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"Development and Evaluation of Rheolube 374C as an Alternative to Andok® C for High-Speed Precision and Instrument Bearings"

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Abstract

Channeling greases, such as Andok® C, have long been recognized as critical to the performance of high-speed miniature and instrument ball bearings. Our goal was to develop an alternative to Andok® C, an NLGI grade four, sodium soap thickened grease, based on petroleum oil, recently discontinued by ExxonMobil. The result, Rheolube 374-C, an NLGI grade four, lithium-complex channeling grease with superior water washout performance, based on polyalphaolefin, has been successfully developed and shown to exhibit properties superior to that of Andok® C. Noise and vibration analysis, conducted on GMN KGE-3 ball bearing analyzer, demonstrates clearly that Rheolube 374-C performs at significantly lower noise and vibration levels than Andok® C. For example, one test produced results for the low band and high band for Andok® C at 18 and 24, respectively, versus 12 and 18 for Rheolube 374-C. The noise level as measured on an oscilloscope produced readings as high as 1/2 grid for Andok® C versus 1/16 grid for Rheolube 374-C. Since lower noise and vibration levels correlate with improved life, these results demonstrated that Rheolube 374C has the capability to outperform Andok® C in high-speed precision ball bearings. Accelerated life testing also demonstrates the superiority of Rheolube 374-C. Grease testing in conjunction with noise and vibration results will be presented. In addition, applications involving high-speed miniature and instrument precision ball bearings utilizing Rheolube 374-C will be presented and discussed.

Introduction

Channeling is a phenomenon associated with grease often discussed in relation to the performance and operation of rolling element bearings. Channeling is the condition that results when a rolling element passes through grease with the proper consistency, producing a permanent track that allows the rolling element to pass on its return and subsequent orbits without having to pass through grease. This type of operation is desirable since the bearing need not pump away the grease as it operates. The opposite condition, also possible in rolling element bearings is known as slumping. Slumping is a condition produced by the grease filling the track produced by the rolling element after it has passed and proceeds to its subsequent orbits. Another way of visualizing slumping is grease continually attempting to fall in front of the rolling elements and the separator, producing a pumping action resulting in increased friction and thermal energy within the bearing. Using 157°F as a baseline, it can be demonstrated that for every 20°F rise in temperature, the expected life of a bearing lubricant will be halved and, subsequently, halved again for every additional increase of 20°F. While several factors influence the ability of grease to channel such as consistency, thickener type, base oil chemistry, etc., producing channeling greases remains a challenge to grease manufacturers concerned with producing greases for use in high-speed applications.

Background

Andok® C, an NLGI grade four, product of ExxonMobil was recently discontinued. The product had a fine reputation for use in high-speed miniature and instrument precision and instrument bearings and was well known in the bearing community for its channeling capabilities. The reputation for long-life and operation under severe conditions were performance characteristics which the product delivered successfully. Unfortunately, the grease possessed several negative attributes. First and foremost, the product had poor water washout. The sodium-thickened petroleum grease, was virtually washed out, 99.5% w/w, of the test bearing when subjected to ASTM D-1264 for 1 hour at 80°C. While this result was directly attributed to the sodium-complex thickener employed in the formulation, the same thickener is also responsible for the desirable channeling capability of the grease. Another negative quality associated with the grease was its high evaporation at 150°C, 6.9% w/w, when run according to ASTM D-972 for 24 hours at 150°C. This result was related to the base oil present in the formulation. The grease was also known to be a major contributor to high noise levels in instrument and instrument precision ball bearings.

Results

We began our development work by addressing the thickening system. While sodium complexes are well known to grease manufacturers, the drawback associated with this thickening system is its susceptibility to water washout due to the tendency of sodium soaps to dissolve readily in water. At the same time, sodium complex thickeners afford high dropping points, a desirable quality for high temperature operation. We envisioned a system with the proper water washout characteristics, without sacrificing the channeling consistency, and suitable for high temperature operation. We selected lithium-12-hydroxystearate (LHS) as our starting point. Our familiarity with this thickening system presented several concerns, however. While LHS thickened greases provide acceptable water washout, they possess lower dropping points than sodium soap based greases. Our approach was to produce complex lithium-12-hydroxystearate (CLHS) grease. By appropriate selection of the co-thickener, we sought to achieve the proper channeling consistency.

The base oil selected for our CLHS grease was PAO-10. This polyalphaolefin would serve to provide the viscosity required by boundary or elastohydrodynamic (EHD), conditions, as well as, improved evaporation and thermal stability. Several additive packages were evaluated for this base oil to determine the most effective antioxidant and anti-wear additives to be employed in the CLHS grease. Our final selection employed a phosphate ester based anti-wear additive with a synergistic combination of phenolic and dialkylphenylamine antioxidants. The PAO-10 oil, see table 1, fortified with the antioxidant and anti-wear package failed to produce an exotherm, as measured by PDSC (150°C, 24 hours, 3500+/- kPa O_2 flow rate of 100 ml/min). In addition to anti-wear and antioxidant additives, we addressed the corrosion inhibition of the metal surfaces that would be serviced by the CLHS grease. The CLHS system being less receptive to moisture would, therefore, require suitable protection against corrosion.

Physical Property	Method	Rheolube 374 C
Viscosity	ASTM D-445	
100°C		9.5 cSt
40°C		60.7 cSt
-40°C		25,300 cSt
Viscosity Index	ASTM D-2270	131
Pour Point	ASTM D-97	-56°C
Flash Point	ASTM D-92	240°C

Table 1. Various physical properties for base oil (Rheolube 374-C).

The preparation of the CLHS grease proved to be challenging with regard to the selection of the co-thickener(s). In order to achieve the proper complex, co-crystallization of the thickeners present must take place. Melting point behavior in a pure solid is affected by the presence of solutes producing a colligative effect, resulting in a decreased melting point for that substance. The target grease system, however, must melt at higher temperature than the melting point of the thickener itself. Evaluations of the candidate greases by measurement of their dropping points proved satisfactory for this purpose. Complex structures, if established, should produce higher dropping points relative to their non-complex analogues.

Investigations directed towards the evaluation of additives to enhance and promote complex formation were conducted. Waxes, inorganic salts, and mixed metal soaps were all investigated. While waxes exist in various forms, higher melting waxes were shown to assist with minimal effect on the dropping point. Inorganic salts proved to be interesting, with boric acid derivatives, effective in very precise concentrations, producing higher dropping points and reduced oil separation. Their presence affected the grease favorably, consistently producing greases with dropping point in excess of 280°C and decreased oil separation at 150°C. Considering that if LHS were isolated, the LHS melting point would be approximately 220°C, dropping points significantly higher than that value are clear indication of complex formation.

Property	Method	Rheolube 374C	Andok® C
P0	ASTM D-217	177	105
P60	ASTM D-217	193	157
Oil Separation, 24 hrs, 150°C	FTM 791b, 321.2	0.44% w/w	0
Evaporation, 24 hrs, 150°C	ASTM D-972	0.9% w/w	6.9% w/w
Dropping Point	ASTM D-2265	281°C	251°C
Water Washout	ASTM D-1264	2.8% w/w	99.5% w/w
Four-Ball Wear	ASTM D-2266	0.66 mm	0.97 mm
Vapor Pressure, 25°C	Nye CTM	5.6×10^{-8} torr	1.0×10^{-6} torr

Table 2. Various physical properties for Rheolube 374-C versus Andok® C.

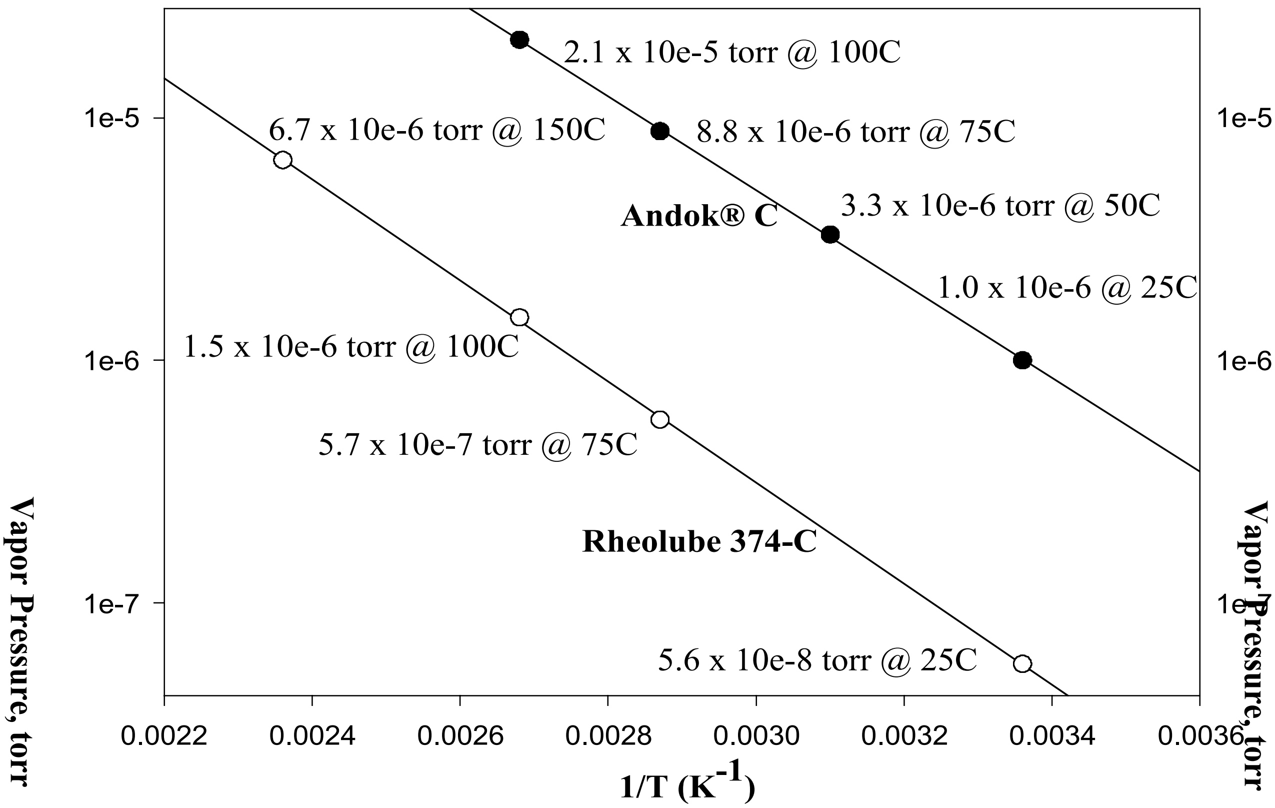

Table 3. Vapor Pressure Behavior for Rheolube 374-C versus Andok® C

The CLHS grease produced, Rheolube 374-C, was tested according to various methodology to determine its physical properties. See table 2 for results. For reference, testing performed on Andok® C was included in table 2. As can be seen by inspection of table 2, the product had a worked penetration of 193. Oil separation for the material, obtained at 150°C after 24 hours, produced a value of 0.4% w/w. Evaporation results, as expected, were strong producing only 0.9% w/w mass loss at 150°C after a testing period of 24 hours. The low oil separation suggested the presence of a complex structure for Rheolube 374-C. The oxidative stability of the product was demonstrated by PDSC producing no exotherm after exposure to 3500 kPa O_2 at a flow rate of 100 ml/min and a temperature of 150°C for 24 hours. The product was subjected to four-ball wear testing, yielding a wear scar of 0.66 mm when subjected to 40 kg load, 1hr, 75°C, 1200 rpm. The water washout result, as expected, produced a mass loss of less than 3% w/w under conditions of 1 hour and 80°C. Unexpectedly, Rheolube 374-C exhibited good vapor pressure behavior yielding an extrapolated value of 5.6×10^{-8} torr at 25°C, a value comparable to grease utilized in aerospace applications. See figure 3. As stated previously, dropping points allow for inferences about grease structure to be drawn. The high dropping point of 280°C is surprising and unexpected. We advance that the high value obtained in our work affords evidence of an intricate complex structure. The channeling capability of the material is not coincidental, and reveals itself upon visual inspection and further analysis.

Ball Bearing Noise and Vibration Analysis

When bearings are subjected to high speed, frictional heating and vibration can result and are known to be fatal to the bearing components. As mentioned earlier, temperature increases produced in bearings decrease lubricant life and, hence, bearing lifetime. Minimization of

Bearing	Low Band	High Band	Oscilloscope	Audio Output
Andok® C				
1	18	24	1/3	sandy
2	22	28	5/8	sandy
3	20	24	1/2	sandy
4	19	25	1/2	sandy
5	18	24	1/2	sandy
6	20	28	5/8	sandy
Rheolube 374-C				
1	12	18	1/8	sibilant
2	14	18	1/8	sibilant
3	10	16	1/16	sibilant
4	15	19	1/8	sibilant
5	13	17	1/8	sibilant
6	14	18	1/8	sibilant

Table 4. GMN KGE-3 Ball Bearing Noise Testing and Vibration Analysis.

friction forces resulting in heat generation can be achieved by selection of an appropriate channeling grease. Noise can also be used as an indicator of bearing performance. Noise in bearings can result from various causes, lubricant selection, lubricant amount, and lubricant placement, being among them. Critical to the smooth operation of a bearing is the morphology of the grease. Bearings lubricated with greases containing aggregated thickener, or large particles of debris, will undoubtedly produce vibration and noise that will immediately prevent the smooth operation of the bearing. Bearing analyses intended to address the noise and vibration were performed on a GMN KGE-3 ball bearing noise and vibration analyzer. This method of analysis afforded information about how Rheolube 374-C grease behaved in a dynamic setting and its potential utility in high-speed miniature and instrument precision ball bearings. Results of this analysis can be found in table 4. Any reading above 25 on the low or high bands, or over one grid on the oscilloscope would be cause to consider the bearing unacceptable for use in electric motors, an application sensitive to noise. The data demonstrated that Rheolube 374-C would be acceptable for use in electric motors, and that the employment of the grease in small bearings operating at high speed has merit. These results have been confirmed by others and support our findings. Testing continues at miniature and instrument precision ball bearing manufacturers.

Experimental

Details of grease formulation and production processes are proprietary. All testing methods associated with grease testing were performed at Nye Lubricants, Inc., see tables 1-3, and were performed according to standard ASTM methods cited, therein, except as noted CTM (company test method). Bearing noise testing was performed at AST Bearings on a GMN KGE-3 ball bearing noise and vibration analyzer according to AST Bearing CTM. Rheolube 374-C is commercially available form Nye Lubricants, Inc.

Applications

The ultimate requirement for any grease intended for use in miniature and instrument precision ball bearings is its successful employment in real-life applications. Several applications containing bearings lubricated with Rheolube 374-C are listed below. At the request of the manufacturers their anonymity has been preserved. The applications involved operated with bearings possessing outer diameters ranging from 0.866-0.250 inches and bore diameters ranging from 0.315-0.125 inches.

> Manufacturer of DC motors, reported 18% reduction in noise and a 10% reduction in starting and running torque achieving the desired operating speed 5 seconds quicker. The operating temperature decreased by 8°F.
>
> Manufacturer of document handling equipment that performs reading, writing, and collating reported quieter operation and a 11% overall drop in torque. The operating temperature decreased by 8°F.
>
> Manufacturer of air turbines reported a 17% increase in life during accelerating testing achieving operating speed 5% more quickly.
>
> Manufacturer of synchros, servos, and resolvers, reported 11 % reduction in noise and a decrease of 9°F in operating temperature.
>
> Manufacturer of optical encoders reported an 11 % reduction in noise and reduction of 9°F in operating temperature. Accelerated testing demonstrated a 9% increase in life.
>
> Manufacturer of food processors reported an appreciable reduction in noise.
>
> A manufacturer of brakes and clutches reported smoother clutch and brake operation resulting in quicker customer acceptance.

The above applications, while but a few, do attest to the performance of Rheolube 374-C. Cooler and quieter operation, in addition to, lower starting and running torques, are certain to extend the lives of these and other applications.

Conclusions

We have successfully prepared a channeling grease, Rheolube 374-C, affording results superior to Andok® C with improved water washout, superior evaporation, better wear, and quieter operation. The employment of Rheolube 374-C in precision and instrument rolling element bearings will extend life by achieving cooler operation with lower starting and running torques. Moreover, the vapor pressure of 10^{-8} torr demonstrates the potential utility of Rheolube 374-C for sensitive applications where out-gassing is of critical concern, such as components containing sensitive optics, including, but not limited to, military and aerospace components.

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