA) developed for the BepiColombo program demanded also new ball bearing designs. In addition to typical requirements for other bearings in space mechanisms, the BepiColombo mission is characterized by a non-operating time of six years at extreme environmental conditions. In cooperation with RUAG Space CEROBEAR has developed different types of ball bearings for this SADA including motor bearings for the drive, a customized stepper motor.

The purpose of this paper is to present and summarize the results of the development of the motor bearings of the SADA.

1. BEARING DESIGN DESCRIPTION

The bearings described in this paper are angular contact ball bearings, assembled as bearing pairs in X-configuration (face-to-face). The bearings are preloaded to withstand the high bearing loads during launch. The bearing preload is obtained by a small gap (5…8 µm) between the outer rings.

For the installed bearing pairs this gap is closed by an axial clamping force and the bearing pair is preloaded then. In comparison to a not preloaded bearing a preloaded bearing provides a relatively constant stiffness in axial direction at different load situations. The dimensions of the bearing pair are shown on Fig. 1.

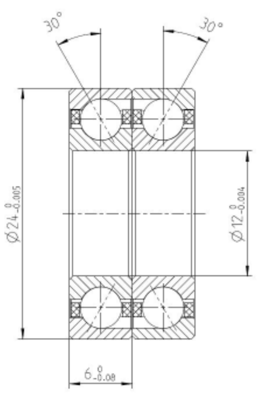

Figure 1: Cross section of bearing pair

Due to the high bearing loads during launch a high bearing stiffness and therefore a high preload is required. On the other hand a bearing with high preload generates higher friction and therefore the bearing described in this paper has been made in two versions, a high preloaded (Version A: 180 N) and a low preloaded (Version B: 80 N). This paper describes test results only for the high preloaded bearing (Version A). The results for the low preloaded bearing are comparable.

Table 1. Main Design parameters

Material rings	AMS 5898	(X 30 CrMoN 15 1)
Material balls	AISI 440 C	(optional: Si3N4)
Material cage	PGM	(optional: Vespel SP3)
Lubricant	MoS_2-coating	Blösch (optional ESTL
No. of balls	10	(per bearing)
Ball diameter	3,969 mm	
Pitch circle diameter	18 mm	

The bearing raceways on inner and outer rings are coated with molybdenum disulphide (MoS_2) used as a dry lubricant. A wet lubrication (e.g. with oil or grease) was rejected because of a long operational time combined with high temperatures, especially close to mercury (6 years interplanetary journey + 1 year nominal + 1 year extended lifetime, operational temperature 90°C with peaks 105°C, qualification margin additional +20°C) and having so the risk of evaporation and degradation in combination with the contact pressure of oil during this time.

The bearing rings are made of a high nitrogen bearing steel (AMS 5898, X 30 CrMoN 15 1) with a very good resistance against corrosion and fatigue. This steel is typically used in combination with rolling elements made of silicon nitride (Si_3N_4). The contact of Si_3N_4 ceramic and a steel raceway eliminates the risk of fretting because of a very low adhesion between the mating surfaces.

'15th European Space Mechanisms & Tribology Symposium – ESMATS 2013'
Noordwijk, The Netherlands, 25–27 September 2013

This is an advantage compared to full steel bearings if the lubricating film degrades but there is also a disadvantage because of the different thermal coefficients of steel (11×10^{-6} 1/K) and Si_3N_4 (3×10^{-6} 1/K). The lower thermal expansion of ceramic leads into an increase of preload at low temperature because of the higher shrinkage of the steel rings. This effect is related to the nominal preload (at room temperature) and to the bearing dimension (cross section, ball size). For this bearings the effect of increased preload should be as small as possible to avoid any negative effect on the bearing friction. Therefore it was decided to use them as full steel bearings in this particular application. The hybrid version was also tested to see the effect of ceramic balls in the friction. Here the potential fail-safe effect of a hybrid bearing with failed lubrication was not investigated.

The bearing rings and the cages have been machined at CEROBEAR, the coating of the rings has been carried out either by ESTL (MoS_2-E) in Great Britain or at Blösch in Switzerland (MoS_2-B). Both suppliers have long experience and heritage in the coating of bearings for space applications. The details of the coating processes are not disclosed but the main difference with regard to the bearing design is the thickness of the coating: MoS_2-B: 0,3…0,5 µm; MoS_2-E: 0,5…1,5 µm.

The bearing cage does influence the bearing performance (friction, wear and lifetime). The bearings have been tested with different cages made of the materials described in Tab. 2.

2. BEARING SAMPLES

Based on the above mentioned bearing design six different bearings have been tested in a test campaign (Tab. 2):

Table 2. Test bearings

Test bearing No.	Materials		
	Balls	Cage	Coating
1	Si_3N_4	Vespel SP3	*MoS_2-B*
2	AISI 440C	Vespel SP3	*MoS_2-B*
3	AISI 440C	PGM (CB)	*MoS_2-E*
4	AISI 440C	PGM (JPM)	*MoS_2-E*
5	Si_3N_4	PGM (CB)	*MoS_2-B*
6	AISI 440C	PGM (CB)	*MoS_2-B*

MoS_2-B stands for a MoS_2 coating from Blösch, MoS_2-E from ESTL. Two different PGM-materials have been tested. PGM (JPM) is a cage material provided by JPM of Mississippi while PGM (CB) is based on a European source. Both PGM materials are a composite of PTFE plus MoS_2-particles reinforced with glass fibre. The baseline for the bearings is the PGM (JPM) material due to its heritage in many space missions. This PGM-material is also known as PGM-HT. This cage was machined by JPM while the alternate material PGM (CB) has been machined by CEROBEAR.

In addition to the cages made of PGM a polyimide (Vespel SP3) cage was tested. Vespel SP3 contains also MoS_2 and it was chosen due to its good mechanical strengths compared to PGM or any other PTFE-based material. The geometry (inner and outer diameter, width, ball pocket size) is identical for all cages.

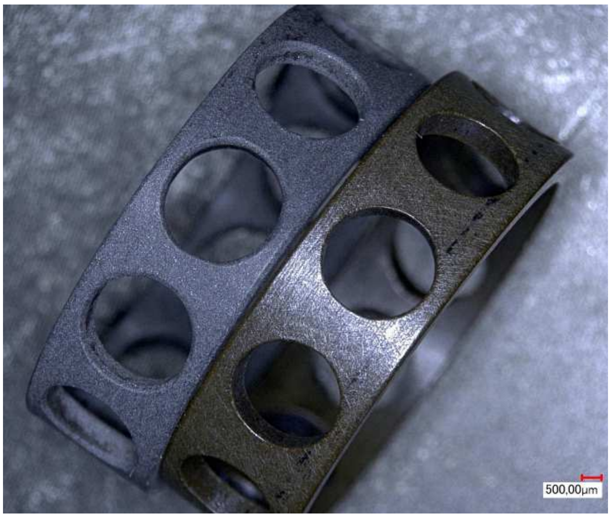

Figure 2: Cages (left side: PGM-HT, right side: Vespel SP3)

3. BEARING TEST PROCEDURE

The tests on bearing level are performed in a test bench at CEROBEAR (Fig. 3). This test bench comprises a clamping device to preload the bearing pair, a drive shaft connected with the inner rings and a load cell to measure the friction. During the test the bearing runs in dry nitrogen atmosphere with a controlled humidity (below 5%).

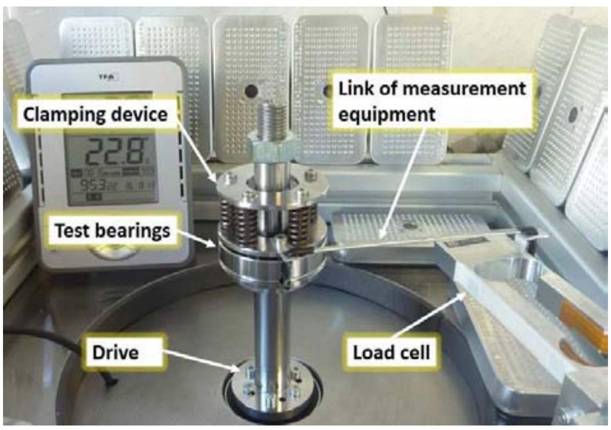

Figure 3. Test Bench

The bearing inner rings clamped on the drive shaft while the outer rings are connected to a load cell. The force to retain the outer ring represents the friction force of the bearing pair.

All bearings have undergone a run-in procedure before the friction test was carried out. The friction test was performed with 10 revolutions with a rotating speed of 1 rpm.
The friction was recorded by a PC-based data acquisition system (NI LabView). The sample rate of the load cell to measure the friction force was set to 100 Hz. After each bearing test the bearing was disassembled and visually inspected.

4. TEST RESULTS

The results of the bearing tests are shown in the following diagrams (Fig. 4 to Fig. 9). In each diagram the yellow line shows the measured friction force, the dark line indicates the calculated mean value of the friction force. The diagrams show the friction measured by a load cell, the friction torque can be calculated by multiplying the value of friction with a constant factor of 25,6 mm.

$$M = F_R \times l$$

with

M: bearing friction torque [Nmm]
F_R: bearing friction [N]
L: lever arm [mm] (25,6 mm)

On Fig. 4 and Fig. 5 the effect of Si3N4-balls (No. 1) and AISI 440-balls (No. 2) are shown. Both bearings have Vespel SP3 cage and the measured friction of these bearings is characterized by a fluctuating friction and high peaks.

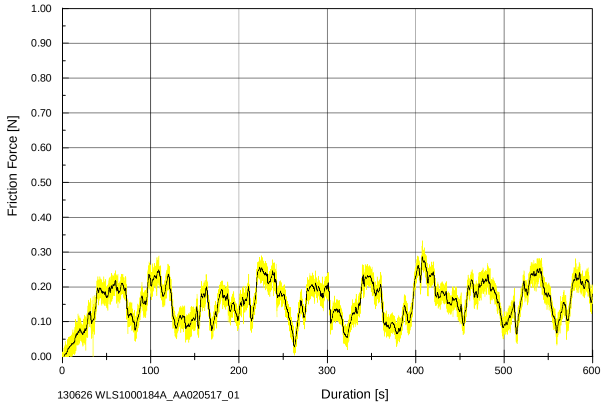

Figure 4. Bearing No 1 (Si3N4, SP3, MoS2-B)

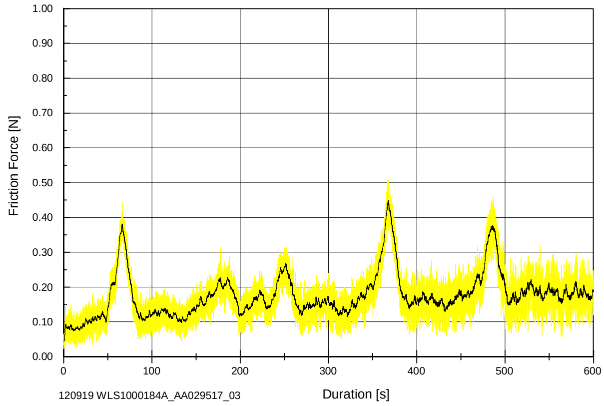

Figure 5. Bearing No 2 (AISI, SP3, MoS2-B)

The high peaks of the bearings with Vespel SP3 cage might be causes by a cage hang-up due to a higher friction between balls and cage. For polyimide parts a higher fiction coefficient in nitrogen than in vacuum was reported.

Fig. 6 shows the same type of bearing as in Fig. 5 but here it is equipped with a PGM (CB)-cage instead of a Vespel SP3 cage. The mean friction is significantly lower and the friction noise is moderate.

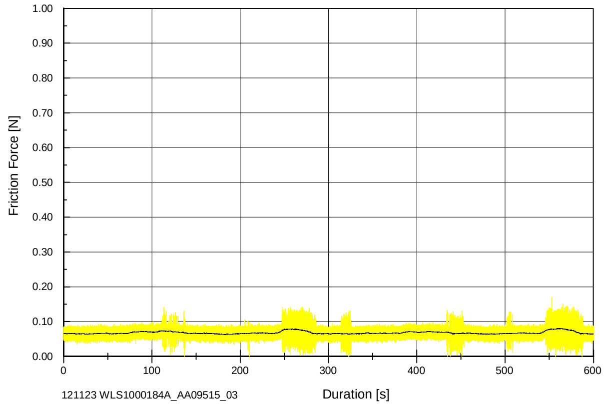

Figure 6. Bearing No 3 (AISI, PGM (CB), MoS2-E)

Fig. 7 shows the same bearing but with PGM (JPM) material. The mean friction and the noise of this bearing is higher than for the PGM (CB) material but less scattering than with the SP3 cage. This indicated a relatively high friction but no cage hang up.

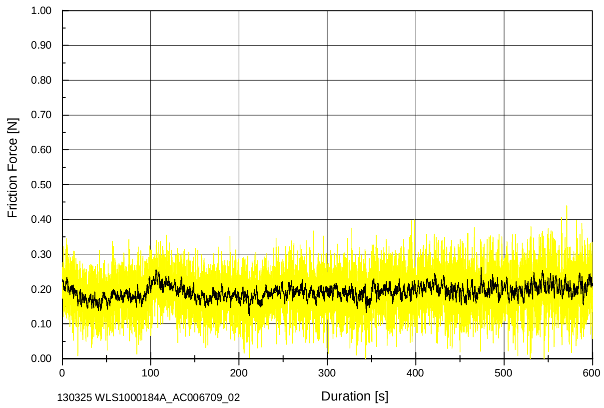

Figure 7. Bearing No 4 (AISI, PGM (JPM), MoS2-E)

In Fig. 8 and Fig. 9 the influence of different balls materials for a bearing with PGM-cage is shown. Bearing No. 5 (Fig. 8) comprises Si_3N_4 balls and bearing No. 6 (Fig. 9) has AISI 440 C balls. Both bearings have the lowest friction of all test bearings and the torque noise is also very low. The direct comparison of this two bearings results in a slightly smother run for the steel bearing but the difference is very small.

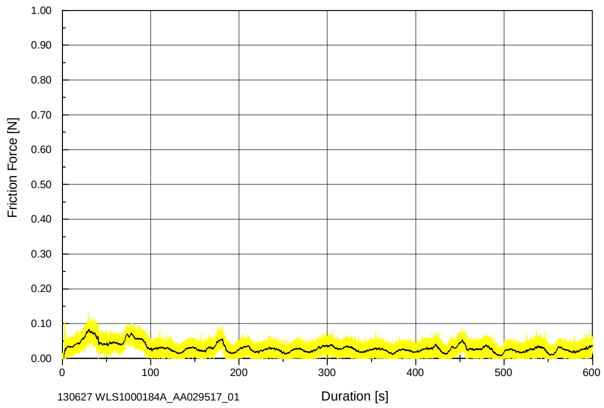

Figure 8. Bearing No 5 (Si_3N_4, PGM (CB), MoS_2-B)

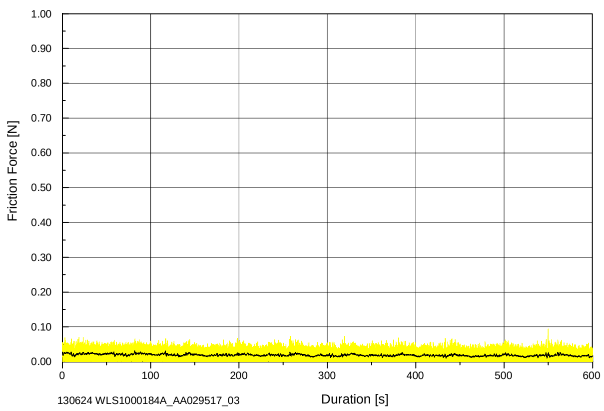

Figure 9. Bearing No 6 (AISI, PGM (CB), MoS_2-B)

Bearing No. 6 (Fig. 9) and Bearing No. 3 (Fig. 6) have identical cages (PGM (CB)) and balls (AISI 440 C). The only difference between these bearing is the supplier of the MoS_2 coating. They have a very similar friction behaviour, the friction measurement does not indicate a significant difference in the performance for the MoS_2-coatings.

The visual inspection after the tests have been done with an optical microscope, photos have been taken with a CCD digital camera. In Fig. 11 the bearing No 6 with MoS2-B (Blösch) and No. 3 MoS2-E (ESTL) are compared, both bearings have AISI 440 C balls. On both rings the ball path is clearly visible and the MoS_2-coating on the raceway is intact.

Figure 11. Bearing race after test, Left side: No. 6 (MoS2-B); Right side: Nr 3 (MoS2-E)

The raceway of a hybrid bearing compared to the raceway of a steel bearing is shown in Fig. 12. Here the ball path of the hybrid type (with Si3N4-balls) is also intact but it appears wider probably indicating a higher wear during the test run.

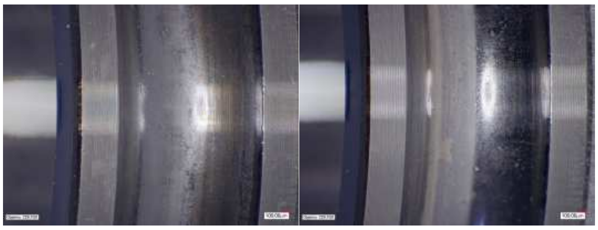

Figure 12. Bearing race after test, Left: Bearing No. 1 (Si3N4-balls) Right: No. 6 (AISI 440C-balls)

In addition to these friction measurements the bearing lifetime of the bearing was investigated for bearing No. 2 (with Vespel SP3-cage) and bearing No. 4 (with PGM (JPM)) cage. This life-time test was done with an increases bearing speed of 10 rpm instead of 1 rpm for the friction measurement. The life for bearing No. 2 was stopped after 92,3 hours (55 380 revs) because of an increased friction torque of two-times of the starting torque. The test run of bearing No. 4 was stopped after 347 hours (208 200 revs), the bearing was still in good condition after this test. There was no significant increase of friction during the test run.

5. SUMMARY

The friction measurement results show a clear influence of the materials. The biggest effect on bearing friction and friction torque noise is caused by the cage material. Considering the test environment of dry nitrogen the PTFE-based material lead into a low friction whereas a polyimide cage results in significant higher friction and wear. But this results should not be taken as a reference for the behaviour in vacuum.

Both PGM-materials have good results and the PGM cages made by JPM have successfully tested. Due to the heritage of this material it will be used for the qualification model (QM). The alternate material (PGM (CB)) has a similar composition and causes very low friction and wear in the bearing. This material might be a good candidate for further investigations.

The comparison the two different MoS_2 coatings did not demonstrate a significant difference in friction torque and torque noise. The effect of the coating thickness on the bearing lifetime was not investigated here.

1. REFERENCES

Zemann J. et al. (2013). Risk Mitigation Testing with the BepiColombo MPO SADA. ESMATS 2013