S1-37

Effect of Bearing Cleaning on Long Term Bearing Life

Tim Jett and Dr. R.L. Thom
Nondestructive Evaluation and Tribology Branch
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
MSFC,Al 35812
(205)544-2514

For many years chlorofluorocarbon (CFC) based solvents, such as CFC113 and 1,1,1, trichloroethane (TCA), were used as bearing cleaning solvents for space mechanism bearings. The 1995 ban on the production of ozone depleting chemicals (ODC) such as CFCs caused a change requiring the use of ODC-free cleaners for precision bearing cleaning. With this change the question arises; what effect if any do these new cleaners have on long term bearing life? The purpose of this study was to evaluate this effect. A one year test using 60 small electrical motors (two bearings per motor) was conducted in a high vacuum environment ($2.0*10^{-6}$ torr) at a temperature of 90 °C. Prior to testing the bearings were cleaned with one of four cleaners. These cleaners included two aqueous based cleaners, a CFC based cleaner and supercritical carbon dioxide. Three space compatible greases were tested. After testing, the mass of each lubricated bearing was measured both pre and post test. Along with mass loss measurements a profilometer trace of each bearing was taken to measure post test wear of the bearings. In addition, the bearings were visually examined and analyzed using an optical microscope.

Introduction

For many years chlorofluorocarbon (CFC) based solvents, such as CFC 113 and trichloroethane (TCA) were used as bearing cleaning solvents for space mechanisms. The 1995 ban on the production of ozone depleting chemicals (ODC) such as CFCs has resulted in a change to new ODC-free cleaners for the precision cleaning of bearings. With this change the question arises; what effect if any do these new cleaners have on bearing life and performance? Many space mechanisms require long life bearings and lubrication. These new ODC-free cleaners may have a negative effect on the long term life and performance of these space mechanisms. These ODC-free cleaners may modify bearing surfaces differently than CFC based cleaners. Performance anomalies may occur due to wetting differences or changes in surface reactivity resulting in shorter bearing life. There is evidence to suggest some new aqueous cleaners are detrimental to bearing operation. These cleaners may actually clean the bearing surface better that the CFC base cleaners. This could leave a reactive surface and contribute to lubricant degradation. It's also possible the detergent used for aqueous cleaners is not completely rinsed which might lead to a reduced bearing life. These new cleaners need to be carefully evaluated to determine the effects that they may have on long term bearing life.

A study was initiated to evaluate the effects, if any, these new ODC-free cleaners have on long term bearing life in a vacuum. For these tests sixty small electric motors (two R-4 angular contact bearings per motor) were tested. These tests were performed at elevated high temperature (90 C) and in a high vacuum (1E-6 torr) environment. Four cleaners and three space compatible greases were evaluated. These cleaners were CFC 113(Freon), Brulin 815 GD, Turco Vitro Clean and supercritical carbon dioxide. The three space compatible greases were Braycote 601EF grease(vacuum baked), Vackote 48822, and Rheolube 2000.

Test Equipment

The tests were conducted at the Marshall Space Flight Center using a High Vacuum Test Manifold. This manifold is connected to two 10 inch diffusion pumps that are capable of maintaining pressures in the 1E-6 torr range during test operation. This manifold has twelve workstations that can be individually valved off. A typical workstation is shown in Figure 1. It consists of a glass bell jar and a temperature controlled aluminum mounting plate. Twenty electrical motors were installed on the plate. For this testing three bell jar work station were utilized. The bell jar workstations were maintained at identical environmental conditions.

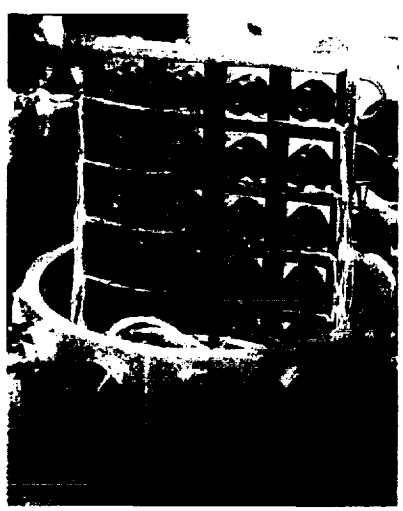

Figure 1. Test Motors in vacuum chamber with bell jar removed.

In this study a total of sixty electric motors, each containing two angular contact bearings, were used. The bearings were R-4 size, 0.635 cm I.D. by 1.59 cm O.D., AISI 440c with ribbon type stainless steel cages. Each bearing was lubricated with a 25 to 30 percent fill of the candidate grease. Motors were run continuously for one year at 90 ° C at approximately 10^{-6} torr pressure. The motors were loaded to maintain a 22.2 N thrust load with no radial load. The bearings operate at 3,600 rpm, and this results in a fully developed elastohydrodynamic film being formed. The motors used for the test have the following characteristics:

1) Type - ac hysteresis, single phase, 60 cycles

2) Speed - 3600 rpm, synchronous

3) Current - 0.22 Amp.

These motors are brushless so no problems with brush dust contamination were encountered. Also the motors used approximately the same current when stalled as when operating so a bearing failure did not cause motor damage due to overheating. A disassembled motor with the R-4 bearing is shown in Figure 2. For this test the motors were operated at an elevated temperature (90 ° C) in order to increase the severity of the test. To control this temperature, the motors were mounted in an aluminum plate that included cooling passages so a thermal control fluid (ethylene glycol) could be used to control the motor temperatures. A re-circulating heated bath was used to circulate and control the fluid temperature and control the bearing operating temperatures.

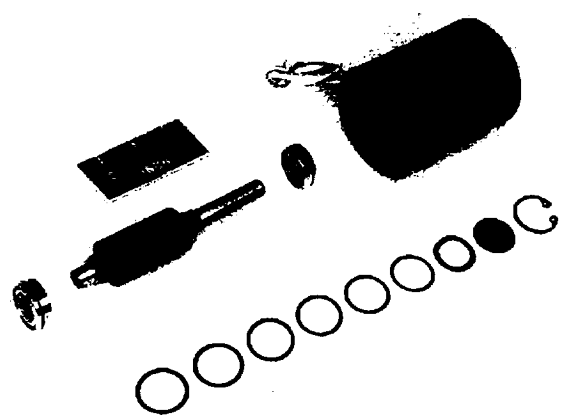

Figure 2. Disassembled ac motor with R-4 Bearing

Test Procedure

The purpose of this study was to determine the effect of cleaning on the long term bearing life. For this testing four cleaners and three space compatible greases were evaluated. These cleaners were CFC 113 (Freon), Brulin 815 GD, Turco Vitro Clean and supercritical carbon dioxide. CFC 113 is a chlorofluorocarbon solvent that historically has been used for precision cleaning of bearings. CFC113 is an ozone depleting chemical, and its production was banned in 1995. Turco Vitro Clean and Brulin 815GD are aqueous based cleaners. The final cleaning method utilized was a supercritical carbon dioxide cleaning method performed by Battelle. The three space compatible lubricants are Braycote 601EF grease, Vackote 48822, and Rheolube 2000. Braycote 601EF is a perfluoroalkylpolyether (PFPE) grease that is manufactured. In order to pass NASA's outgassing requirements (MSFC 1443) this grease was vacuum baked out. Vackote 48822 is a vacuum baked version of Vackote 44147EF. This grease is synthetic hydrocarbon grease that is manufactured by Ball Aerospace. Rheolube 2000 is a cyclic synthetic hydrocarbon grease which is produced by Nye Lubricants.

For this study sixty motors or 120 bearings were tested. Twenty motors were lubricated with Braycote 601EF (Vacuum Baked out). Twenty motors were lubricated with Vackote 48822 and the remaining twenty motors were lubricated with Rheolube 2000. A bell jar was dedicated to each type of grease.

Prior to lubrication, the bearings were contaminated by placing them in a solution of used grinding machine coolant for 1 hour. The bearings were cleaned with one of the four test cleaners. Twenty five percent of the bearings were cleaned with each cleaner.. All bearings were ultrasonically cleaned with Freon, Turco or Brulin according to one the procedures shown in Table 1; or they were cleaned by Battelle supercritical carbon dioxide method. After cleaning the bearings were lubricated with a 25 to 30 percent volume filled of the test lubricant. Next, the bearings were mounted on amartures and placed in the motors.

Cleaner	Step	Procedure	Bath	Temp C	Time(min)
Brulin 815 GD	**1**	**ultrasonic**	**Brulin GD(10:1)**	**60 max**	**10**
	2	rinse	distilled water	ambient	4
	3	rinse(ultrasonic)	distilled water	60 max	4
	4	dry	air	ambient	n/a
Turco	**1**	**ultrasonic**	**Turco vitro clean**	**60 max**	**10**
	2	rinse	distilled water	ambient	4
	3	rinse(ultrasonic)	distilled water	60 max	4
	4	ultrasonic	Turco 4215 additive(3.5%)	60 max	10
	5	rinse	distilled water	ambient	10
	6	rinse(ultrasonic)	distilled water	60 max	10
	7	dry	air	ambient	n/a
Freon	**1**	**ultrasonic**	**Freon**	**ambient**	**10**
	2	ultrasonic	Freon	ambient	4
	3	dry	air	ambient	n/a

Table 1. Cleaning Procedures

The motors were installed in the aluminum mounting plate which was held at a constant 90 ^{0} C temperature. The motors ran continuously for one year in the bell jar vacuum system at approximately 1E-6 torr pressure. The load to the test bearing was a thrust load applied by a wave washer. The motors were loaded to maintain a 2.3 N (5lb) thrust load on both bearings. This load results in a maximum hertzian contact stress of 1.69 Gpa (246,000 psi) on the inner race. The bearings operated continuously at 3,600 rpm. This speed and load condition result in a full elastohydrodyamic film being form in the contact area. Each bearing that survives for the full test completed 1,892,000,000 revolutions.

The evaluation criteria for the test was based primarily on a go/no-go system. The motor torque was low and the inertia of the system was also low. As a result if a bearing drag torque increased due to a lubricant or bearing failure then the motor stops without further damage to the bearing. The following data was monitored during the test.

1. Total test time

2. Vacuum in bell jars

3. Temperature of mounting plates

The bearings were weighed before and after testing on a high precision balance, and the percent of lubricant weight loss was calculated. After testing the bearings were visually examined under an optical microscope to determine the condition of the bearings and grease.. A Rank Talyor Hobson Taly-Surf profilometer was used to measure wear depth of the inner race wear track inner race.

Test Results

In this study sixty motors were tested. Twenty motors were lubricated with Braycote 601EF and all of these motors were installed in Bell Jar 1. The results of this test are shown in Table 2. These results showed that eleven motors failed during the one year test period. All of these failures were verified to be bearing failures due to poor lubrication. It must be noted the results from Bell Jar 1 are questionable. At approximately 4,440 hours into the testing a problem with the re-circulating bath occurred. No coolant was supplied to the motors for a period of at least twelve hours. This caused a significant increase in operating temperature and a noticeable fogging of the bell jar glass due to grease outgassing. This temperature spike probably had an impact on the lubricant life. A large majority (nine) of the failures occurred either at the temperature spike or after it.

For this severe and off nominal test the type of cleaner didn't appeared to have an effect on bearing life. The failure rates for each cleaner were similar. CFC113, Brulin, and CO2 yielded a 60 percent failure rate while for Turco the rate was 40 percent. The lubricant weight loss results were all high. At MSFC there is a long history of testing Braycote 601 grease. In the past, under very similar test conditions, the average lubricant weight loss was approximately 15 %[1]. In this study the average lubricant weight loss was 41 percent. This higher weight loss is probably due to the temperature spike that occurred during the testing.

A profilometer was used to measure the depth of the inner race wear tracks. The results of the testing showed that the average wear depth of bearings lubricated with Braycote 601 grease was 6.04 microns. The bearings cleaned with CFC 113 exhibited the lowest wear, while the bearings cleaned with Turco had the highest wear as seen in Table 1. The results do not correlate well with the bearing life results.

Post test inspection of the bearings lubricated with Braycote 601 grease showed the lubricant to be significantly degraded. The used grease had turned black and was dried out. Originally, this grease was slightly tan in color. A typical post test bearing is shown in Figure 3. In most cases the bearings still had a small to moderate amount of grease, and the bearings still operated fairly smoothly. However, for several bearings the grease was dry with practically no visible lubricant. Dry, black powder was observed to come from the motors when the amartures were removed from the motor's housing. A typical example of a dry bearing is shown in Figure 4. The type of cleaner used appeared to have no influence on this lubricant degradation. Bearings with very little lubricant and black residue were observed for each type of cleaner. After lubricant inspection the bearings were cleaned and re-examined under an optical microscope. All bearings were in good condition with a visible wear track on both, the inner and outer raceways. No surface distress was noted on any raceways.

Figure 3. Bearing CB7, a typical post test bearing that was lubricated with Braycote 601EF

Figure 4. Bearing FB7, an example of dried out bearing(Braycote 601EF)

Motor #	Cleaner	Failure	Run Time (Hours)	Weight Loss (%)	Wear Depth (microns)
FB1	Freon	YES	4656	45.67	1.51
FB3	Freon	YES	4944	68.79	0.99
FB5	Freon	YES	4440	58.11	3.08
FB7	Freon	NO	8760	60.31	5.92
FB9	Freon	NO	8760	33.93	4.79
Average			**6312**	**53.36**	**3.26**
BB1	Brulin	YES	6624	53.44	9.21
BB3	Brulin	NO	8760	23.44	2.29
BB5	Brulin	YES	648	29.54	5.98
BB7	Brulin	YES	4680	62.10	3.67
BB9	Brulin	NO	8760	34.54	7.63
Average			**5894.4**	**40.61**	**5.76**
TB1	Turco	NO	8760	48.25	2.83
TB3	Turco	YES	3480	37.94	12.54
TB5	Turco	NO	8760	14.60	8.67
TB7	Turco	YES	576	60.72	11.57
TB9	Turco	NO	8760	0.73	6.69
Average			**6067.2**	**32.45**	**8.46**
CB1	CO2	YES	4440	100.00	3.83
CB3	CO2	YES	6024	54.62	3.80
CB5	CO2	NO	8760	14.64	7.25
CB7	CO2	YES	5280	9.20	12.84
CB9	CO2	NO	8760	7.65	5.78
Average			**6652.8**	**37.22**	**6.70**

Table 2. Summary of Bell Jar #1, Braycote 601EF

Twenty motors were lubricated with Rheolube 2000 and all of these motors were tested in Bell Jar 2. The results of this test are shown in Table 3. These results show that two motors failed in the one year time period. These failures were verified to be bearing failures. The type of cleaner didn't appear to have an effect on bearing failure rate or run time. The average lubricant loss for motors lubricated with Rheolube 2000 was 27.6 percent. This was the lowest of three lubricants tested. The highest weight loss was observed in motors cleaned with CO2 cleaning method. One motor in particular (CR3) had a very high weight loss (57.85 %). The motors cleaned with Turco had the lowest weight loss. The amount of wear observed from profilometer trace of the inner race was relatively mild (1.88 microns). Bearings lubricated with Rheolube 2000 exhibited the lowest amount of wear of the three lubricant tested.

Post test inspection of the bearings lubricated with Rheolube showed the lubricant to have turned to dark black color. Originally, the grease was tan in color. Most bearings had a significant amount of grease still in the bearing. The lubricant was still fairly moist and was still very lubricious. The bearings were still operating smoothly. Figure 5 shows a typical post test bearing. An exception was the bearings in motor CR3. The front bearing in this motor was very dry and rough operating. This motor was one of the two motors that failed. This motor exhibited the greatest amount of bearing wear. After visual observation of the lubricant the bearings were cleaned and inspected under a optical microscope. All bearings were in good condition with a visible wear track on both the inner and outer raceways. No surface distress was noted in any raceway.

Motor #	Cleaner	Failure	Run Time (Hours)	Weight Loss (%)	Wear Depth (microns)
FR1	Freon	NO	8760	26.76	0.41
FR3	Freon	YES	7752	28.57	1.80
FR5	Freon	NO	8760	19.79	2.07
FR7	Freon	NO	8760	25.15	0.74
FR9	Freon	NO	8760	33.41	0.44
Average			**8558.4**	**26.74**	**1.09**
BR1	Brulin	NO	8760	23.68	1.45
BR3	Brulin	NO	8760	28.83	2.85
BR5	Brulin	NO	8760	33.89	2.22
BR7	Brulin	NO	8760	21.95	0.52
BR9	Brulin	NO	8760	28.91	2.22
Average			**8760**	**27.45**	**1.85**
TR1	Turco	NO	8760	22.13	2.11
TR3	Turco	NO	8760	16.49	2.63
TR5	Turco	NO	8760	14.60	2.46
TR7	Turco	NO	8760	25.01	0.91
TR9	Turco	NO	8760	14.90	2.45
Average			**8760**	**18.63**	**2.11**
CR1	CO2	NO	8760	27.14	0.69
CR3	CO2	YES	6840	57.85	4.12
CR5	CO2	NO	8760	33.21	0.56
CR7	CO2	NO	8760	29.84	3.42
CR9	CO2	NO	8760	39.86	3.63
Average			**8376**	**37.58**	**2.48**

Table 3. Summary of Bell Jar, Rheolube 2000

Figure 5. Bearing BR10, a typical post test bearing with Rheolube 2000

Twenty motors were lubricated with Vackote 48822 and tested in Bell Jar 3. The results of this test are shown in Table 4. These results show that 19 of the twenty motors failed during the one year test period. This was the highest failure rate of the three lubricant tests. No correlation between bearing failures and cleaner used could be made. The average run time for the twenty motors lubricated with Vackote was 4,266 hours, which was the lowest average run time for the three lubricants tested. The average lubricant weight loss was 47 percent, which was the highest of the three lubricants tested. The average inner race wear track depth was 2 microns, it was only slightly higher than the Rheolube 2000, and much lower than wear obtained using Braycote 601 grease.

Post test inspection of the bearings lubricated with Vackote showed the lubricant to be significantly degraded. All of the grease had turned black. Originally, the grease was white. In general, there was a small to moderate amount of dried grease remaining in the bearings, and the bearings were very rough running. A typical bearing is shown in Figure 6. In several bearings the grease had turn into a black powder and there was virtually no grease remaining. An example of this is shown in Figure 7. The type of cleaner appeared to have little influence on the lubricant life. After lubricant inspection the bearings were cleaned and examine under an optical microscope. The bearings were all in good condition with a visible wear track on both the inner and outer race. No surface distress was observed on any bearing raceways.

Figure 6. Typical post test bearing with Vackoke 48822

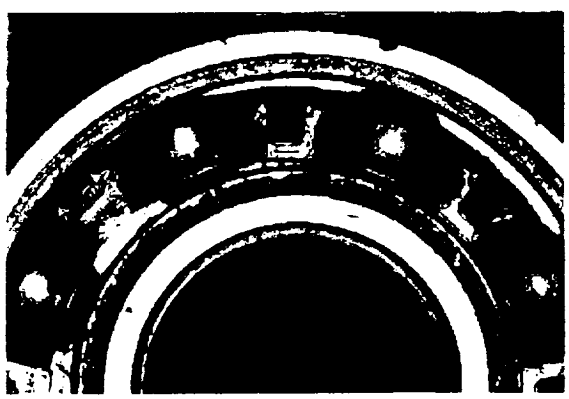

Figure 7. Bearing BV3, an example of a bearing with very little Vackote grease remaining

Motor #	Cleaner	Failure	Run Time (Hours)	Weight Loss (%)	Wear Depth (microns)
FV1	Freon	YES	1152	57.65	3.21
FV3	Freon	YES	1776	18.99	0.50
FV5	Freon	YES	3840	58.79	0.64
FV7	Freon	YES	5520	59.35	2.40
FV9	Freon	YES	2760	57.99	1.20
Average			**3009.6**	**50.55**	**1.59**
BV1	Brulin	NO	8760	25.09	2.33
BV3	Brulin	YES	8208	56.41	0.61
BV5	Brulin	YES	5592	53.20	0.20
BV7	Brulin	YES	2520	5.27	0.82
BV9	Brulin	YES	3792	56.91	0.31
Average			**5774.4**	**39.38**	**0.85**
TV1	Turco	YES	2496	43.90	3.94
TV3	Turco	YES	3360	59.07	0.44
TV5	Turco	YES	5592	52.01	1.99
TV7	Turco	YES	3840	59.96	3.01
TV9	Turco	YES	1224	54.22	5.43
Average			**3302.4**	**53.83**	**2.96**
CV1	CO2	YES	5952	45.27	1.82
CV3	CO2	YES	7872	39.10	1.77
CV5	CO2	YES	3360	42.97	1.25
CV7	CO2	YES	4512	46.72	4.02
CV9	CO2	YES	4200	57.24	3.97
Average			**5179.2**	**46.26**	**2.57**

Table 4. Results from Bell Jar 3, Vackote 48822

In this testing there were two test variables, lubricant used and cleaner used. In general the type of cleaner used did not have a significant effect on bearing life. The failure rate for all bearings cleaned with CFC 113 was 60% (9out 15). This compares to 47% failure rate for both, Turco and Brulin. These failure rates are relatively high. This rate is probably due to the temperature excursion that occurred in Bell Jar number 1 (Braycote 601EF). Prior to testing it was thought that aqueous based cleaners might be detrimental to bearing life. It was also thought that CFC113 might leave behind a protective film that helped delay or prevent the degradation of the PFPE based Braycote 601EF. The aqueous cleaner probably would not leave this film thus giving a cleaner and more reactive surface. This reactive surface could have higher tendency to cause the fluorinated lubricant to breakdown in service.

Unfortunately, due to the temperature excursion in Bell Jar 1, this testing neither proved nor disproved this theory. The results from Bell Jar 1 showed no significant difference in the bearing failure rate for the different cleaners. The overall bearing failure (11/20) was high, and this appears to be highly influence by the temperature spike that occurred during testing. Prior to this temperature spike only two motors had failed. Both of the motors had been cleaned with aqueous base cleaners (one Brulin and Turco).

The lubricant used, definitely had an impact on bearing life. Vackote 48822 had the highest bearing failure rate (19/20). Rheolube 2000 was the best performing grease with only two bearing failures. Braycote 601EF had 11 failures, but as noted previously these results are questionable. Figure 8 shows a comparison of bearing run time for the three lubricants tested. This chart shows that Rheolube is the best performing lubricant, and the Vackcote is the worst. No correlation between bearing run time and cleaner used could be made. Figure 9 shows a comparison of average lubricant weight loss for the three greases. These results show that Rheolube was the best while Vackote had the highest weight loss. No correlation between lubricant weight loss and cleaner used could be made. Figure 10 shows the inner race wear depth. This graph also shows that Rheolube gave the best performance.. This graph also shows that Brulin and Freon cleaned bearings tended to have lower wear.

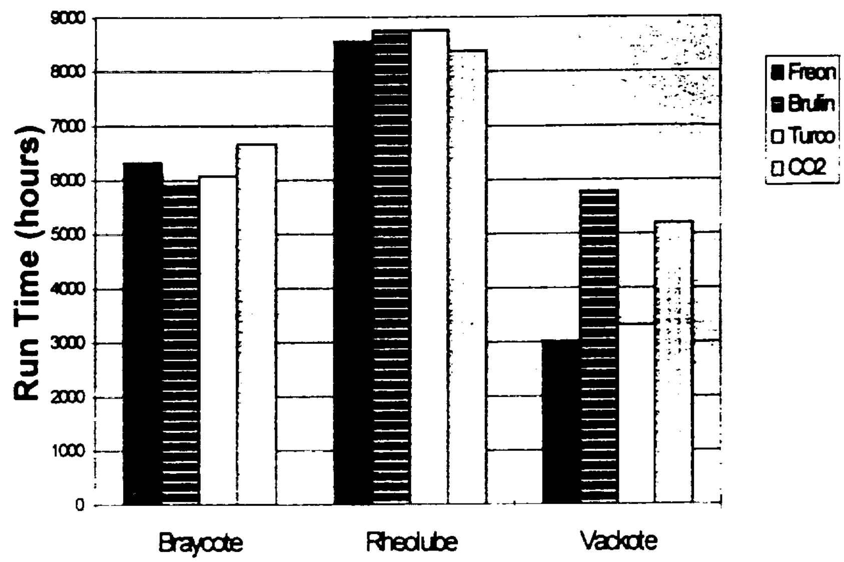

Figure 8. Comparison of average bearing run time

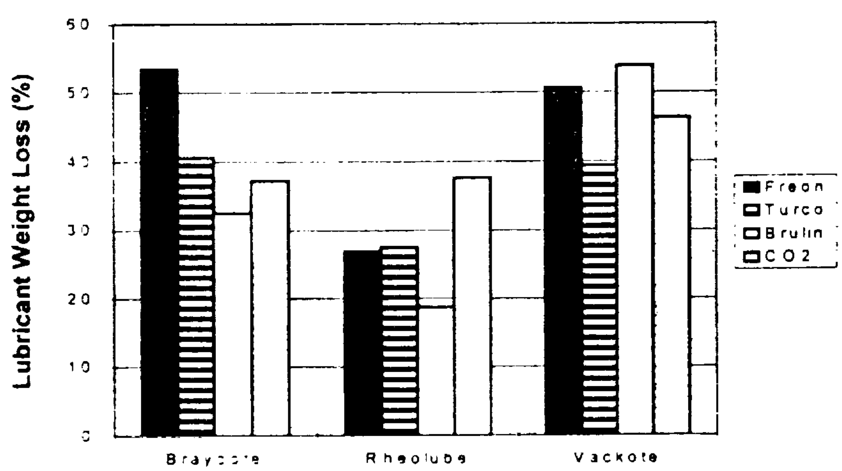

Figure 9. Comparison of average lubricant weight loss

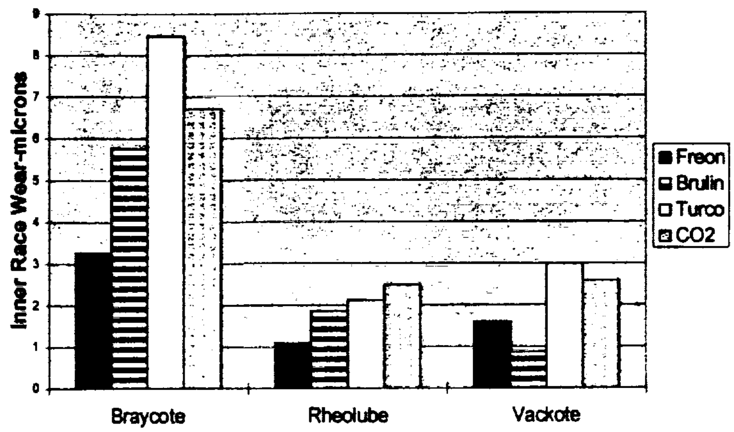

Figure 10. Comparison of average inner race wear

Conclusions

1) In a one year continuous high vacuum and high temperature bearing tests the type of cleaner didn't have a significant effect on bearing life.

2) Test Results from 3 different test grease provide useful design data.

References

1)McMurtrey, E. L.: An Evaluation of Grease-Type Ball Bearing Lubricants Operating in Various Environments(Final Status Report No. 8). NASA/Marshall Space Flight Center, Al, NASA TM-86480.