Testing and Lubrication for Single Race Bearings

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R. G. Steinhoff

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TESTING AND LUBRICATION FOR SINGLE RACE BEARINGS

R. G. Steinhoff

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Topical Report

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Abstract

Three ES&H-compatible lubricants (Environment, Safety and Health) for single race bearing applications and one hybrid-material single race bearings were evaluated and compared against single race bearings with trichlorotrifluoroethane (Freon) deposition of low molecular weight polytetrafluoroethylene (PTFE) bearing lubricant extracted from Vydax™ . Vydax is a product manufactured by DuPont consisting of various molecular weights of PTFE suspended in trichlorotrifluoroethane (Freon), which is an ozone-depleting solvent. Vydax has been used as a bearing lubricant in stronglink mechanisms since 1974. Hybrid bearings with silicon nitride balls and molded glass-nylon-Teflon retainers, bearings lubricated with titanium carbide (TiC) on the balls, bearings lubricated with sputtered MoS_2 on races and retainers, and bearings lubricated with electrophoretically deposited MoS_2 were evaluated. The bearings were maintained in a preloaded state in bearing cartridges during cycling and vibration tests. Bearings with electrophoretically deposited MoS_2 performed as well as bearings lubricated with Vydax and were the best performing candidate. All candidates were suitable for low preload applications. Bearings with TiC coated balls and bearings lubricated with sputtered MoS_2 on the races and retainers performed well at high preloads, though not as well as bearings lubricated with electrophoretic deposition of MoS_2. Bearings with silicon nitride balls were not suitable for high preload applications.

Summary

Three ES&H-compatible lubricants (Environment, Safety and Health) for single race bearing applications and one hybrid-material single race bearing were evaluated as replacements for single race bearings lubricated with trichlorotrifluoroethane (Freon) deposition of low molecular weight polytetrafluoroethylene (PTFE) extracted from Vydax™ . Vydax is a product manufactured by DuPont consisting of various molecular weights of PTFE suspended in Freon, which is an ozone-depleting solvent. Manufacturing of Freon has been curtailed in response to environmental, safety, and health concerns over damage to the earth's ozone layer. Exemptions at the Kansas City Plant (KCP) are required in order to use Vydax and Freon.

Single race bearings lubricated with electrophoretic deposition of MoS_2 on races and retainers, sputtered

MoS_2 on races and retainers, titanium carbide (TiC) coating on balls, and single race bearings with silicon nitride balls with molded glass-nylon-Teflon retainers were evaluated and compared against a baseline that was established for Vydax. As an added check, a baseline for a commercially available diester oil was also established and compared against Vydax.

In order to evaluate these lubricants in mechanism-type environments, fixturing and test methods were developed to axially preload the bearing pairs at 1 lb and 10 lbs and maintain the preload during testing, cycling, and vibration. The cycling fixture was designed to rotate the bearing cartridge shaft back and forth through 25 degrees of rotation 15 times every second. This is representative of the speed and cycling rates of bearing-supported shafts in stronglink mechanisms. In order for the vibration loading of the bearings to be representative of stronglink mechanisms, the bearing cartridge shaft was designed to have a mass and mass moment of inertia representative of solenoid shafts in stronglink assemblies. The vibration fixture clamps onto the bearing cartridge base and allows the bearing cartridge shaft to float freely, applying vibration loads to the bearings. The test procedure required the bearings to be tested for torque on a bearing torque tester every 3,600 cycles up to 18,000 cycles. The preloaded cartridges are vibrated according to a 23.5 grams random vibration spectrum for 20 minutes in two axes and then tested again for torque. The bearing cartridges are cycled more and tested for torque every 18,000 cycles up to a total of 72,000 cycles. The baseline bearings and all candidates were tested in this manner.

Bearings with electrophoretically deposited MoS2 exhibited torque performance better than oiled bearings and bearings lubricated with Vydax at both low and high load applications. This was the best performing candidate. One negative to using bearings with this lubricant is that electrophoretic deposition must be done on the pieces of the bearing prior to bearing assembly by the bearing manufacturer. The bearing manufacturer does not have experience with this coating and there is not a known supplier that applies this coating. Transfer of this technology would be fairly easy and inexpensive, making these bearings relatively inexpensive.

Bearings with TiC coated balls also performed well at both high and low preload applications. The high cost of these bearings makes this candidate not as appealing as other candidates. This type of bearing may not be available in extremely small sizes.

Bearings with sputtered MoS2 on the races and retainers also performed well at both high and low preload applications. Bearings of this type are also expensive due to the cost of sputtering on the races and retainers.

Bearings with silicon nitride balls and molded glass-nylon-Teflon retainers exhibited unacceptable torque at high preloads. Torque was acceptable for low load applications, but high cost and long lead time for procurement make this candidate unappealing as a replacement for low load applications.

Discussion

Scope and Purpose

The objective of this project was to identify potential ES&H-compatible (Environment, Safety and Health) lubricant candidates for single race bearings and evaluate the most promising candidates against current baselines. The single race bearing was used as the test bed for this evaluation. This bearing is used in the solenoid of a dual stronglink assembly and was planned for use in future stronglinks. This project was undertaken because the current lubricant, Vydax™ , contains PTFE suspended in Freon and requires Freon for dilution during the application process. Manufacturing of Freon has been curtailed in response to environmental, safety, and health concerns over damage to the earth’s ozone layer.

Exemptions at the Kansas City Plant (KCP) are required in order to use Vydax and Freon.

The following ES&H-compatible lubricant candidates were evaluated to replace Vydax in single race bearings:

- Electrophoretic deposition of MoS_2 on races and retainers,
- Sputtered MoS_2 on races and retainers,
- Titanium carbide (TiC) coating on balls,
- Silicon nitride balls with molded glass-nylon-Teflon retainers.

A baseline was established for Vydax and, as an added check, a baseline for a commercially available diester oil was also established and compared against Vydax.

In order to evaluate these lubricants in mechanism-type environments, fixturing and test methods were developed to preload the bearing pairs at two different levels and maintain the preload during testing, cycling, and vibration.

Prior Work

Several evaluations have been done on these same lubricants or similar ES&H-compatible lubricants for both high load duplex bearings and regular duplex bearings. None of these evaluations have looked at the effect of vibration on bearing lubrication. The topical report *ES&H Compatible Lubrication for Duplex Bearings*, KCP-613-6015, describes testing of duplex bearings with silicon nitride balls and molded glass-nylon-Teflon retainers, bearings with sputtered MoS_2 on the races and retainers, and bearings with electrophoretically deposited MoS_2.[1] The topical report *ES&H Compatible Lubricants for High Load Duplex Bearings*, KCP-613-5983, describes testing of bearings with titanium carbide coated balls, bearings with sputtered MoS_2 on the races, and bearings with supercritical CO_2 deposition of Vydax AR/IPA (alcohol based Vydax).[2] The final report *Dry Film Lubricant Evaluation*, KCP-613-5044, describes testing of Dicronite (WS_2) lubrication of high load duplex bearings.[3] In all of these evaluations, the lubricated bearings were all compared to bearings lubricated with Freon deposition of Vydax.

Activity

Background

Stronglink switches designed since 1974 have required lubrication of axially preloaded bearings in order to operate reliably under various environments. The bearing lubricant of choice in these mechanisms is Freon deposition of low molecular weight PTFE extracted from Vydax. Vydax is a product manufactured by DuPont consisting of various molecular weights of polytetrafluoroethylene (PTFE) suspended in trichlorotrifluoroethane (Freon). The application process consists of siphoning off the soluble portions (low molecular weight PTFE particles) of a settled Freon/Vydax mixture and further diluting the siphoned off portion in Freon. This diluted mixture is then applied to bearings. The Freon is evaporated off, leaving a light film of PTFE "grease" on the bearing. This "grease" is then baked on the bearings.

Tester and Test Procedure

Bearing Cartridge

The bearing cartridge shown in Figure 1 was designed to test bearing pairs and to interface with the bearing torque tester, the cycling fixture, and the environmental test fixture. The center shaft was designed to have mass and mass moment properties similar to rotors in stronglink mechanisms. It was also designed to allow an axial preload of either 1 lb +/- 0.5 lb or 10 lbs +/- 1 lb to be applied to a flanged bearing pair. This preload is applied through a wavy washer under the bearing flange. By slightly tightening a nut on the bearing cartridge shaft, the inner races of the bearing pair are brought towards each other, resulting in a loading of the outer races compressing the wavy washer against the bearing cartridge base. The nut is adjusted until the correct preload is obtained through compression testing of the assembly on an Instron universal tester. When the correct preload is obtained, a second nut is then tightened on the shaft to lock the first nut in place so the preload will not change through cycling or vibration. The preload is verified again though compression testing. Figure 2 shows a cross section of an assembled bearing cartridge.

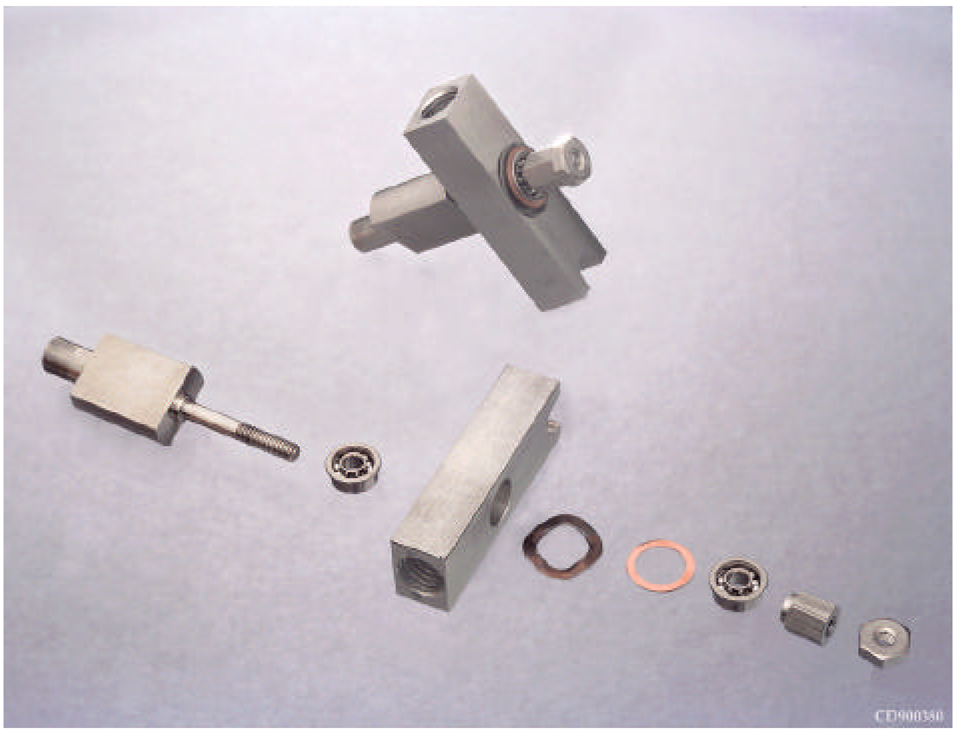

Figure 1. Preloaded Bearing Cartridge

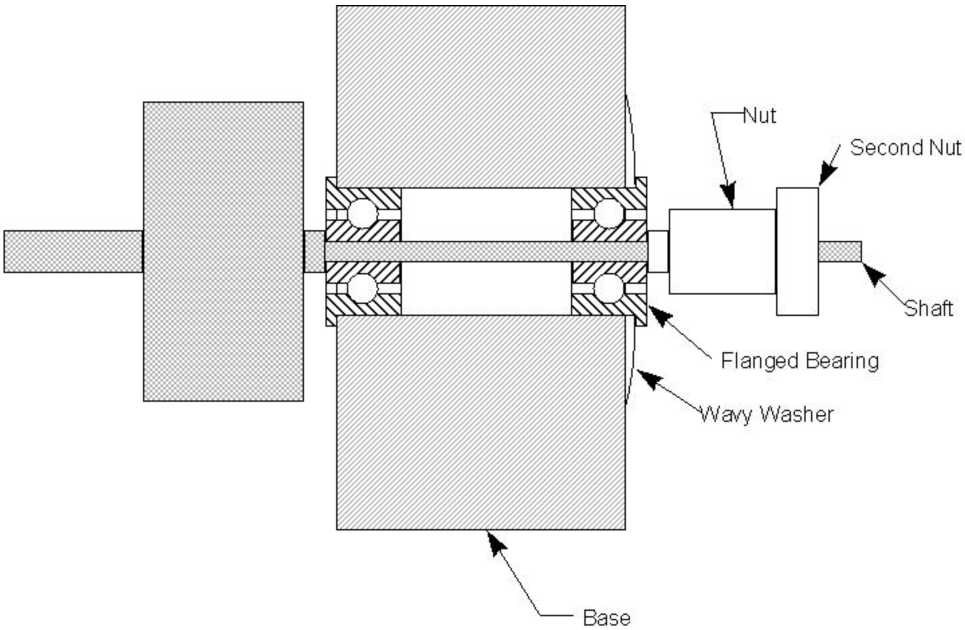

Figure 2. Cross Section of an Assembled Bearing Cartridge

Cycling Fixture

The cycling fixture as shown in Figure 3 is a modified dual stronglink assembly C-module without the discriminating mechanism. It was modified to mate with the bearing cartridge. The bearing cartridge is assembled on top of one of the C-module solenoids and locked in place with a set screw. A circuit board to drive the solenoid was developed. When hooked to a DC power supply set at 15.0 volts DC, the drive circuit causes the solenoid to cycle (forward and back through 24.7 degrees) once every 0.0653 second. This oscillation speed is representative of the speeds that are typical of stronglink mechanisms.

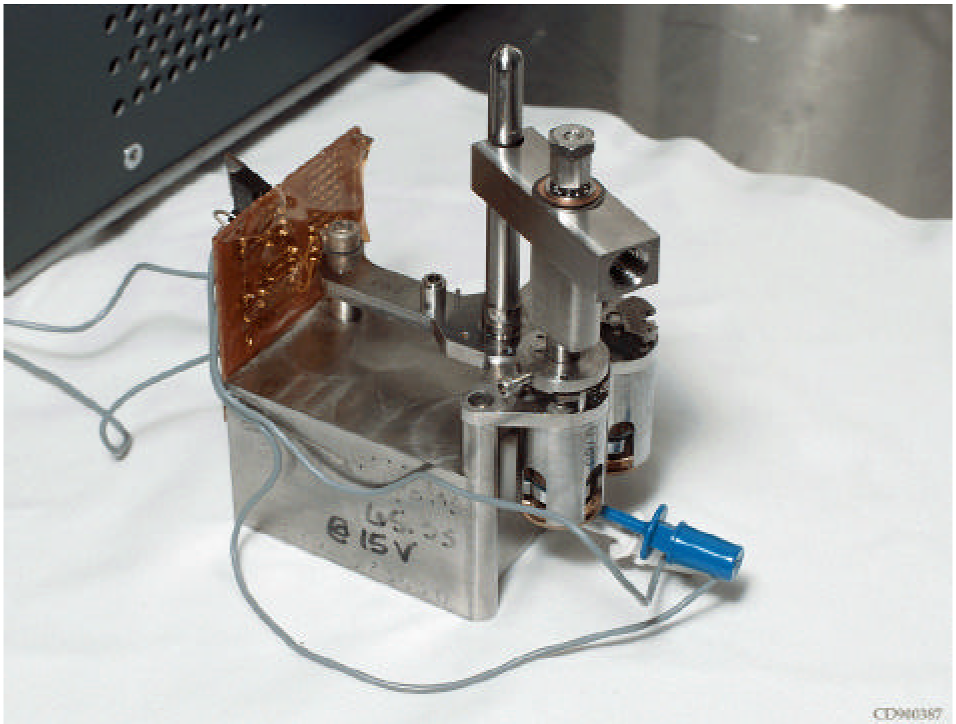

Figure 3. Bearing Cartridge Cycling Fixture

Environmental Test Fixture

The environmental test fixture shown in Figure 4 was designed to environmentally test five bearing cartridges at once at either shock or vibration. The bearing cartridges are held only by their base. Since the bearing cartridge shaft has similar mass moment of inertia properties to rotor shafts in stronglink mechanisms, the loads on the bearings due to the shaft during vibration or shock are representative of loads seen by bearings in stronglink mechanisms.

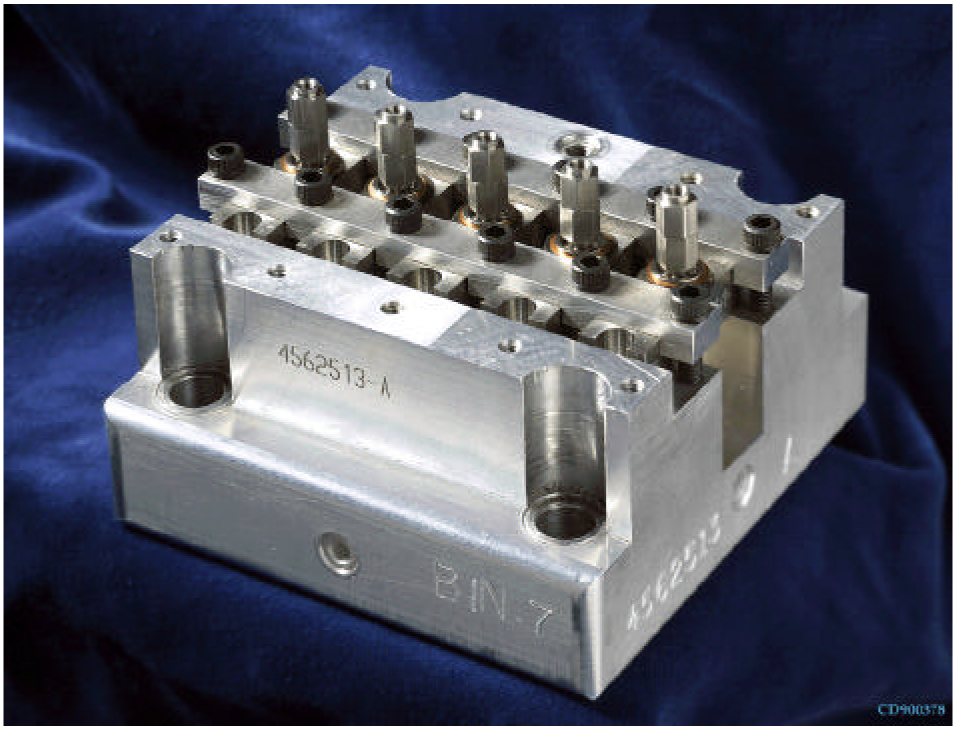

Figure 4. Bearing Cartridge Environmental Test Fixture

Torque Test Fixture

The torque tester with a bearing cartridge ready for test is shown in Figure 5. This tester rotates the bearing cartridge shaft at 0.5 rpm while it records torque data. The data is taken from one revolution of the bearing, and outputs from this tester are Average Torque, Standard Deviation (Hash), Range, Max Torque, and Min Torque. Only Average Torque and Standard Deviation (Hash) were used for comparisons of the bearings in this evaluation.

Figure 5. Bearing Torque Tester

Test Procedure

Bearing pairs are loaded into bearing cartridges and axial preload is set to either 1 lb or 10 lbs. The bearing cartridge is initially loaded on the bearing torque tester and tested. Torque testing consists of measuring average torque, standard deviations, and range of the bearing pair through one revolution. The bearing cartridge is cycled on the cycling fixture and then retested on the torque tester in the following sequence.

Representative Cum #

Sequence Cum # of Cycles of Stronglink Actuations

Torque test

Cycle 3600 3600 100

Torque test

Cycle 3600 7200 200

Torque test

Cycle 3600 10800 300

Torque test

Cycle 3600 14400 400

Torque test

Cycle 3600 18000 500

Torque test

Environmental Test: Random vibration, 23.5 grams, 20 minutes in radial direction, 20 minutes in axial direction. Reference Figure 6 for Power Spectrum Density. After vibration, the bearing cartridge is tested in the following sequence.

Representative Cum #

Sequence Cum # of Cycles of Stronglink Actuations

Torque test

Cycle 18000 36000 1000

Torque test

Cycle 18000 54000 1500

Torque test

Cycle 18000 72000 2000

Torque test

(36 cycles are representative of an actuation of a stronglink mechanism.)

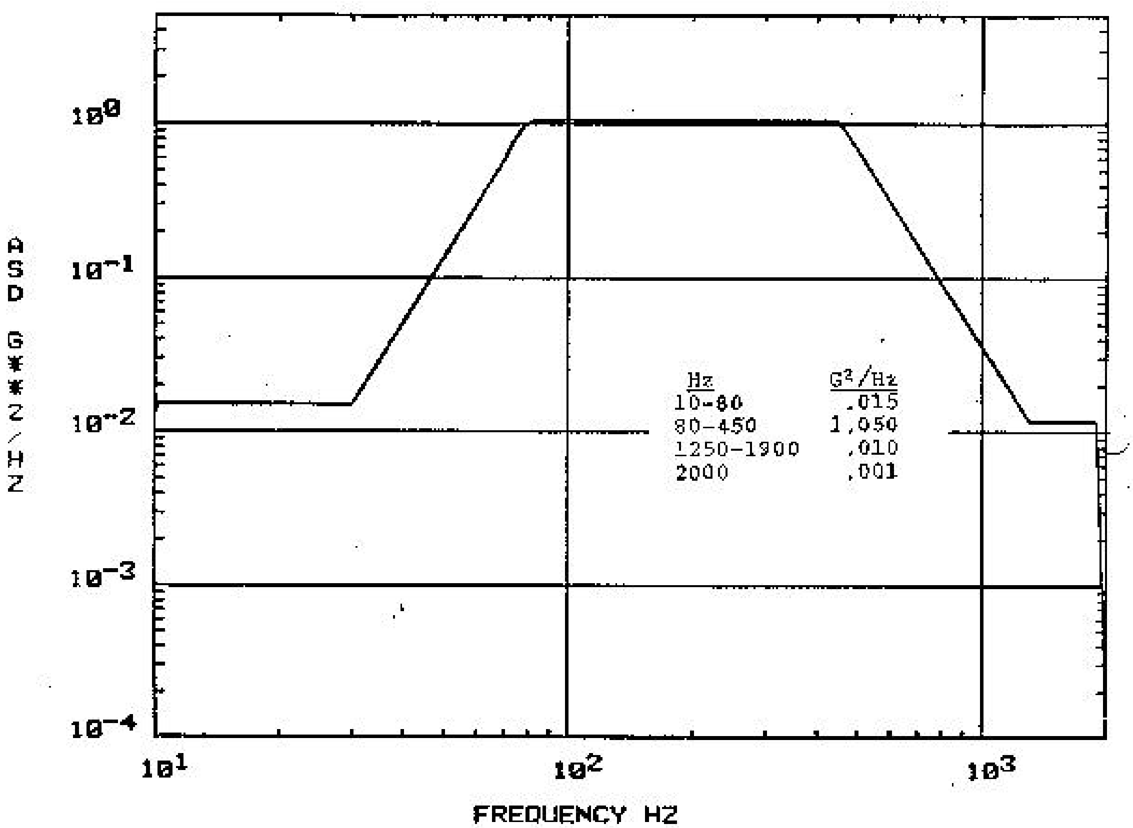

Figure 6. Power Spectrum Density, Random Vibration

Baseline Lubricants

Vydax

The baseline lubricant in stronglink mechanisms is Vydax. Figures 7 and 8 show average torque with +/- 2 sigma error bars and average of the standard deviation of the torque readings for Vydax-lubricated bearings with 1-lb and 10-lb axial preloads. At 1-lb preload, the average torque starts out at 2.9 gm-cm and decreases to less than 1 gm-cm after 72,000 cycles. This decrease is most likely due to the balls pushing the higher molecular weight particles of Vydax from the wear track or mashing them into the wear track. The length of the error bars is large at the start of testing and decreases as the bearings are cycled. This indicates that there is variability between bearings until they have been cycled. The average of the standard deviation of the torque readings (average hash) started out a 0.7 gm-cm and stabilized at 0.5 gm-cm after 7200 cycles. This indicates that the bearings run smoothly and are stable.

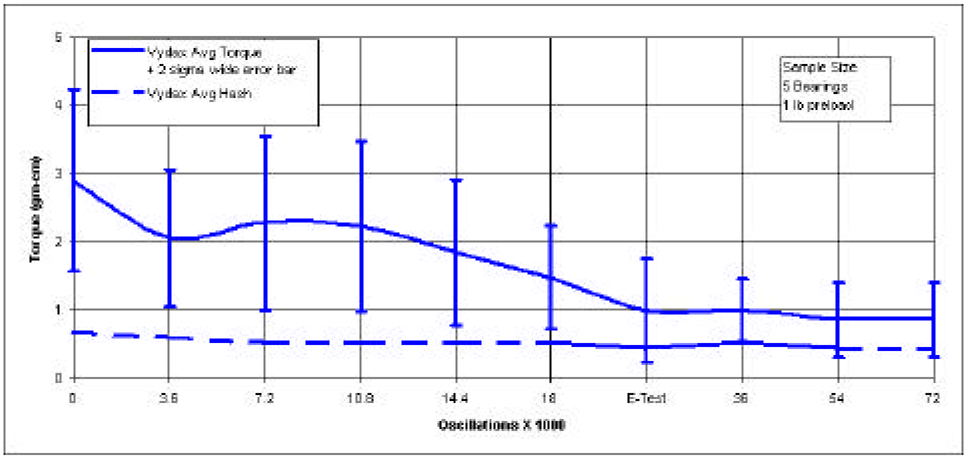

Figure 7. Average Torque and Average Hash - Vydax at 1-lb Preload

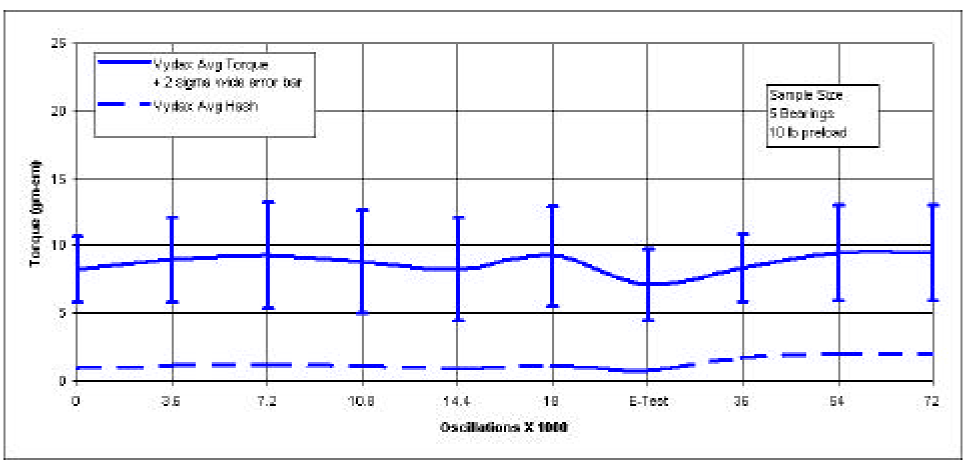

Figure 8. Average Torque and Average Hash - Vydax at 10-lb Preload

At 10-lb preload, the average torque stayed between 7.1 and 9.5 gm-cm through all the testing. The error bars are relatively small and consistent, indicating that the bearings are consistent. The average hash was between 1 and 1.3 gm-cm prior to vibration but increased to 2.2 gm-cm after vibration. This increase was due to one bearing and all others stayed low. These results indicate that bearings lubricated with Vydax are very stable and consistent throughout the life of a stronglink mechanism at both 1-lb and 10-lb preloads.

Diester Oil

As an added baseline comparison, bearings lubricated with a diester oil were tested. The diester oil is typical of lubrication of bearings in commercial applications. These oils cannot be used in stronglink mechanisms due to contamination concerns with the rest of the mechanism. Figures 9 and 10 show average torque with +/- 2 sigma error bars and average hash for 1-lb and 10-lb preloads. Average torque and average hash for Vydax is also shown. At 1-lb preload, the average torque is considerably lower than Vydax but increases greater than Vydax after vibration. The error bars are much smaller than the Vydax error bars, indicating that the bearings are much more consistent prior to vibration. After vibration, the error bars increase to the same levels as Vydax-lubricated bearings. Average hash is approximately the same as Vydax prior to vibration but also increases greater than Vydax after vibration. This would indicate that in normal operation, oiled bearings perform as well if not better than Vydax. After vibration, the performance of oiled bearings degrades slightly.

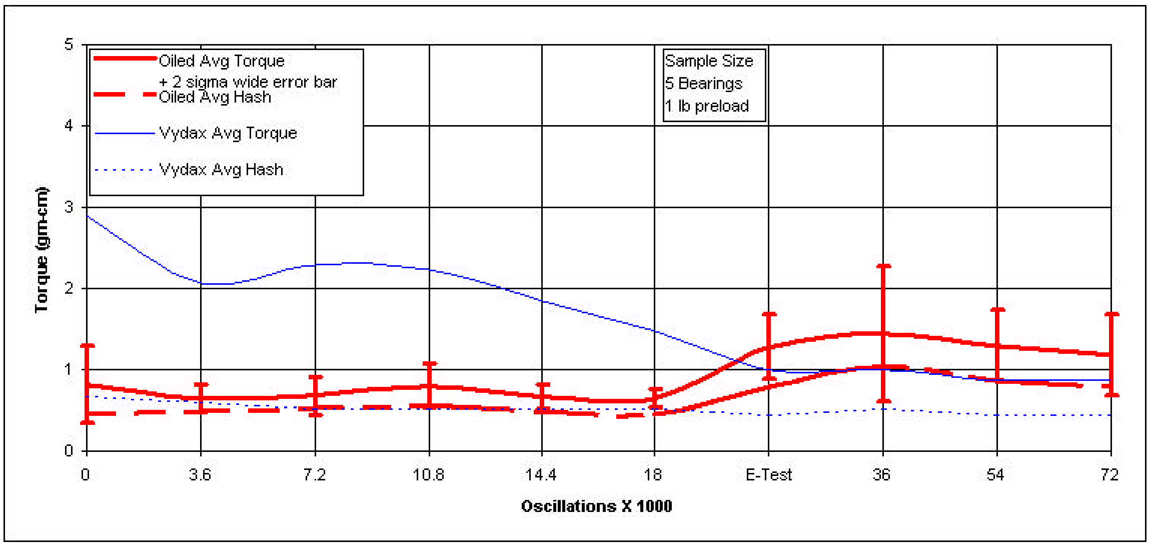

Figure 9. Average Torque and Average Hash - Oiled at 1-lb Preload

At 10-lb preload, the oiled lubricated bearings performed almost identically to the Vydax-lubricated bearings. The error bars are smaller than Vydax-lubricated bearings, indicating that the bearings are more consistent than Vydax. Oiled bearings appear to behave the same as bearings lubricated with Vydax for both 1-lb and 10-lb preloads.

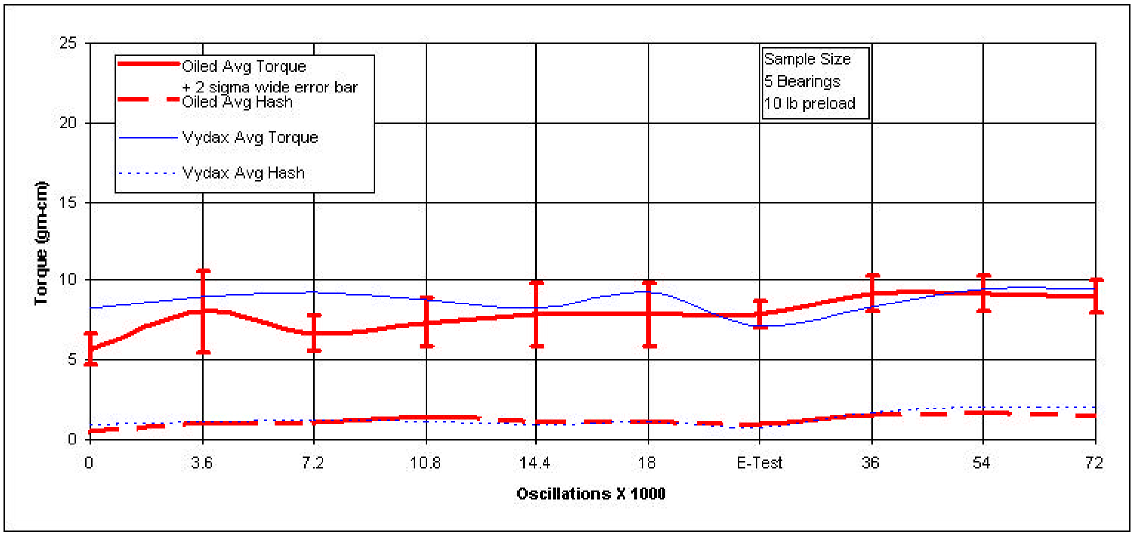

Figure 10. Average Torque and Average Hash - Oiled at 10-lb Preload

Candidates

Electrophoretic Deposition of MoS_2

Electrophoretic deposition of MoS_2 was performed by Sandia National Laboratories on disassembled bearings that were supplied by Federal Manufacturing & Technologies (FM&T) from production stores. The inner and outer races were coated by electrophoretically depositing a 50/50 mixture of MoS_2 and graphite. After coating, these races were sent back to New Hampshire Ball Bearing for re-assembly. One negative to using bearings with this lubricant is that electrophoretic deposition must be done on the pieces of the bearing prior to bearing assembly by the bearing manufacturer. The bearing manufacturer does not have experience with this coating and there is not a known supplier that applies this coating. Transfer of this technology would be fairly easy and inexpensive.

The test results of bearings with this lubrication for 1-lb and 10-lb preloads are shown in Figures 11 and 12. At 1-lb preload, the average torque starts out at 4.3 gm-cm but decreases to between 2.8 and 3.2 gm-cm prior to vibration. After vibration the average torque decreases to 2.2 gm-cm and stabilizes at 2.1 gm-cm for the last 36,000 cycles. The error bars were similar to those with Vydax-lubricated bearings. Vibration may have caused the larger MoS_2/graphite particles to move from the wear track or resulted in the balls crushing the larger particles due to increased loads at vibration. The average of the standard deviation of the torque readings (average hash) tracked closely with the average hash for Vydax. These results indicate that this bearing lubrication is stable and robust at low preload.

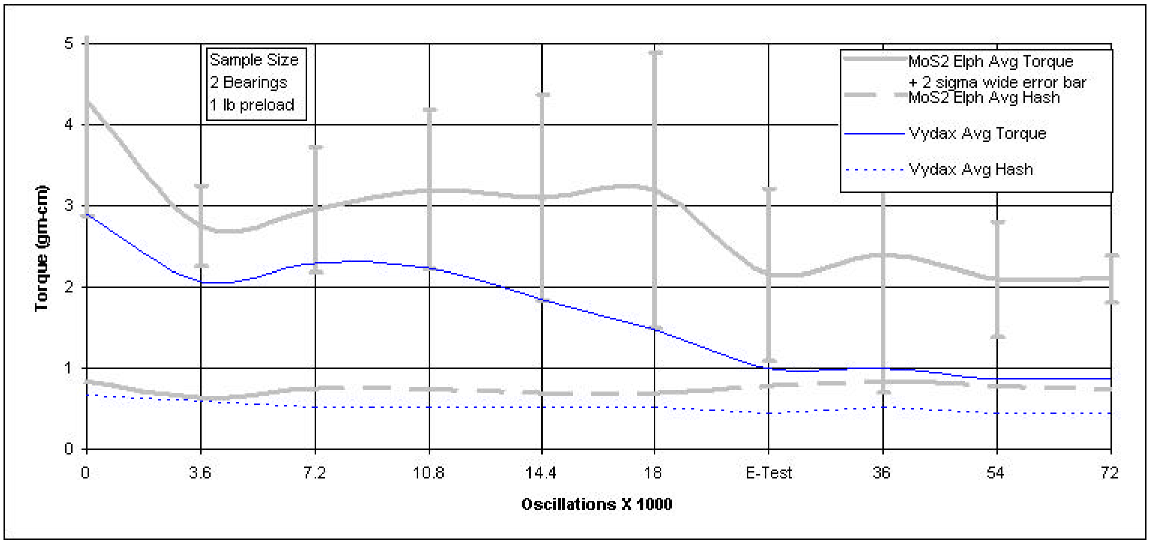

Figure 11. Average Torque and Average Hash - MoS_2 Electrophoretic at 1-lb Preload

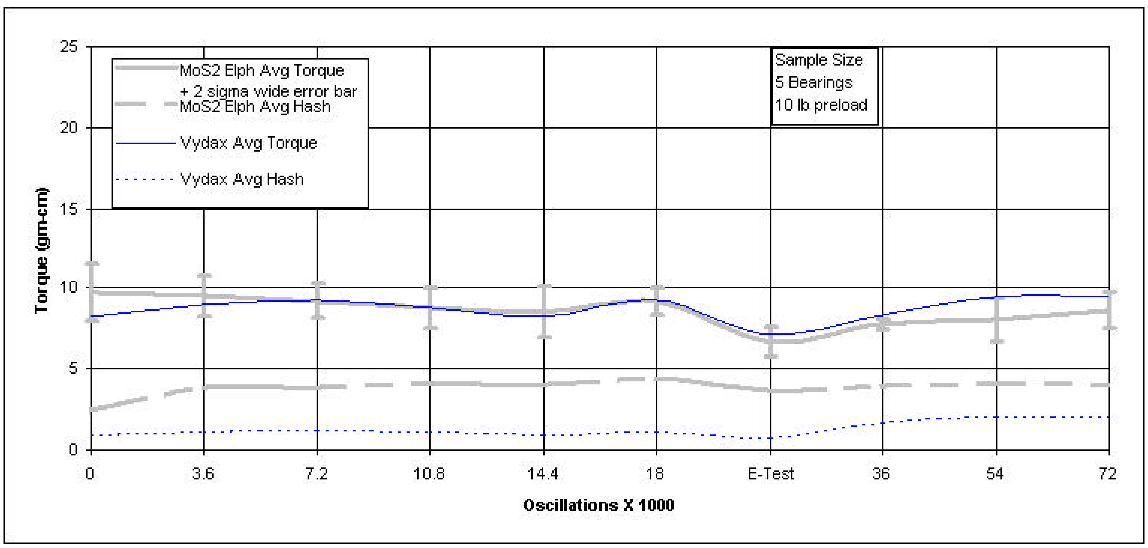

Figure 12. Average Torque and Average Hash - MoS_2 Electrophoretic at 10-lb Preload

At 10-lb preload, bearings with electrophoretic deposition of MoS_2 performed very much like Vydax for average torque. The small error bars indicate that the bearings were very consistent with each other. Average hash was two to three times higher than Vydax, which would indicate a substantial amount of "noise" in the bearing. This is most likely due to the balls rolling over the particles of MoS_2/graphite. It does appear to be stable. Electrophoretic deposition of MoS_2 appears to be an excellent replacement for Vydax for both 1-lb and 10-lb preload applications as long as bearing "noise" is not a concern.

Sputtered MoS_2

Bearings were procured from Miniature Precision Bearings Corporation (MPB) specified with 0.3 - 1 micron of MoS_2 co-sputtered with Antimony Oxide in accordance with the DC Triode method at Hohman Plating and Manufacturing Company in Dayton, Ohio. This sputtering was done on the races and retainers and then the bearings were assembled at MPB. One negative to using bearings lubricated in this manner is the high cost and long lead time for procurement.

Figures 13 and 14 show the test results for bearings preloaded at 1 lb and 10 lbs. At 1-lb preload, the average torque was better than Vydax prior to vibration, then rose slightly after vibration before stabilizing at the same level as Vydax. The error bars are small compared to Vydax, which indicates that the bearings are repeatable with each other. Average hash was slightly higher than Vydax. These results would indicate that this lubricant performs comparably to Vydax lubrication for low load applications.

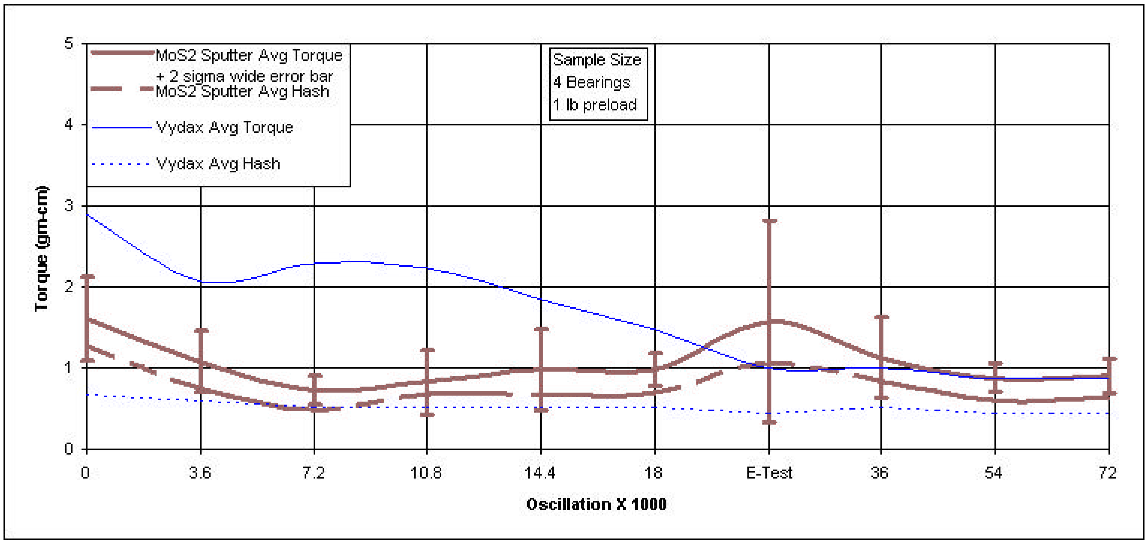

Figure 13. Average Torque and Average Hash - MoS_2 Sputtered at 1-lb Preload

At 10-lb preloads, the average torque started out twice as high as Vydax but came down to the same level as Vydax after 7200 cycles and stayed at levels comparable to Vydax throughout the rest of the testing. Except for the initial test, the error bars are much smaller than Vydax, which indicates that the bearings are repeatable with each other. The average hash was two to three times greater than Vydax but was stable. This would indicate that the bearing is "noisy." This is most likely due to the balls rolling over the particles of MoS_2/graphite. These results indicate that sputtered MoS_2 would be an excellent replacement for Vydax at both 1-lb and 10-lb preload applications. The bearings with this lubrication at high load applications may feel gritty but will be consistent during operations.

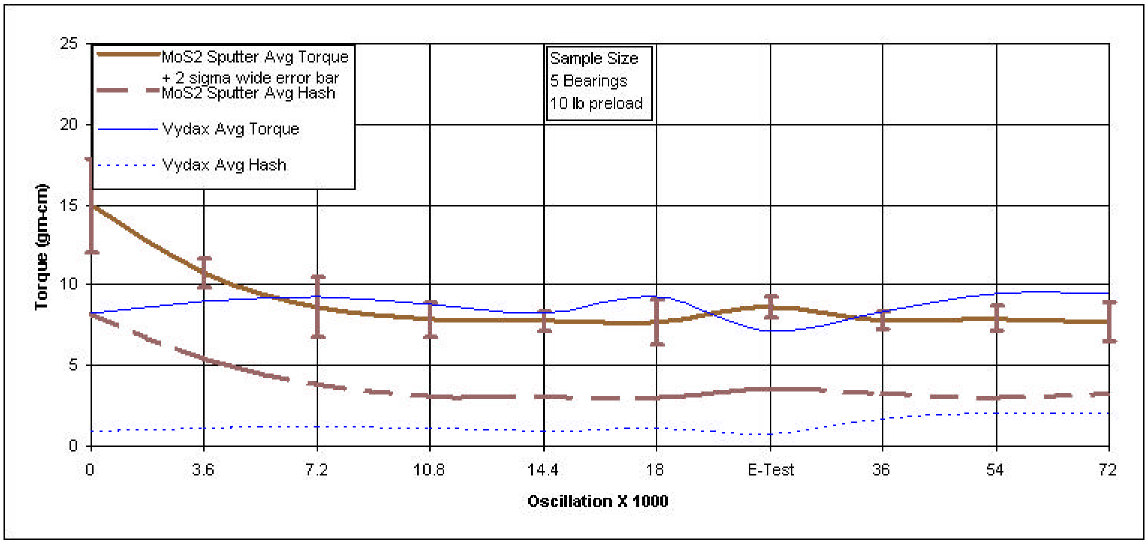

Figure 14. Average Torque and Average Hash - MoS_2 Sputtered at 10-lb Preload

Titanium Carbide (TiC)

Bearings with TiC coated balls were obtained from MPB. These bearings are expensive and require a long lead time for procurement. TiC coating of extremely small balls is difficult. Bearings with extremely small TiC coated balls may not be available.

Test results as shown in Figure 15 indicate that at low load applications in the 1-lb preload range, the TiC coated bearings perform better than bearings coated with Vydax. Average torque stayed below 1.1 gm-cm through most of the testing. The small error bars indicate that the bearings are consistent from bearing to bearing. Average hash was also less than Vydax, which indicates that this is a very smooth running bearing.

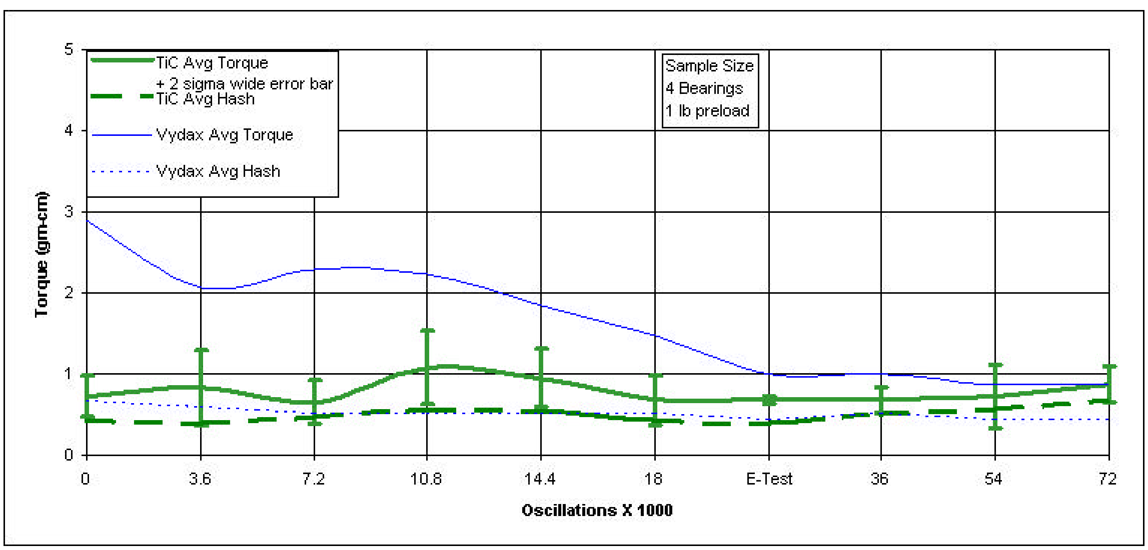

Figure 15. Average Torque and Average Hash - TiC at 1-lb Preload

At 10-lb preload, the average torque was up to 50% greater than Vydax, as shown in Figure 16. This torque is stable through 72,000 cycles and the variability from bearing to bearing is small, as shown by the error bars. The average hash was the same as Vydax, which indicates that the bearing is running smoothly. This bearing is an excellent replacement for Vydax at both high and low axial preload applications.

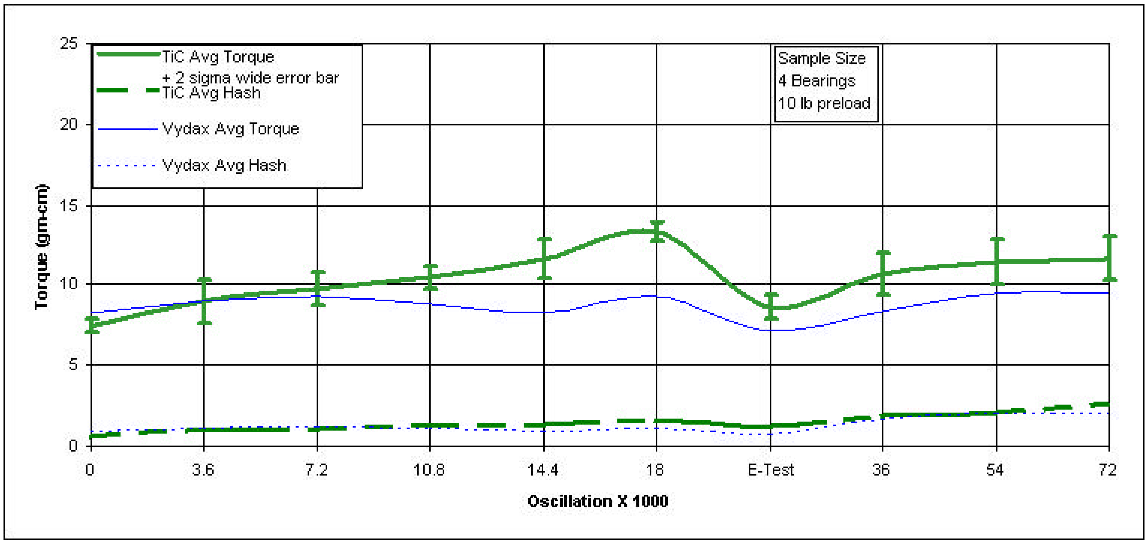

Figure 16. Average Torque and Average Hash - TiC at 10-lb Preload

Silicon Nitride Balls with Molded Glass-Nylon-Teflon Retainers

Bearings with silicon nitride balls and molded glass-nylon-Teflon retainers were procured from MPB. These bearings are very expensive and require long lead times for procurement.

Figure 17 shows average torque with +/- 2 sigma error bars and an average of the standard deviation of the torque readings (average hash) for low load applications at 1-lb preload. The average torque was lower than bearings lubricated with Vydax prior to vibration. After vibration, the average torque was the same as Vydax. The average torque was very stable throughout testing. The small error bars for average torque indicate that the bearings are consistent from bearing to bearing. The average hash was only slightly higher than Vydax. This indicates that the bearing is running very smoothly. There appears to be no degradation seen at low load testing. This bearing appears to be an excellent replacement for Vydax for low load applications.

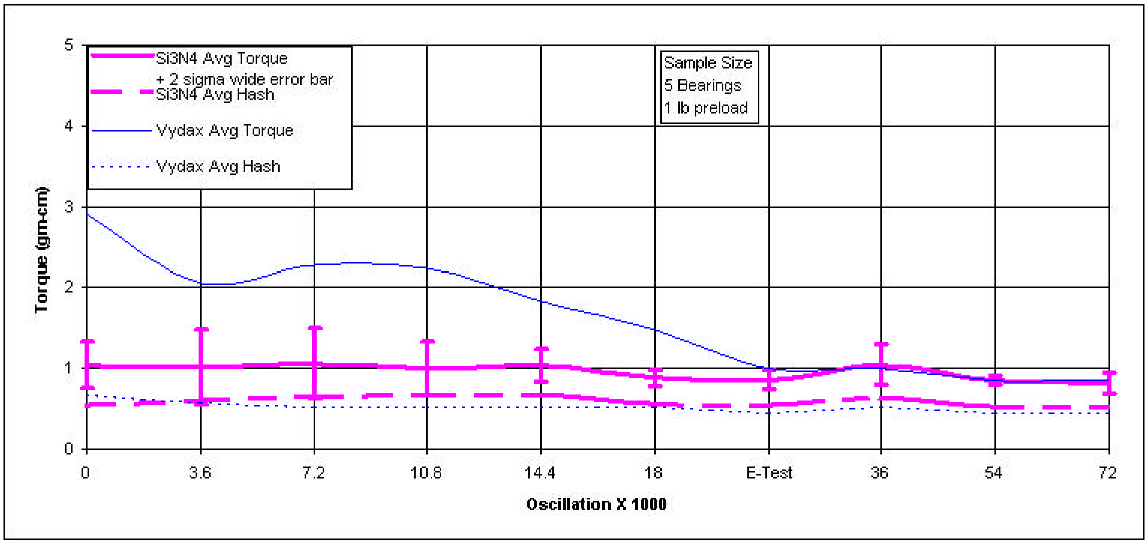

Figure 17. Average Torque and Average Hash - Si3N4 at 1-lb Preload

Test results for bearings preloaded axially at 10-lbs are shown in Figure 18. The average torque was greater than bearings lubricated with Vydax. The bearings degraded after vibration to the point where they are not acceptable for mechanism applications. Average hash was higher than Vydax and degraded after vibration. Bearings with silicon nitride balls are not acceptable for high load applications.

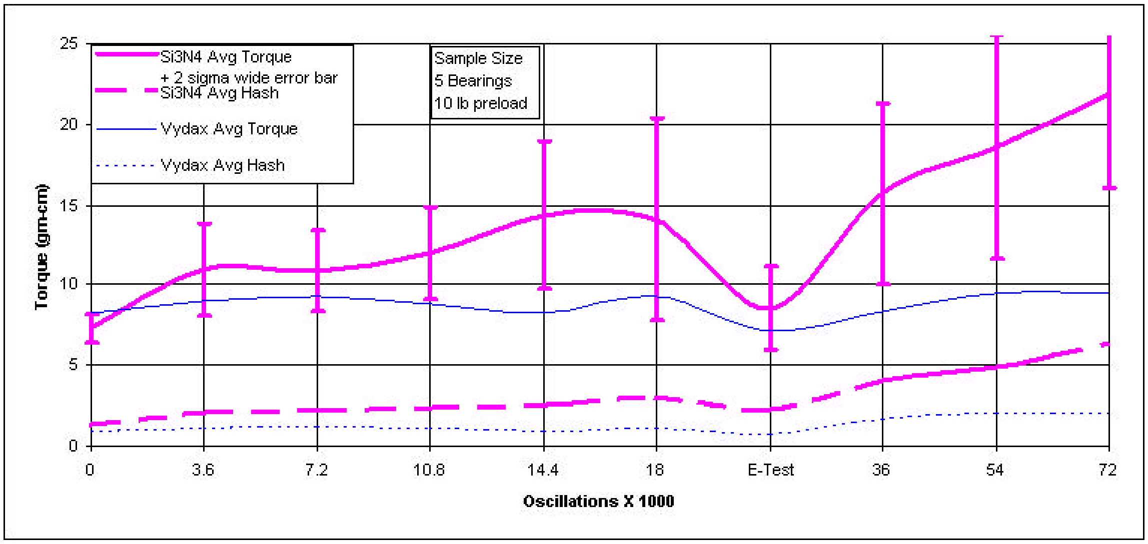

Figure 18. Average Torque and Average Hash - Si3N4 at 10-lb Preload

Accomplishments

Fixturing was developed and a test procedure was established to evaluate single race bearings under various axial preloads and under conditions that bearings may see in stronglink applications. Most importantly, once the bearings are preloaded, the preload is not removed through the entire testing process.

Four lubricant replacement candidates for single race bearings were evaluated and compared with bearings lubricated with Freon-deposited PTFE from Vydax and bearings lubricated with a diester oil. Freon-deposited PTFE from Vydax is the current baseline lubricant for duplex bearings in mechanism applications at KCP. Bearings lubricated with diester oil represent a baseline for commercial use. These baseline bearings exhibited extremely consistent performance for average torque and average standard deviation over 72,000 cycles.

Bearings with electrophoretically deposited MoS_2 exhibited torque performance better than oiled bearings and bearings lubricated with Vydax at both low and high load applications. This was the best performing candidate. One negative to using bearings with this lubricant is that electrophoretic deposition must be done on the pieces of the bearing prior to bearing assembly by the bearing manufacturer. The bearing manufacturer does not have experience with this coating and there is not a known supplier that applies this coating. Transfer of this technology would be fairly easy and inexpensive, making these bearing relatively inexpensive.

Bearings with TiC coated balls also performed well at both high and low preload applications. The high cost of these bearings makes this candidate not as appealing as other candidates. This type of bearing may not be available in extremely small sizes.

Bearings with sputtered MoS_2 on the races and retainers also performed well at both high and low preload applications. Bearings of this type are also expensive due to the cost of sputtering on the races and retainers.

The bearings with silicon nitride balls and molded glass-nylon-Teflon retainers exhibited unacceptable torque at high preloads. Torque was acceptable for low load applications, but their high cost and long lead time for procurement make this candidate unappealing as a replacement for low load applications.

References

1R. G. Steinhoff, *ES&H-Compatible Lubrication for Duplex Bearings* (Topical Report). AlliedSignal Federal Manufacturing & Technologies: KCP-613-6015, October 1997 (Available from NTIS).

2R. G. Steinhoff, *Lubrication for High Load Duplex Bearings* (Topical Report). AlliedSignal Federal Manufacturing & Technologies: KCP-613-5983, August 1997 (Available from NTIS).

3R. M. Bryan, *Dry Film Lubricant Evaluation* (Final Report). AlliedSignal Federal Manufacturing & Technologies: KCP-613-5044, April 1993 (Available from NTIS).