ES&H-Compatible Lubrication for Duplex Bearings

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ES&H-COMPATIBLE LUBRICATION FOR DUPLEX BEARINGS

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Topical Report
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Abstract

Two ES&H-compatible lubricants (environment, safety, and health) for duplex bearing applications and one hybrid-material duplex bearing were evaluated and compared against duplex 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 duplex bearings with silicon nitride balls and molded glass-nylon-Teflon retainers, duplex bearings lubricated with sputtered MoS_2 on races and retainers, and duplex bearings lubricated with electrophoretic deposited MoS_2 were evaluated. Bearings with electrophoretic deposited MoS_2 performed as well as bearings with Freon deposition of PTFE from Freon-based Vydax. Hybrid bearings with silicon nitride balls performed worse than bearings lubricated with Vydax, but their performance would still be acceptable for most applications. Bearings lubricated with sputtered MoS_2 on the races and retainers had varying amounts of film on the bearings. This affected the performance of the bearings. Bearings with a uniform coating performed to acceptable levels, but bearings with no visible MoS_2 on the races and retainers did not perform as well as bearings with the other coatings. Unless process controls are incorporated in the sputtering process or the bearings are screened, they do not appear to be acceptable for duplex bearing applications.

Summary

Two ES&H-compatible lubricants (environment, safety, and health) for duplex bearing applications and one hybrid-material duplex bearing were evaluated and compared against duplex 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. 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 are required in order to use Vydax and Freon.

Hybrid duplex bearings with silicon nitride balls and molded glass-nylon-Teflon retainers, duplex bearings lubricated with sputtered MoS_2 on races and retainers, and duplex bearings lubricated with electrophoretic deposited MoS_2 were evaluated. They were compared to a baseline consisting of duplex bearings lubricated with trichlorotrifluoroethane (Freon) deposition of low molecular weight polytetrafluoroethylene (PTFE) bearing lubricant extracted from Vydax. Vydax-lubricated bearings were also compared to bearings lubricated with diester oil which is representative of bearing lubricants that are used commercially. Bearings with Vydax lubrication were found to perform consistently with oiled bearings. Average torque was slightly lower with Vydax, but oiled bearings ran smoother than Vydax-lubricated bearings. Bearings without any lubrication (dry) were also tested. These bearings degraded quickly.

A comparison was made of average torque for the candidates and baselines. Bearings with electrophoretic deposited MoS_2 performed as well as bearings with Vydax lubrication. Bearings with silicon nitride balls performed worse than bearings lubricated with Vydax and bearings lubricated with oil, but their performance would still be acceptable for most applications. Bearings with sputtered MoS_2 on the races and retainers had varying amounts of film on the bearings. This affected the performance of the bearings. Bearings with a uniform coating performed to acceptable levels, but bearings with no visible MoS_2 on the races and retainers did not perform as well as bearings with the other coatings. Unless process controls are incorporated on the sputtering process or the bearings are screened, they do not appear to be acceptable for duplex bearing applications.

Discussion

Scope and Purpose

The objective of this project was to evaluate the most promising ES&H-compatible (environment, safety, and health) lubricant replacement candidates against current baselines for duplex bearing applications. This project was undertaken because the current lubricant, Vydax™, contains PTFE (polytetrafluoroethylene) suspended in Freon (trichlorotrifluoroethane) 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 are required in order to use Vydax and Freon.

The following ES&H-compatible lubricant replacement candidates were evaluated to replace filtered Vydax for duplex bearings:

A. Silicon nitride balls with molded glass-nylon-Teflon retainers
B. Sputtered MoS_2 on races and retainers
C. Electrophoretic deposited MoS_2

Prior Work

Other lubricants have been evaluated in the past for high load duplex bearings. These bearings are much the same as these except the balls are under loads up to the yield point of the materials and no retainer is used. The final report *Dry Film Lubricant Evaluation*, KCP-613-5044, describes testing of Dicronite (WS2) lubrication of high load duplex bearings.[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] These bearings were all compared to bearings lubricated with Freon deposition of Vydax.

Activity

Background

A duplex bearing has two rows of balls, one outer race, two inner races, and retainers to separate the balls as shown in Figure 1. The inner races, which have a gap between them when unloaded, are pushed together which causes the balls to be compressed between the inner and outer races. This stabilizes the bearing with no end play and very little radial play. The duplex bearing was used as a test bed for this evaluation. With 5 to 10 pounds-force applied to bring the inner races together, approximately 1 to 4 pounds-force is applied to the balls. This bearing was designed specifically for use in dual stronglink assembly modules for locating discriminator wheels and safing wheels.

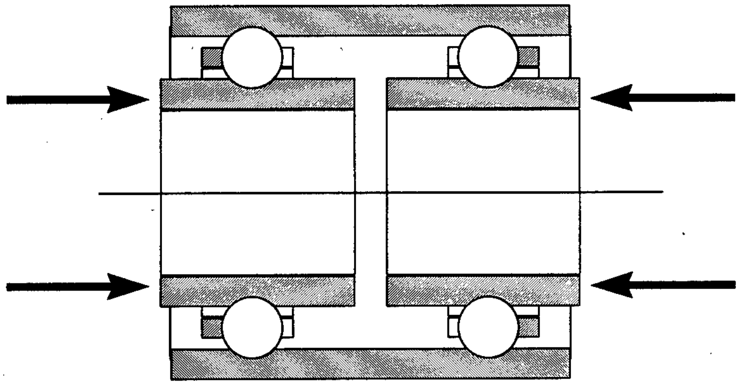

Figure 1. Cross Section of a Duplex Bearing

Stronglink switches designed since 1974 have required lubrication of 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

Functional testing of all bearings was performed on the bearing torque tester. This tester preloads the duplex bearing and rotates it 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. The tester can also rotate the bearing at 24 rpm without taking torque readings in order to put cycles on the bearing between tests without removing the preload. Figure 2 shows the torque tester. The bearing test procedure is to take measurements on the cycles (revolution) 1, 2, 5, 10, 25, 50, 100, 200, 300, 400, 500, 1000, 1500, and 2000.

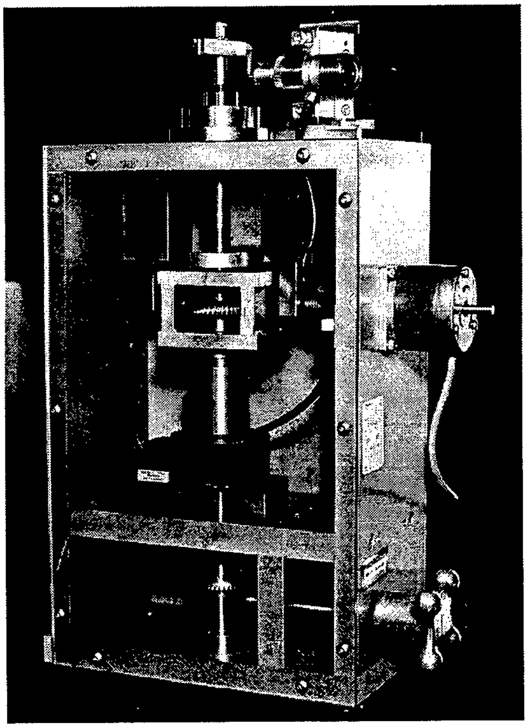

Figure 2. Bearing Torque Tester

Baseline Lubricant

Vydax is the baseline lubricant for comparing bearing test data. However, diester oil, a commercially available bearing lubricant, and dry bearings were also used as baselines when evaluating test results. Figure 3 shows a comparison of average torque for the candidate lubricants and baseline.

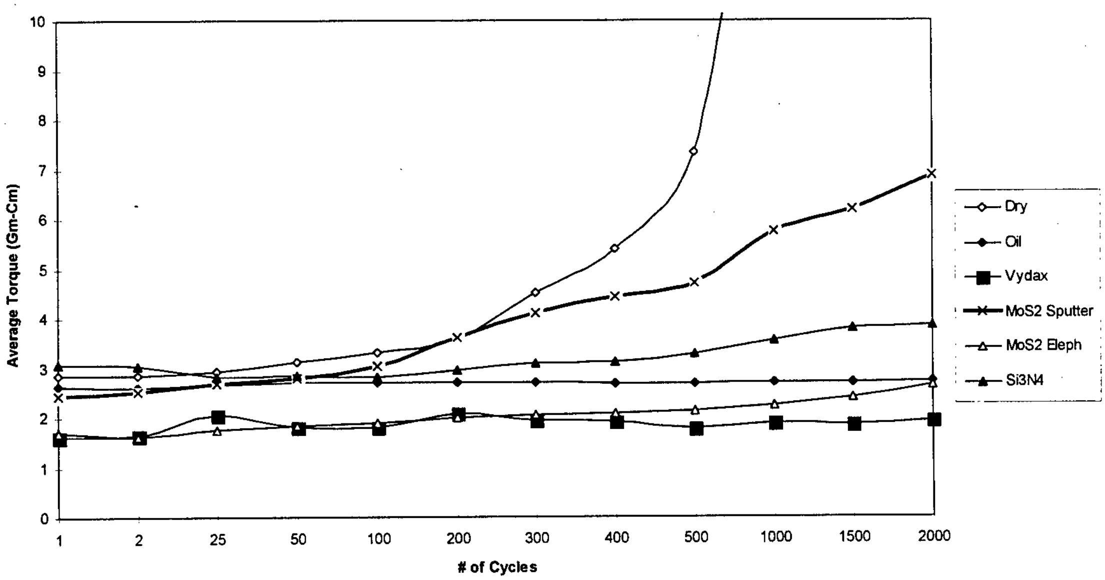

Figure 3. Average Torque Comparison

Vydax

The baseline lubricant for this bearing is Vydax. Figure 4 shows average torque with +/-2 sigma error bars and average standard deviation of the torque (average hash) for 15 bearings tested. The average torque varied between 1.61 and 2.09 gm-cm torque, which is low and stable. Error bars are also shown representing +/-2 standard deviations of the average torque of the 15 bearings. This showed less than 1 gm-cm standard deviation, which means that the bearings were consistent with each other. The average of the standard deviation of the torque readings (average hash) is shown as a dotted line. This stayed between 0.42 and 0.47 gm-cm which, indicates that the bearing is running smoothly during the one revolution that test data is being taken.

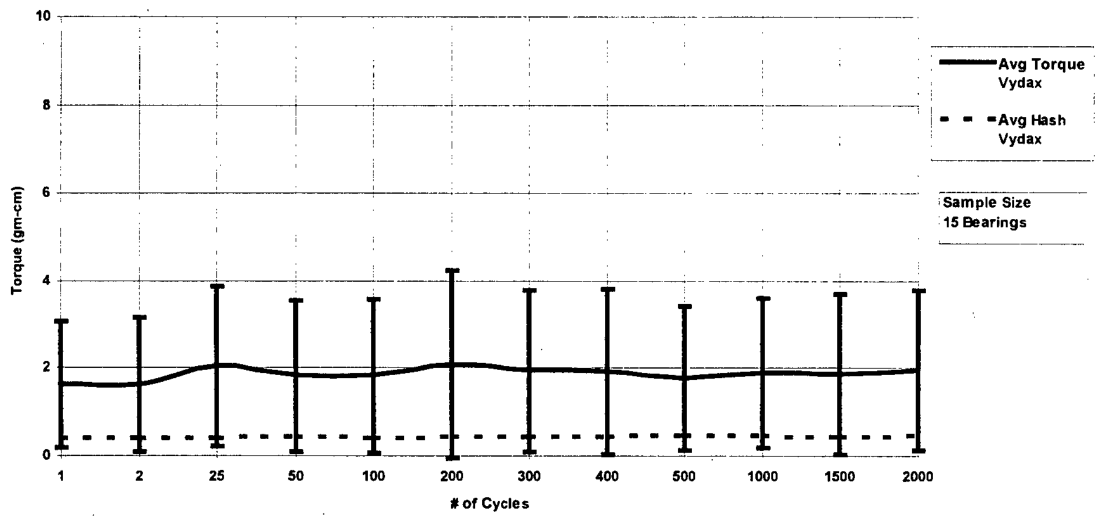

Figure 4. Average Torque and Average Hash—Vydax

Oiled

As an added comparison, a baseline was established for the bearing lubricated with a diester oil which is typical of oils used to lubricate bearings in commercial applications. These oils cannot be used in stronglink mechanisms due to contamination concerns within the rest of the mechanism. Figure 5 shows average torque with +/-2 sigma error bars and average hash for 10 bearings tested. The average torque varied between 2.6 and 2.8 gm-cm torque, which is slightly higher than Vydax, but it is extremely stable. Error bars are also shown representing +/-2 standard deviations of the average torque of the 10 bearings. This showed between 0.9 and 1.1 gm-cm standard deviation, which means that the bearings were consistent with each other. The average of the standard deviation of the torque readings (average hash) is also shown as a dotted line. This stayed between 0.20 and 0.30 gm-cm, which indicates that the bearing is running smoother than the Vydax bearings. This was lower than any of the bearing types tested.

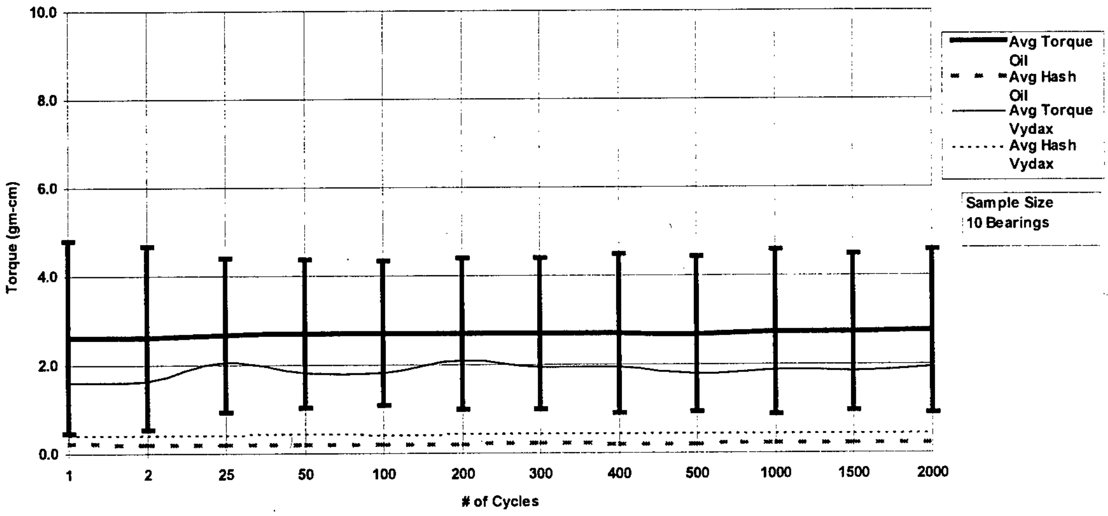

Figure 5. Average Torque and Average Hash—Oiled

Dry

To show how bad a bearing can get, a comparison baseline was established for unlubricated or dry bearings. The average torque started out at 2.8 gm-cm and stayed fairly stable through 100 revolutions as shown in Figure 6. After that, the average torque increase to 21.7 gm-cm by the completion of 2000 revolutions. The average torque standard deviation stayed between 0.7 and 0.8 gm-cm through 100 revolutions, then quickly degraded with a maximum of 6.7 gm-cm at 2000 revolutions. Average hash readings were not reported.

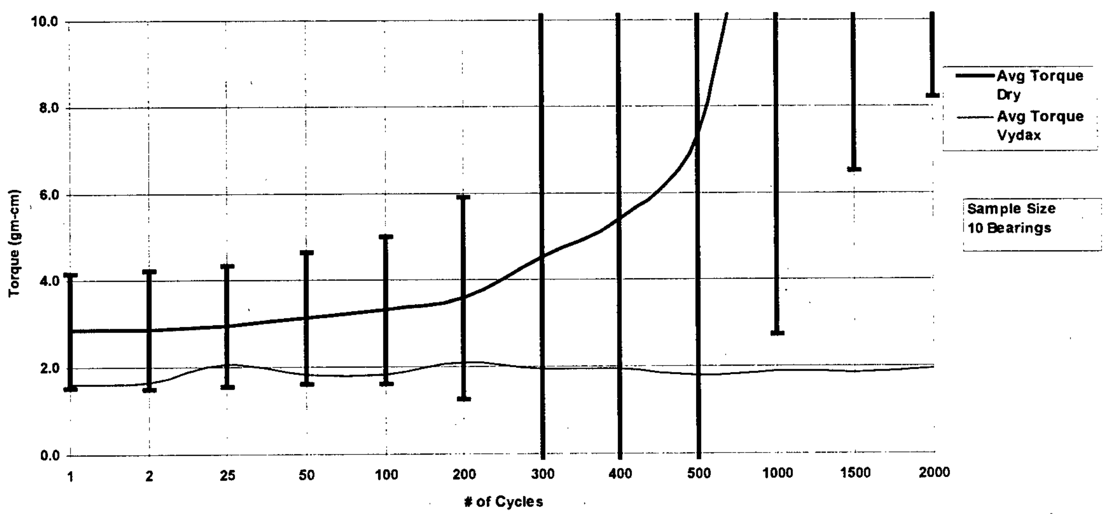

Figure 6. Average Torque—Dry

Silicon Carbide Balls With Molded Glass-Nylon-Teflon Retainers

Bearings with silicon carbide balls and molded glass-nylon-Teflon retainers were obtained commercially from Miniature Precision Bearings Corporation (MPB). As shown in Figure 7, the average torque started out initially at 3.1 gm-cm and decreased slightly to 2.8 gm-cm before slowly climbing to 3.9 gm-cm by the time 2000 cycles were completed. This torque is approximately 50% higher than bearings with Vydax, but it is only slightly higher than oiled bearings. There is a trend of increasing torque as cycles are put on the bearings, which is a concern. Also shown in Figure 6 are error bars representing +/-2 standard deviations of the average torque for the ten bearings tested. The standard deviation started out at 1.3 gm-cm, dropped to 0.9 gm-cm, and then rose to 1.5 gm-cm as the number of cycles rose to 1.5 gm-cm. This is only slightly higher than bearings with Vydax, but it still indicates that the bearings are running consistently with each other. The average of the standard deviation of the torque readings (average hash) was between 0.7 and 0.5 gm-cm, which indicates that the bearings are running fairly smoothly. Again, this is worse than the bearings with Vydax, but it remained stable throughout the cycling of the bearing. These bearings performed worse than bearings lubricated with Vydax and bearings lubricated with oil, but their performance would still be acceptable for most applications.

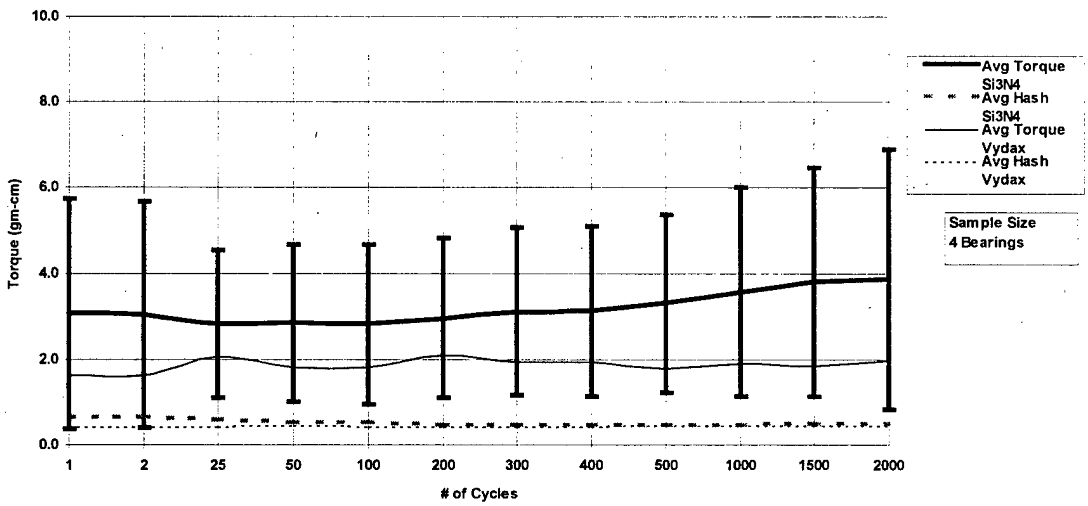

Figure 7. Average Torque and Average Hash—Silicon Carbide Balls With Molded Glass-Nylon-Teflon Retainers

Sputtered MoS_2 on Races and Retainers

Duplex bearings were procured from 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 piece parts and then assembled at MPB. Figure 8 shows the test results for 29 bearings. Average torque started out at 2.1 gm-cm and rose to 4.0 gm-cm by the end of 2000 revolutions. The trend for average torque was increasing. Also shown are the error bars which represent +/-2 standard deviations of the average torque for the 29 bearings. The standard deviation started at 0.9 gm-cm and increased to 3.8 gm-cm, which indicates a lot of variability between bearings as the bearings are cycled. The average of the standard deviation of the torque readings (average hash) started at 0.4 gm-cm and increased to 0.6 gm-cm, which indicates that the bearings are running fairly smoothly even though there is an upward trend.

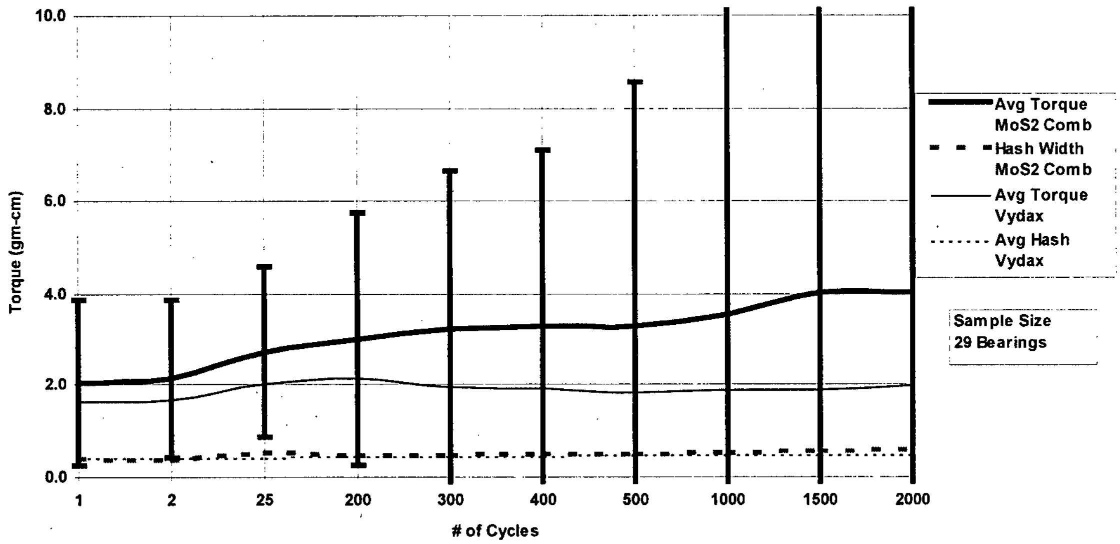

Figure 8. Average Torque and Average Hash—Sputtered MoS_2 Combined

These bearings were run in 3 groups. The first group had the MoS_2 film estimated to be between 0.1 and 0.5 μm thick. The second group had films not visible to the naked eye and were estimated to be less than 50 nm thick. The third group was randomly selected from the remaining bearings. The following looks at each group independently.

Results of tests from the first group are shown in Figure 9. The average torque started at 1.8 gm-cm and increased to 2.9 gm-cm after 200 cycles and then dropped to 1.8 gm-cm after the 2000 cycles. The standard deviation of the average torque was initially 0.75 gm-cm and increased to 0.95 gm-cm before dropping off to 0.56 gm-cm, which indicates that the bearings are running very consistently. The average of the

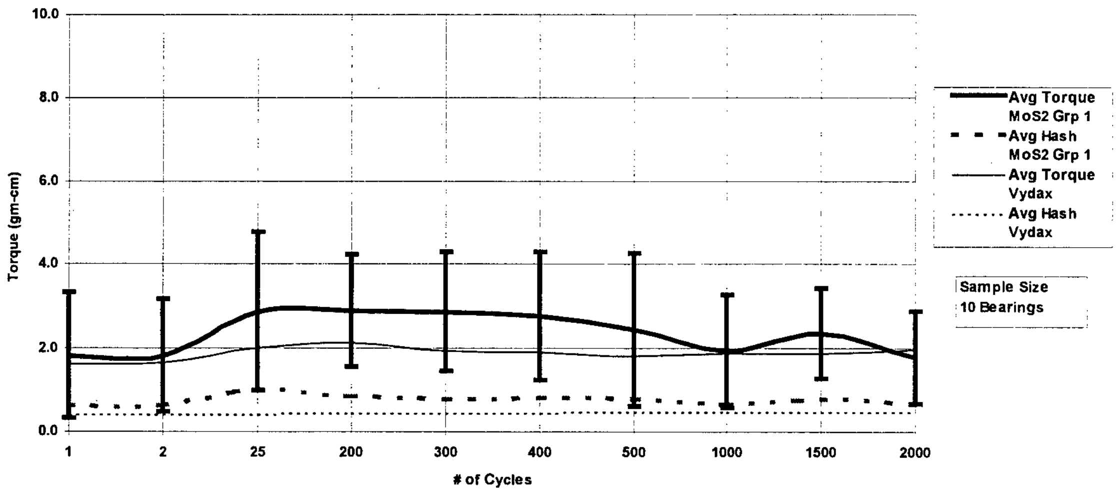

Figure 9. Average Torque and Average Hash—Sputtered MoS_2, Group 1

standard deviation of the torque readings (average hash) started out at 0.6 gm-cm and increased to 1 gm-cm before decreasing back to 0.66 gm-cm. This indicates that the bearings are running with some roughness but it does not appear to be degrading. Bearings of this type would be acceptable for mechanism application.

Results of tests from the second group (no visible film) are shown in Figure 10. The average torque started out at 1.9 gm-cm and increased steadily to 3.4 gm-cm at 2000 cycles. The standard deviation of the average torque started out at 0.7 gm-cm and decreased steadily to 1.5 gm-cm. This indicates that the bearings are degrading with wear and do not behave as predictably as cycles are accumulated. The average of the standard deviation of the torque readings (average hash) stayed steady at 0.3 gm-cm throughout testing, which indicates that the bearings are running very smoothly. These bearings would most likely be acceptable for mechanism application but the trend is not good.

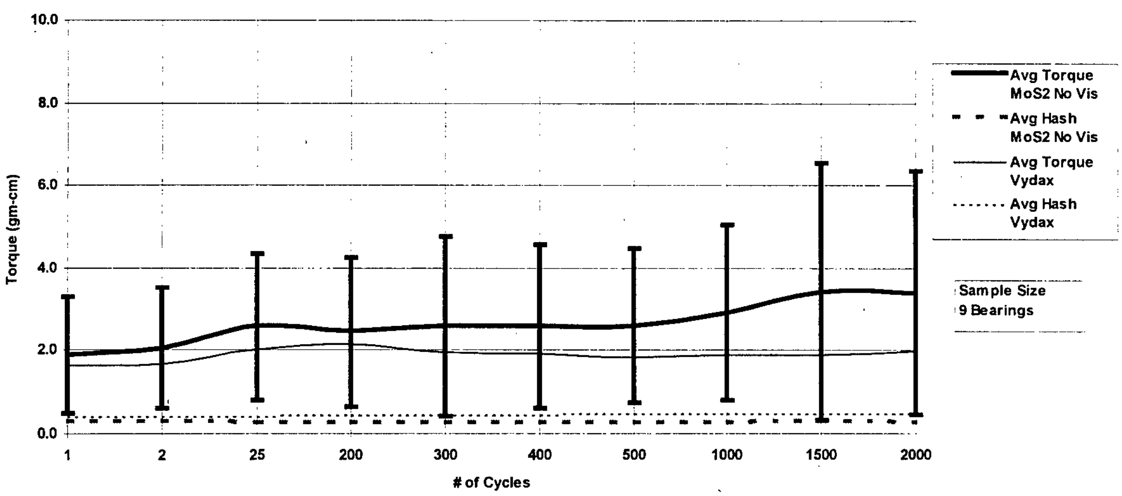

Figure 10. Average Torque and Average Hash—Sputtered MoS_2, No Visible Film

Results of testing from the third group are shown in Figure 11. Average torque started out at 2.4 gm-cm but then doubled within 500 revolutions and rose to 6.9 gm-cm by the end of 2000 revolutions. The trend for average torque is increasing. Also shown are the error bars which represent +/-2 standard deviations of the average torque for the ten bearings. The standard deviation started at 1 gm-cm through 100 revolutions and increased to 5.3 gm-cm, which indicates a lot of variability between bearings. The average standard deviation (average hash) started at 0.3 gm-cm and increased to 0.8 gm-cm, which indicates that the bearings are fairly smooth but are becoming rougher as cycles are accumulated. Even though the torque on these bearings is relatively low, they are much worse than Vydax and oiled bearing baselines; and the trend shows that the bearing is degrading as the bearings are cycled. The inconsistency of these bearings makes them unacceptable for mechanism application.

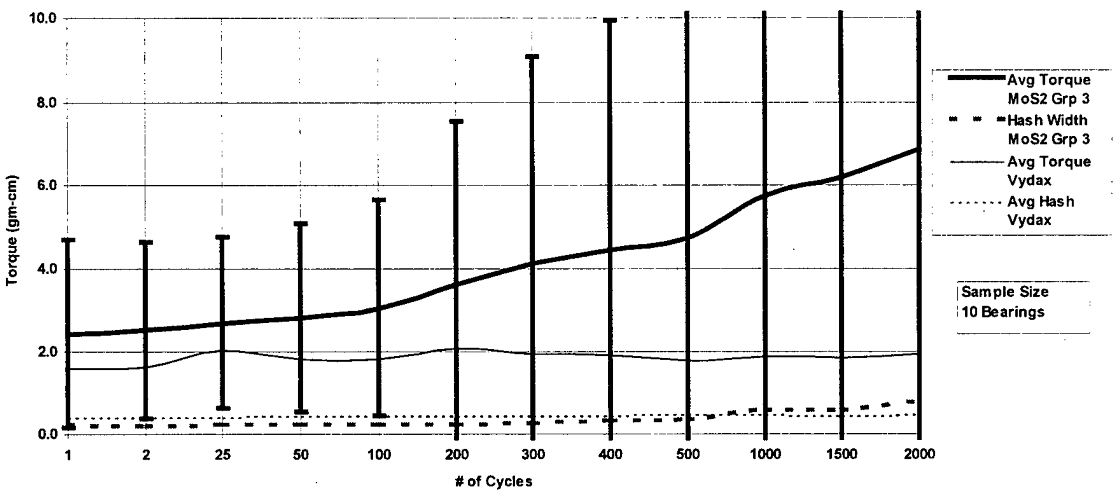

Figure 11. Average Torque and Average Hash—Sputtered MoS_2, Group 3

Electrophoretic Deposited MoS_2

Duplex bearings with electrophoretic deposited MoS_2 were originally coated at Sandia as assemblies, but these exhibited corrosion of the balls and races as well as nonuniformity of the coating. At first this corrosion was believed to be due to slow drying of the deposition solution, but subsequent evaluations revealed that oxidation occurs in tight crevices during the electrophoretic process. Duplex bearings for this evaluation were coated by electrophoretic depositing a 50/50 mixture of MoS_2 and graphite on disassembled races. Two deposition cycles were used to coat the races with burnishing in between cycles. These races were sent back to MPB for assembly and returned for testing.

The test results are shown in Figure 12. The average torque for 8 bearings with electrophoretic deposited MoS_2 was between 1.6 and 2.7 gm-cm, which is slightly higher than bearings lubricated with Vydax and lower than bearings lubricated with oil. There is a trend upward in average torque as the bearing is cycled but the slope

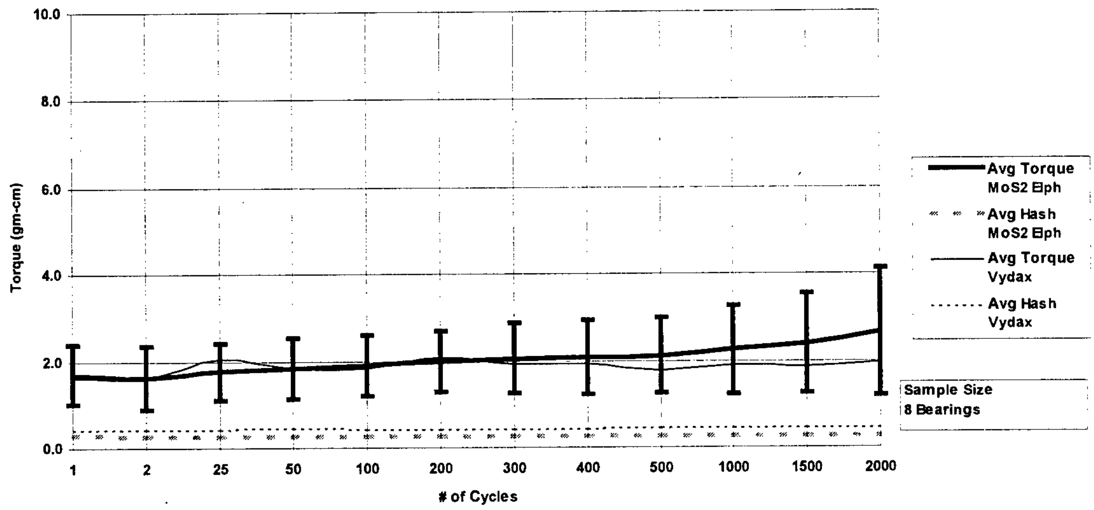

Figure 12. Average Torque and Average Hash—Electrophoretic MoS_2

appears to be small. The standard deviation of the average torque for the 8 bearings was between 0.3 and 0.7 grams, which is better than bearings with Vydax or oil. This indicates that there is very little variability between bearings. The average standard deviation (average hash) was 0.3 grams, which indicates that these bearings run nearly as smoothly as oiled bearings and smoother than bearings with Vydax.

Accomplishments

Three lubricant replacement candidates for duplex bearings were evaluated and compared against bearings lubricated with Freon-deposited PTFE from Vydax and bearings lubricated with a diester oil. Bearings with Freon-deposited PTFE from Vydax is the current baseline lubricant for duplex bearings in mechanism applications at the Kansas City Plant. 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 across 2000 revolutions.

Bearings with electrophoretic deposited MoS_2 exhibited average torque performance better than oiled bearings and only slightly lower than bearings lubricated with Vydax. There was a slight upward trend as the bearings with electrophoretic deposited MoS_2 were cycled. These bearings also ran as smoothly as oiled bearings, which is better than bearings lubricated with Vydax.

The bearings with silicon nitride balls and molded glass-nylon-Teflon retainers exhibited higher average torque than bearings lubricated with Vydax and bearings lubricated with oil. These bearings also exhibited an upward trend for average torque as they accumulated cycles. The silicon nitride bearings also do not run as smoothly as the baseline bearings. Even though these bearings exhibited these characteristics, they may still be acceptable for current applications. Current applications would require bearings with less than 5 gm-cm average torque and average standard deviation (average hash) less than 1 gm-cm.

Bearings with sputtered MoS_2 on the races and retainers exhibited varying degrees of film thickness when visually examined. The film thickness variability appears to affect the performance of the bearings. Bearings with a standard film thickness exhibited characteristics which are slightly worse than the baseline but would be acceptable for mechanism application. Bearings with no visible film thickness and bearings pulled at random exhibited degradation of performance to unacceptable levels as the bearings were cycled. The bearings stayed at better than acceptable levels through 500 cycles but degraded quickly past that point.

References

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

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

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