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India Chapter
ISSN : 0972-2742

GREASETECH INDIA

A Quarterly Journal of NLGI-India Chapter

Vol. XXVI, No. 3, **Jan-March 24**

GREASETECH INDIA

A Quartely Journal of NLGI-India Chapter

Vol. XXVI, No. 3, Jan-March 24

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Effect of Grease Soap Chemistry on EP, Anti-wear and Corrosion Performance of Different Additive Chemistries

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New products must inherently be able to provide lubrication under higher loads and lowerspeeds, possess improved thermal and oxidative stability, and operate in wider temperature ranges and harsher environments. The need originated from OEMs who arecontinuously striving to improve energy efficiency of machines by designing equipment with higher power densities and sumps with smaller capacities. Whereas end user is operating machines at slower speeds to reduce churning and traction losses, using lowergrease and lubricant levels and opting for longer drain intervals. These drivers are placinghigher performance demands on greases and other lubricants.

Grease is a complex multi-phase material, produced by combining a thickener and base oil. Simple soap greases are based on lithium, calcium or a mixture of lithium and calciumor sodium. Complex greases use soaps based on lithium, calcium, sodium, barium or aluminum. Less common thickeners made from polyurea, clay, silica or polymers may be used in specific applications like food manufacturing, electric motors or very low temperature or high-temperature environments. Polyurea, calcium sulfonate and complex thickeners have largely replaced clay thickeners for high-temperature applications.

In order to meet higher performance trends with multipurpose, EP, water resistant and quiet greases, it is essential that effect interactions of soap chemistry with respect to the type and functionality of key EP, anti-wear and corrosion inhibitor additives used to formulate these products is studied carefully. Typical additives used for load bearing aremetal dithiocarbamates, sulfurised olefins, polysulfides, sulfurised esters and metalsulfides, etc. In recent years, ashless multifunctional additives such as thiadiazoles and alkyl dithiocarbamates, phosphate amines and ashless dialkyl dithio phosphates have gained popularity. These additives collectively can achieve higher load bearing performance, effective resistance to wear and corrosion.

The additive chemistry interaction with soap interactions can be well understood by the fact that weight percentage for corrosion inhibitor sufficient in lithium-calcium grease was 1%, 2% to lithium grease and 3% to sodium grease whereas calcium and calcium sulphonate grease required none. Same corrosion inhibitor could not work in Poly urea &clay grease.

This paper discusses test results for grease formulation options with different soap chemistries and their interactions with select additives to attain high load bearing, better anti-wear and corrosion performance.

Introduction

NLGI defines grease as a mixture of three main elements namely base oil, thickener, andadditives. The base oil is the primary component of grease, which can either be petroleumderived or synthetic base oil produced from chemical building blocks. The thickener helpsto maintain the grease in a semi-solid state. The additives are only present in a small quantity to enhance the performance of the grease. During the formulation process, the thickener produces entanglement networks that trap the oil while also contributing to theproper functioning of the grease. The composition and microstructure of the grease during production process, influence the performance of the lubricating grease.

NLGI Lubricating grease survey for the year 2021 published recently indicates that 69% of the greases sold world over are based on Lithium Soap. In India approximately 83% share of greases sold are Lithium soap based.

In past one year there has been a spike of 80 to 120% in the prices of Lithium containingproducts due to more than 250% increase in prices of viz. Lithium Carbonate used in making batteries and Lithium Hydroxide used in making grease worldwide.

The increased price of lithium soap greases and inconsistent availability in future has led to a debate on use of alternates for the soap bases in greases. Many customers are evaluating alternates not only as cheaper options only but also as equivalent of better performance alternatives.

In order to enhance the quality of grease performance, additives added to grease at 2–8percent. A well formulated grease has features that are appropriate for its use, such as consistency, thermal stability, oxidation, wear protection, corrosion resistance, water washout etc. The additives performing in Lithium greases do not perform the same way in greases made from other soaps like calcium or aluminum or poly urea. Hence the choice of performance-enhancing additives mainly defines the performance properties ofan alternative grease.

This paper discusses test results for grease formulation options with different soap chemistries and their interactions with select additives to attain high load bearing, better anti-wear and corrosion performance.

Greases of NLGI 2 consistency were prepared. Lithium grease was prepared using Lithium 12 hydroxy stearate soap. Lithium complex was prepared by using Lithium 12 hydroxy stearate soap and complexed with di basic acid or borate ester. Calcium complexgrease was prepared by using anhydrous Calcium 12 hydroxy stearate and Sebacate. Calcium sulphonate complex using 12 Hydroxy Stearic Acid, 400 BN sulphonate, acetic acid. Aluminum complex Greases were prepared using aluminium iso propoxide, benzoicacid and 12 Hydroxy Stearic Acid / stearic acid combination.

The Extreme pressure additives (EP) used were based on Sulphur phosphorus chemistry using either sulfurized iso butylene or poly sulfides. The anti-wear additives (AW) were based on zinc dialakyl di thio phosphate or ashless dialakyl di thio phosphate and phosphate amine chemistry. The anti rust additves (CI) were based on metal salts of sulfonic acid or dibasic acids.

The tests were conducted using standard test methods as used in grease industries. Consistency, emcor rust, four ball wear and fretting wear were studied for different additive systems and their combinations.

Base greases were prepared with same formulation and base oil combinations, having similar soap contents and consistencies. The anti-oxidant and yellow metal passivator content added in base grease was sufficient to take care of oxidation stability before andafter addition of Extreme pressure and ant wear additive combinations as per field requirements.

Results and discussions

Lithium Greases

The rust inhibitor used was sulfonic acid metal salts to meet the emcor rust test. Since dibasic acid metal salts interfered with grease consistency and drop points, same was notused in study of Lithium greases. BG represents base grease without additive, and additive combinations as describes above in experimental.

Table 1 – Tribological properties of Lithium Grease with additive combination 1

Property	BG	BG+EP1	BG+EP1 +AW1	BG+EP1 +AW2	BG+EP1 +AW3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.78	0.67	0.5	0.5	0.43
Four Ball weld load, Kgs	126	250	250	250	250
Fretting Wear, mg	87	55	47	13	9

Table 2 – Lithium Grease with additive combination 2

Property	BG	BG+EP2	BG+EP2 +AW1	BG+EP2 +AW2	BG+EP2 +AW3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.78	0.67	0.5	0.5	0.43
Four Ball weld load, Kgs	126	250	250	250	250
Fretting Wear, mg	87	67	42	8	8

Lithium complex Greases

The rust inhibitor used was sulfonic acid metal salts to meet the emcor rust test. Since dibasic acid metal salts interfered with grease consistency and drop points, same was notused in study of Lithium complex greases.

Table 3 – Tribological properties of Lithium complex Grease with additivecombination 1

Property	BG	BG+EP1	BG+EP1 +AW1	BG+EP1 +AW2	BG+EP1 +AW3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.66	0.48	0.45	0.44	0.38
Four Ball weld load, Kgs	250	315	315	315	315
Fretting Wear, mg	64	61	58	27	14

Higher concentration of complexing agent (Borate ester) had positive impact on wear scardia, weld load and fretting wear, but inconsistency of results due to changes in rheology restricted study with 3.5% borated ester only.

Table 4 – Lithium complex Grease with additive combination 2

Property	BG	BG+EP2	BG+EP2 +AW1	BG+EP2 +AW2	BG+EP2 +AW3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.66	0.47	0.45	0.44	0.40
Four Ball weld load, Kgs	250	315	315	315	315
Fretting Wear, mg	64	62	60	30	16

With dibasic acid complexing, though initial weld loads were similar to lithium grease as in Table 1, but other properties with additive and combinations were similar to properties as in Table 3 and 4.

Table 5 – Tribological properties of Calcium complex Grease with additivecombination 1

Property	BG	BG+EP1	BG+EP1 +AW1	BG+EP1 +AW2	BG+EP1 +AW3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.52	0.58	0.54	0.54	0.48
Four Ball weld load, Kgs	200	250	250	250	280
Fretting Wear, mg	107	95	80	84	27

Table 6 – Calcium complex Grease with additive combination 2

Property	BG	BG+EP2	BG+EP2 +AW1	BG+EP2 +AW2	BG+EP2 +AW3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.52	0.56	0.54	0.52	0.45
Four Ball weld load, Kgs	200	250	250	250	280
Fretting Wear, mg	107	104	90	67	7

Calcium complex Greases

Calcium Complex greases had Good Corrosion resistance as such. Mild EP and good antiwear properties as determined by Four ball test but additive response was poor.
Additive choice becomes very critical.

Calcium Sulfonate complex Greases

Table 7 – Tribological properties of Calcium sulfonate complex Grease

Property	BG	BG+EP1 or EP 2	BG+ AW1	BG+ +AW2	BG+AW 3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.42	0.42	0.42	0.42	0.38
Four Ball weld load, Kgs	400	400	400	400	400
Fretting Wear, mg	48	51	47	17	4

Calcium sulfonate Complex greases had Good Corrosion resistance as such. Excellent EP and good antiwear properties as determined by Four ball test but additive response was poor. Additive choice becomes very critical.

Aluminum complex Greases

Table 8 – Tribological properties of Aluminum complex Grease with additivecombination

Property	BG	BG+EP1 or EP 2	BG+ AW1	BG+ +AW2	BG+AW 3
Consistency	NLGI 2				
Four Ball Wear scar dia, mm	0.7	0.42	0.42	0.42	0.38
Four Ball weld load, Kgs	250	315	315	315	315
Fretting Wear, mg	40	51	27	11	8

Conclusion

Surface damage that occurs between two contacting surfaces experiencing cyclic motion (oscillatory tangential displacement) of small amplitude is fretting wear. Lubricant is squeezedout, resulting in metal-to-metal contact. Since the low amplitude motion does not permit the contact area to be re-lubricated, failure occurs.
The additive response to Four ball EP and AW tests have not been able to discriminate between lubricants used by many modern engineered components created in food industry and EV's.
The conventionally used EP and AW additives have been providing great performance with different types of soaps by simply varying the additive concentrations and combinations of conventional chemistries. It is possible to target high weld loads and mitigate wear scars. The requirement of fretting wear performance is unique as greaseswith very high weld loads and lower wear scar diameter fail to prevent failures. The grease structure, soap chemistry and additive chemistry play a definite role in preventing the wear.

Soap fibre structure plays an important role and lithium greases having long fibre structure were slow to respond and aluminium grease with short tight fibre structure has shown good response to additive at very low dosages.

Acknowledgement

The authors are thankful to the management of Hindustan Petroleum Corporation Limited for allowing publication of this work.

Innovative Design Of Electrical Lubricants Test Rig For E-Grease And E-Fluids

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Abstract:

A new generation of component test rigs relevant to battery powered electric vehicles (EV's) have become essential for lubricants industry that is spending almost all the R&D cost into creating value in EV's market space. In this talk, we will describe our innovative product design of Electrical Lubricants Test Rig with a two stage lubricated bearings that can be tested up to 30,000 rpm and at load up to 15 kN. Bearings can be lubricated with grease or oils, that can be heated up to 150 deg C using our proprietary heat exchanger. Rotor dynamics and cooling system are key techniques to reduce its downtime and improve safety of the operator. We will elaborate on these techniques during the presentation. Each bearing station is embedded with smart sensors that captures the vibration, noise, bearing friction and temperature of the lubricated system. The sensor system is MOOHA enabled that completely automates the process of data collection, cloud storage, analytics, and reporting, collectively they provide insight to e-grease or e-fluid performance i.e. anti-wear, thermal conductivity, friction and fatigue resistance. We will share a case study that describes the performance of few electrical lubricants widely used in electric motor and electric wheel hubs of battery powered EV's. Electrical Lubricants Test Rig is the first in market that is aimed at creating high value lubricants for better performance of EV's and empower the idea of reducing carbon emission through electrification.

Keywords: e-grease, e-fluid, durability, high speed, bearing

1. Introduction

Electric vehicles have been widely adopted as a cleaner alternative for mobility. Further developments are focused on increased battery capacity that offers longer driving distance thereby reducing the range anxiety. However, larger battery capacity adds significant weight to the vehicles and understanding mass-energy efficiency trade-offs becomes important. Such a study has been undertaken in 2020 (Ref - Energy efficiency trade-offs in small to large electric vehicles, Environ. Sci. Eur. (2020), 32:46) across 218 passenger cars in German market with power, mass, and battery capacity spanning over a range of 10–350 kW; 630–3370 kg, 8–100 kWh). The key findings are summarized in Figure 1 which has been reproduced from the publication.

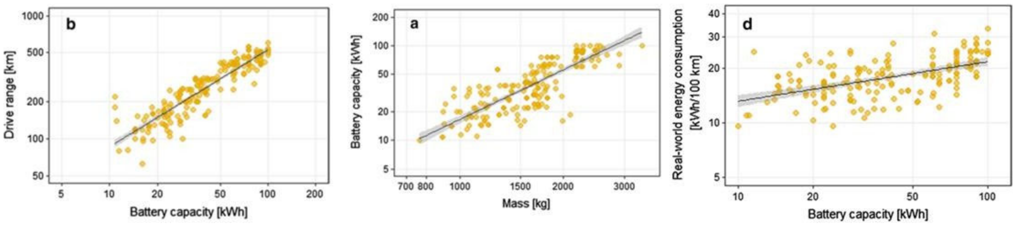


Fig 1. Battery capacity, vehicle mass and energy consumption trends reproduced from (Ref - Energy efficiency trade-offs in small to large electric vehicles, Environ. Sci. Eur. (2020), 32:46)

The dataset suggests that every 10 kWh of battery capacity increased drive range by 40-50 km, but also resulted in vehicle mass going up by 15 kg and energy consumption by 0.7–1.0 kWh/100 km that is equivalent to 1.2 ± 0.9 to 3.8 ± 3.0 g CO2/km of indirect carbon emissions at the current European electricity mix. To compensate for the increased vehicle mass, a higher power density motor that is more compact would be required. One approach to doing that would be to increase the motor speed while reducing torque to have the same power output. This approach would result in a more compact and lighter e-motor by almost 50% with additional savings on expensive permanent magnets. This is shown schematically in Figure 2 that is adopted from AVL Hummingbird's high speed e-axle platform (Ref - https://chargedevs.com/sponsored/a-closer-look-at-avls-hummingbird-high-speed-e-axle/)

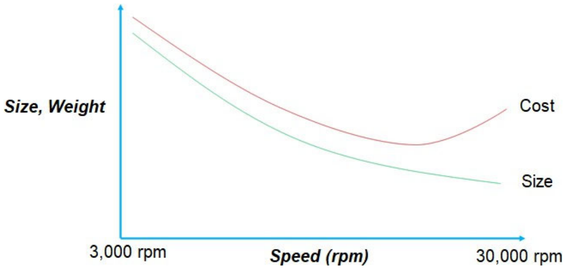


Fig 2. Tradeoff curve for e-motor speed versus cost/weight/size. This has been reproduced from (Ref - https://chargedevs.com/sponsored/a-closer-look-at-avls-hummingbird-high-speed-e-axle/)

While increasing speed at constant power reduced the motor size and weight, there was an optimum speed of ~ 28,000 rpm beyond which the cost would be prohibitively high (Figure 2). This was due to the increased centrifugal forces and resultant loads that would necessitate exotic high strength/cost materials for the rotor. Typical electrical bearings failure observed in e-motor applications include frosting, fluting, pitting, and spark tracks and have been previously described (Ref - "Electrical bearing failures in electric vehicles", Friction, (2020), 8, 4028). The next generation of e-greases have to satisfy conflicting requirements. The grease should not be too viscous to prevent overheating at high speeds but at the same time should not have too low a viscosity so that rolling contact fatigue failure get accelerated. The grease should have adequate electrical conductivity to avoid dielectric breakdown and electric discharge related damage in the EHD lubrication regime. Furthermore, high speed grease behaviour for e-motor bearings is not well understood.

Need for Speed

The electrical lubricants test rig (Figure 3) has been designed to evaluate the next generation of e-greases for EV motor. It is based on a two bearing configuration and capable of speeds upto 30,000 rpm.

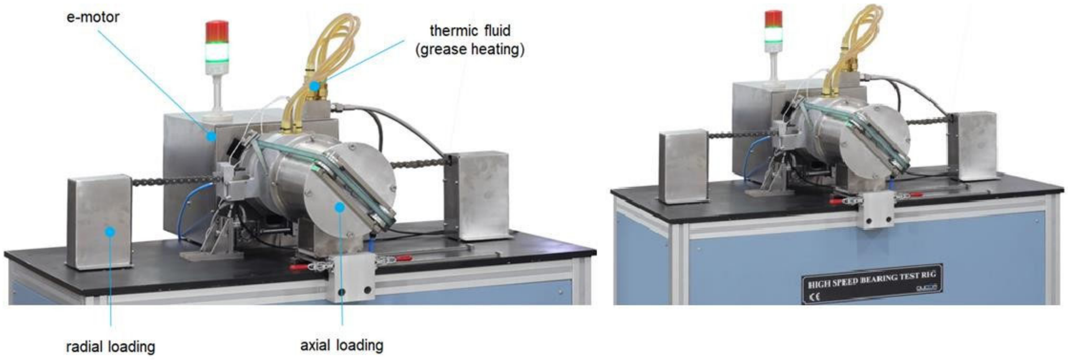
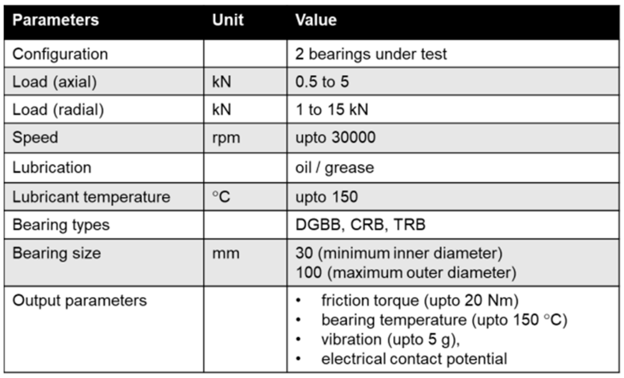


Fig 3. Ducom electric lubricants test rig HSB 2.0 based on high speed bearing configuration

Design and Innovation

The detailed specifications of HSB 2.0 are shown in Table 4 and it features several capabilities that are unique and not available in any other test rig available in the market.

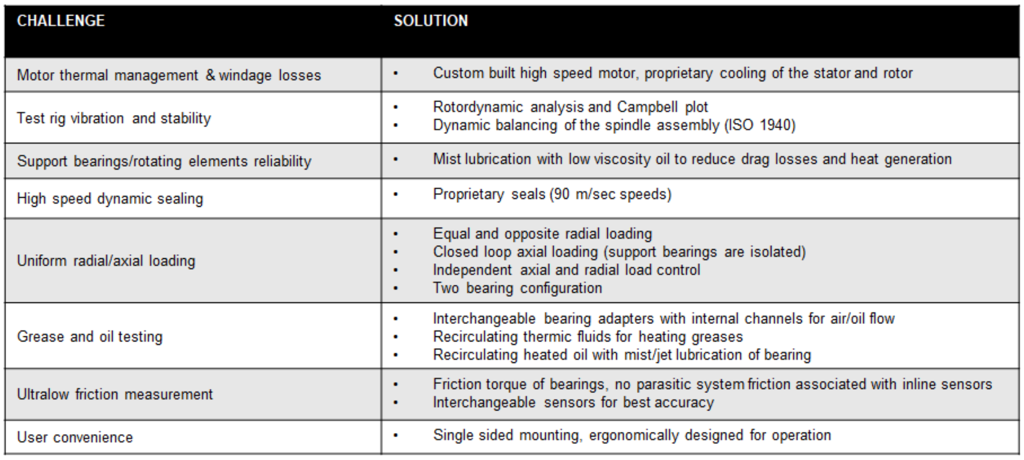


Parameters	Unit	Value
Configuration		2 bearings under test
Load (axial)	kN	0.5 to 5
Load (radial)	kN	1 to 15 kN
Speed	rpm	upto 30000
Lubrication		oil / grease
Lubricant temperature	°C	upto 150
Bearing types		DGBB, CRB, TRB
Bearing size	mm	30 (minimum inner diameter) 100 (maximum outer diameter)
Output parameters		• friction torque (upto 20 Nm) • bearing temperature (upto 150 °C) • vibration (upto 5 g), • electrical contact potential

Table 4. Key technical specifications of electric lubricants test rig HSB 2.0

HSB 2.0 features independent radial and axial loading < 15 kN, speeds of 30,000 rpm and ability to test both greases and oils at temperatures upto 150 C. Furthermore, a wide range of sensors are integrated with the system so as to map both energy efficiency (from friction torque data) as well as endurance (from vibration and bearing temperature data) characteristics of e-lubricants. The two bearing configuration was chosen to provide accessibility for mounting, inspection and remounting of bearings.

To meet the specifications in Table 4, there were several key design innovations and technologies that had to be developed and validated as summarised in Table 5.



CHALLENGE	SOLUTION
Motor thermal management & windage losses	• Custom built high speed motor, proprietary cooling of the stator and rotor
Test rig vibration and stability	• Rotordynamic analysis and Campbell plot • Dynamic balancing of the spindle assembly (ISO 1940)
Support bearings/rotating elements reliability	• Mist lubrication with low viscosity oil to reduce drag losses and heat generation
High speed dynamic sealing	• Proprietary seals (90 m/sec speeds)
Uniform radial/axial loading	• Equal and opposite radial loading • Closed loop axial loading (support bearings are isolated) • Independent axial and radial load control • Two bearing configuration
Grease and oil testing	• Interchangeable bearing adapters with internal channels for air/oil flow • Recirculating thermic fluids for heating greases • Recirculating heated oil with mist/jet lubrication of bearing
Ultralow friction measurement	• Friction torque of bearings, no parasitic system friction associated with inline sensors • Interchangeable sensors for best accuracy
User convenience	• Single sided mounting, ergonomically designed for operation

Table 5. Design challenges and innovative solutions developed and deployed

Validation

Loading was achieved using a servo-pneumatic loading mechanism. The load stability was established to be better than ± 0.01 kN and ±0.05% of full scale even under different speeds and profiles as shown in Figure 6.

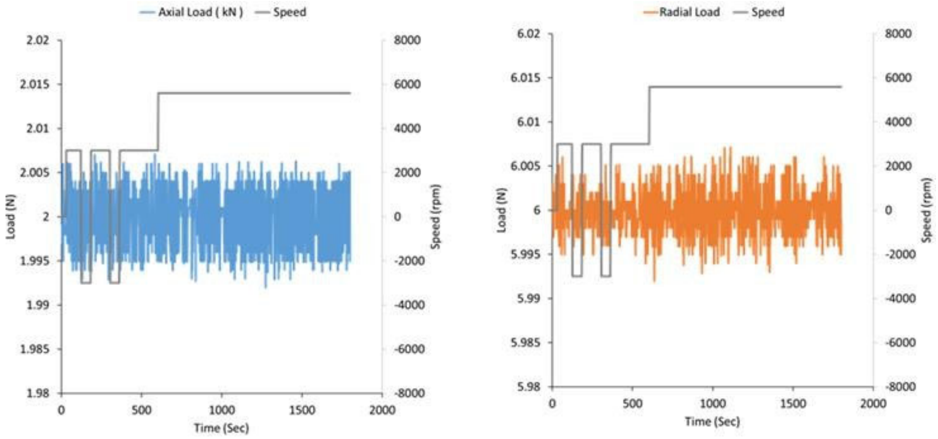


Figure 6. Axial and radial load stability under varying speed profiles

A unique friction torque measurement system was developed that enabled measurement from each bearing. The flexure based system also avoided parasitic friction from the support bearings. Typically noise levels for coefficient of friction were ~ 10^{-4} (Figure 7), an order of magnitude lower than expected friction of the grease lubricated bearings.

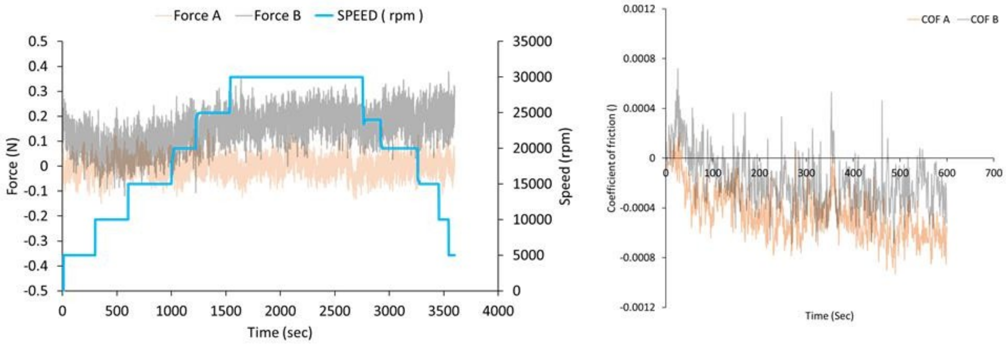


Figure 7 Characteristic friction force and coefficient of friction noise levels.

The entire rig could be operated from a LabView based WinDucom interface and had safety features such as CE complaint electrical design, safety enclosure for rotating parts and user settable trip limits.

Test Protocol - I

A 62208-2RS1 DBGG was used along with a grease developed specifically for high speed e-motor applications. The grease was NLGI grade 2-3 with a polyurea based mineral oil. The load and speed conditions are shown in Table 8.

Parameters	Values
Axial Load (N)	1000
Radial Load (N)	1000
Speed (rpm)	0 to 15000
Temperature (°C)	Ambient

Speed (N-rpm)	Mean bearing dia. (d_m-mm)	Nd_m Factor (rpm·mm)
5000	60	300000
10000	60	600000
15000	60	900000

Table 8. Load and speed profiles used for greased bearing test

The speed profile was programmed to change direction in a cyclic manner at low speeds to capture the system hysteresis beyond which the speed was increased in steps to 15,000 rpm corresponding to an Ndm of 900000. Radial and axial load plots with the speed profile is shown in Figure 9a. The corresponding friction from each of the bearings is shown in Figure 9b where some hysteresis was observed at low speeds curing the cyclic reversals but the CoF values converged at higher speeds.

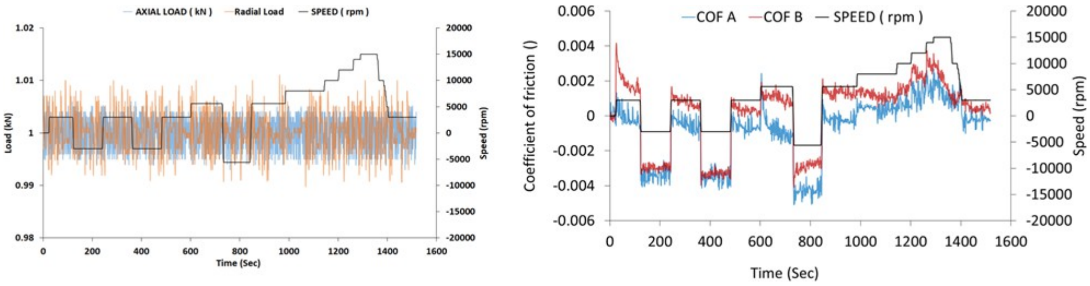


Figure 9a and 9b. Load and speed profiles as well as coefficient of friction profiles for both bearings under test

The vibration and bearing temperatures were captured simultaneously for both bearings under test and shown in Figure 10a and Figure 10b. The images of the bearing before and after test is shown as well.

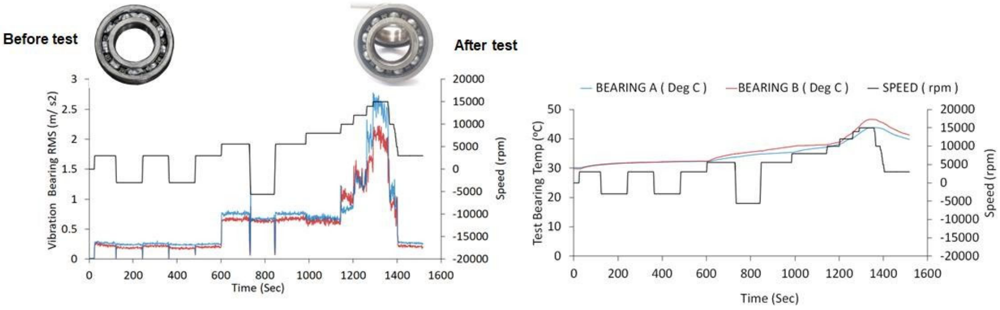


Figure 10a and 10b. Vibration and bearing race temperatures for both bearing under test

The bearing race temperatures increased during the test as did the vibration levels. However, the vibration reduced to the baseline level at the end of test indicating no bearing failure. A further visual inspection confirmed that.

Test Protocol - II

In this study, the effect of heating upto 140 □C on grease performance was evaluated. The conditions used for the test are shown in Table 11.

Parameters	Values
Axial Load (N)	2000
Radial Load (N)	6000
Speed (rpm)	0 to 5500
Temperature (°C)	145

Table 11. Load, speed and temperature profiles used for greased bearing test

The real-time load and speed profiles are shown in Figure 12.

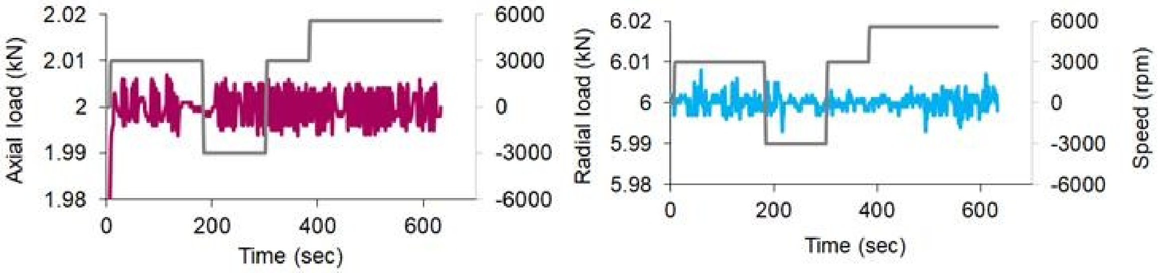


Figure 12. Axial, radial load and speed profiles

The corresponding bearing temperature and friction is shown in Figure 13a and Figure 13b.

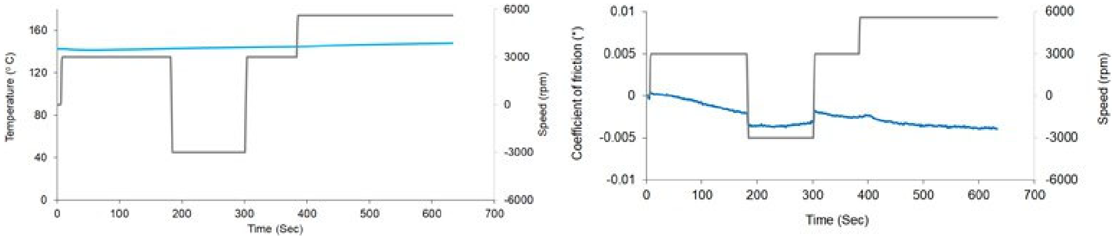


Figure 13a and 13b. Bearing temperature and coefficient of friction profiles

The bearing temperature was observed to be stable even with varying speed profiles indicating an accurate control of the grease temperature. Furthermore, CoF was found to decrease and stabilise over time.

Test protocols I and II and results obtained show that the electrical lubricants test rig is capable of evaluating e-lubricant performance under high speed conditions.

“Top-Shelf Synthetic Hub Grease” via Green Route

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NK Pokhriyal & Vishwajeet Singh

ABSTRACT

The Automotive Industry utilises field trials to evaluate the performance of a new grease/ lubricant formulation against existing baseline data. Field trials are very common and considered as most reliable of all methods currently available within the industry. Development & validation of a new grease formulation takes several years because of extensive field trials. It involves large data collection and close monitoring in field for millions of kilometres.

- Recording, managing and analysing this data is very challenging.
- Unreliable data may affect the quality & breakdowns in field can further push the deadlines.
- Human Resource Problem : Extensive skilled manhours required to conduct and monitor the field trials.
- Validation cost running into crores of Rupees

So to validate a new part, years of planning is required to sync the requirement vis-à-vis actual availability. Due to these factors, it becomes difficult to approve new products and induct alternate suppliers. Many automotive companies tend to depend on single source for supplies because of this. The lack of flexibility leads to higher purchase cost, thereby increasing overall cost of ownership. Competitors with better product may gain market-share.

Globally, lubricant manufacturers uses laboratory methods to validate the performance and life of grease. However, it is mostly limited to industrial applications. This approach has not been popularly adopted for automotive grease validation. Customised laboratory test to simulate automotive applications is an ongoing research. Key Challenge is to validate the grease in a limited time, without field trials (which takes years to provide result) and while doing so, replicating the field conditions inside a laboratory to effectively validate the grease life. Another challenge is to develop a grease formulation which is cost effective, having better performance with increased life cycle.

This paper talks about development, validation and approval of a next-gen synthetic automotive grease for a leading automotive OEM. By employing a world-class envisioned laboratory test, without conducting large scale field trials. Thus creating a replicable statistical model for the OEM for any future iterations, placing it ahead of the curve. In doing so, saving crores of Rupees and curtailing thousands of tonnes of potential CO2 emissions.

KEYWORDS: Automotive Industry, Field Trial, Life cycle analysis, Synthetic Hub Grease

1.0 INTRODUCTION

Grease lubrication is widely applied to rolling element bearings Increasingly, rolling element bearings are required to operate at higher speeds, loads, and temperatures and for extended re-lubrication intervals. This imposes severe performance related demands on the greases and it is necessary to accurately predict the lubricating life or the re-lubrication interval to prevent lubrication or component failure. To reliably estimate the field life in the bearings in automotive wheel bearing applications, there are several laboratory bearing tests which are used extensively.

With the increase in equipment power densities, bearings are required to run under extremely severe operating conditions for a longer period of time. Besides, the grease relubrication intervals have become longer, and many of the bearings especially in automotive wheel bearing applications are greased for life. The design life of the grease must exceed the wheel bearing life under the prevalent operating conditions. This estimation of grease life would require extended field trials under simulated conditions in automotive wheel bearing applications. However, it is not easy to precisely maintain the running conditions, so this method could be subject to variation. Besides, the costs of these trials could be exorbitantly high [1].

Weibull distribution is commonly used in industry for life studies of machine components and even for human life expectancy. The automotive industry and leading OEMs use this methodology for establishing the warranty period and also to reduce the cost of free replacement of parts, within the warranty period. Any critical part supplier in automobile sector has to submit the expected life data for their parts, which is generated under simulated conditions. The life value should be much higher than the set warranty period (Kms run) for the subject part. Heavy penalties are levied for any premature failure. The penalty imposed is in addition to the cost of replacement.

This paper describes a study carried out on approach of automotive industry on selection of Hub-grease and the factors influencing the service life of greases. This paper also covers the development of novel grease formulation to lubricate satisfactorily at high temperatures by a lubricant manufacturer and estimation of the life of a grease formulation at the typical operating conditions.

2.0 METHODOLOGY AND OBSERVATION

The selection of new automotive hub grease by an automotive OEM is a long-drawn process. Following five agendas were set at the outset before conducting this study for selection of grease:

1. **Objectives:**
   a. Extended Life from a new grease formulation
   b. DVP (Development & Validation Program): The key to the successful selection of a new automotive grease is devising a correct DVP.
   c. Trial duration: The DVP must be able to establish a meaningful validation process for conclusion in a limited time and to establish a replicable model.
2. **Assigning responsibility/ requirements to each element**: Break-up of tests and properties. For example, the requirement from a particular thickener type/ base oil in a new grease formulation.

3. **Flexibility:** Modularity of grease formulation. If the same grease can also be applied to other applications without compromising on durability and commercial viability.
4. **Consistency:** The consistency at which the grease formulation can be put into production without any variation from batch to batch. Upscaling the production and improving overall supply chain.
5. **Customer:** Selection of any new grease must benefit the end user/ customer. It can be manifested as extended drain life, reduced cost, lower friction, etc.

Going forward, Sustainability would be the key to any new development program.

Grease manufacturer needs to consider the specific lubrication requirement of rolling bearings. As per Lugt [2], the main role of grease in a rolling bearing is to provide the rolling element ring contact with a lubricant to ensure a separation of the two such that the bearing has a long life and low friction. Mechanical work on the grease deteriorates its structure and in cases of high temperature, oxidation takes place, severe lubricant starvation occurs, causing bearing failures. This implies that the service life of the bearing may be determined by the life of the grease. This is especially so in bearings that cannot be relubricated and which constitute more than 90% of population of all rolling element bearings that may be greased and sealed for life. So, grease is effectively an important bearing component similar to rolling elements and seals.

The selection of thickener, base oil and additives must be done considering the actual bearing operating conditions in mind. Another challenge has been to develop a grease formulation which is cost effective, having better performance coupled with increased life. In rolling element bearing applications, grease is subject to high operating temperatures and severe shear stresses. During the extended running of the bearing, the grease undergoes both mechanical and chemical degradation that results in the failure of the lubrication action and, ultimately, the bearing. High operating temperatures are seen to be the most significant factor leading to failures. Since the life of grease is thought to be shortened substantially under high temperature conditions [3]. The usual figure quoted is a 50% reduction in grease life for every 10°C increase [4]. The grease lubricating life at high temperatures is usually dependent upon the oxidation stability of the base oil [5]; however, other factors including the thickener type, the presence of additives, and the bearing operating conditions also have an effect. Lubrication failure in bearing tests is indicated by a rapid increase in torque or the temperature which is the crux of all the bearing tests used for the evaluation of High temperature life of greases in rolling element bearings. It is usually assumed that this is due to the lubricating film dropping below a certain critical thickness, and thus the friction increases. Depending upon the severity of this condition, this is usually accompanied by surface damage and debris formation. With this, we can conclude that the mechanism of film generation has failed and this might be due to a reduction in the amount of lubricant available

[6] or a change in the lubricant properties. [7] give the most comprehensive analysis of grease degradation changes in various bearing tests. Other studies (Bailey and Pratt [8]; Komatsuzaki, et al. [9]; Hosoya and Hayano [10] lead to the following conclusions regarding the chemical and Physical Deterioration experienced by the grease in rolling bearings.

- Grease undergoes both chemical and physical deterioration during use.
- Chemical changes include:
    - Loss of antioxidant due to the oxidation reactions rather than evaporation
    - Increase in acidity (after depletion of the antioxidant)
- Formation of oxidized hydrocarbon species leading to the formation of acidic and/or high viscosity products
    - Loss of carboxyl bands of soap thickener
- Physical deterioration includes:
    - Increase in bleeding rate and oil leakage
- Destruction of the thickener structure, either due to working or the chemical breakdown
    - Loss of the base oil due to evaporation or loss of volatile oxidation products.

There is limited published research into the effects of grease additives on lubrication life. It is to be expected that the antioxidant additives will have the greatest effect. One of the most comprehensive studies was by McClintock [11], who carried out lubrication life tests for a range of greases (both model and commercial) and additive packages. Typical increases in grease life of 30-80% were observed for additized greases. Oxidation inhibitors generally increased the lubrication life and this was found for both peroxide decomposers and radical inhibitors, although the response does depend on the thickener type (Cann and Lubrecht [12]). EP/AW additives also increased life, probably because they reduce the severity of contact conditions and thus the operating temperature. Snyder [13] indicates the impact during the recent years which have seen a substantial increase in sealed-for-life bearing applications. These are applications in which bearings are expected to function satisfactorily for the life of the equipment in which they are mounted. In such cases the grease life is expected to be more than the bearing life at the operating temperature. This needs to be evaluated for the selection of the right grease.

The Automotive Industry generally uses the field trial route to evaluate the performance of any new grease/ lubricant formulation against the existing baseline data. Field trials are very common and still considered the most reliable of all methods currently available within the industry. The development & validation of a new grease formulation could take several years owing to the extensive field trials involved. This trial process could involve a huge amount of data collection and close monitoring in the field end application for millions of kilometers. This approach suffers from certain drawbacks. Globally, lubricant manufacturers use laboratory methods to validate the performance and life of grease under simulated conditions. The major challenge encountered has been to validate the grease within a limited time without the need for field trials (which could take several years to yield meaningful results) and while doing so, replicating the field conditions inside a laboratory to effectively correlate with the grease life.

The field trial methodology involves running multiple vehicles for evaluation of grease life in a series of pre- determined intervals after which the bearings and grease are taken out of the vehicle for evaluation. The bearings are checked for pitting and any kind of damage due to loss of lubrication. The grease is essentially taken from inside the bearings for conducting laboratory tests such as FTIR, drop point, consistency to check for any sign of degradation. The target grease relubrication interval was set to 2 Lacs Km in this study which necessitates continuing the trial/evaluation up to 2.4 Lacs Km as per industry standard. In normal scenario, the field trials would have required running at least 10 Heavy Duty Commercial vehicles for evaluation. Grease and bearing evaluation must be conducted at set intervals such as 80K Km, 1.6 Lac Km and 2.4 Lac Km to clearly identify the grease re-lubrication interval for the particular model of the commercial vehicle. However, in this case a mixed approach/ methodology was followed which required limited field trials along with laboratory evaluation of various grease parameters and bearing tests. Multiple grease samples with known service life in field were studied to generate desired grease specification. With existing baseline data in hand and correct understanding of the bearing operating condition, the grease was formulated to meet the desired results.

3.0 CONCLUSIONS

The new approach of conducting limited field trials along with laboratory evaluation of various grease parameters and bearing tests can be successfully utilised for grease selection process. The following conclusions are made from the present study:

- The selection process for automotive grease has been correctly defined by the five-point agenda employed in this study.
- With correct baseline data and understanding of bearing operating condition, desired grease specification can be fixed to formulate suitable candidate.
- With limited field trials, more than 2000 tonnes of CO2 emissions were saved in addition to XCrores of saving against the routine validation cost.

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