Assessment of the Lubricating Efficiency of Current Greases in Electric Vehicle Applications

Carl F Kernizan, Raj Shah, Kunle Kernizan

2023 NLGI Meeting

Outline

- Introduction
- ICE vs EV
- Types of EVs
- Tribo-components to be Monitored
- Grease Specifications
- Grease Composition & Formulation
- Existing & New Electric Motor Grease Requirements
- Disruptive Type of EV
- Conclusion
- Acknowledgement

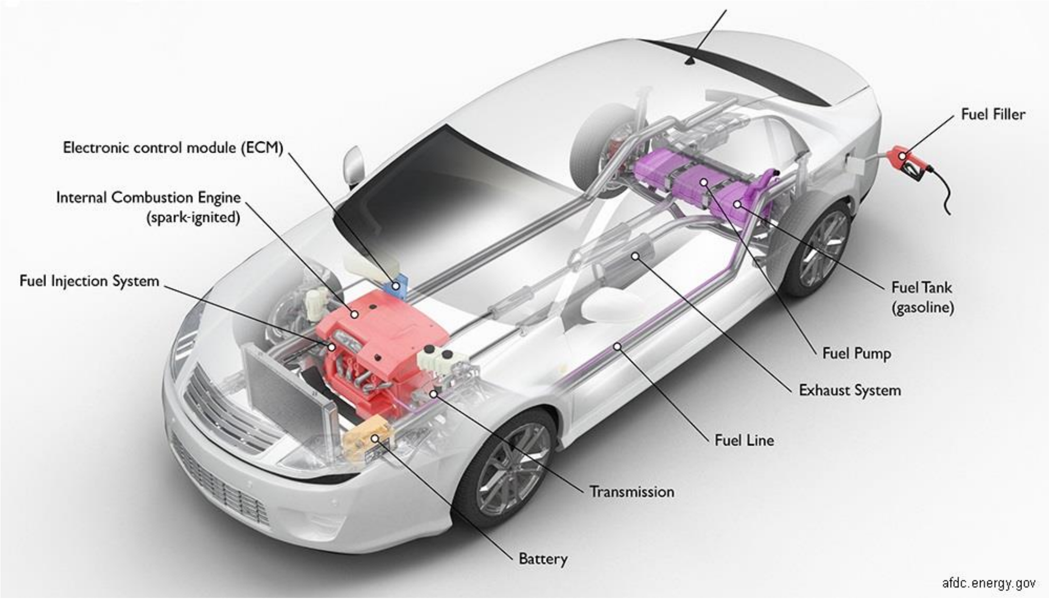
Introduction

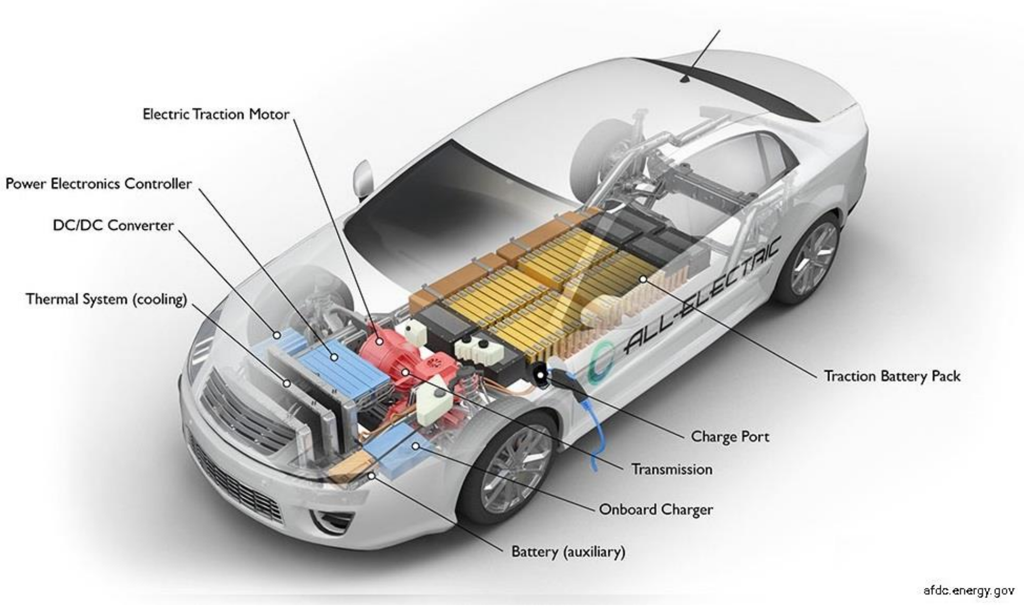
- Enforcement of vehicle emission policies and focus on the environment Issues is forcing the shift from internal combustion engine (ICE) based mode of transportation to Electric vehicles (EVs)
- This shift is causing engineers to determine if the current gear oils, coolants and greases formulated for ICE based vehicles are still capable of meeting the lubrication requirements for EVs.
- These new requirements include noise reduction, thermal transfer, seals and materials compatibility, lubrication efficiency in the presence of electrical current and electromagnetic fields generated by electric modules, sensors and circuits.
- This paper will analyze existing greases requirements and formulations to determine if they will meet the needs of EVs and suggest possible paths for the development of future formulations.

ICE VS EV

An ICE car typically uses a spark-ignited internal combustion engine, rather than the compression-ignited systems used in diesel vehicles. In a spark-ignited system, the fuel is injected into the combustion chamber and combined with air. The air/fuel mixture is ignited by a spark from the spark plug.

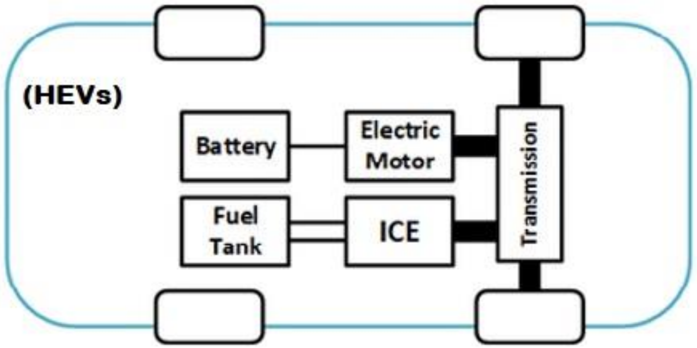
The vehicle uses a large traction battery pack to power the electric motor and must be plugged in to a wall outlet or charging equipment, also called electric vehicle supply equipment (EVSE)



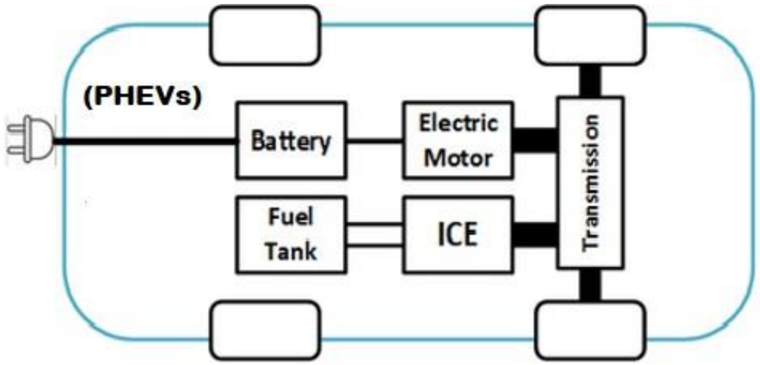


Types of Electric Vehicles (EVs)

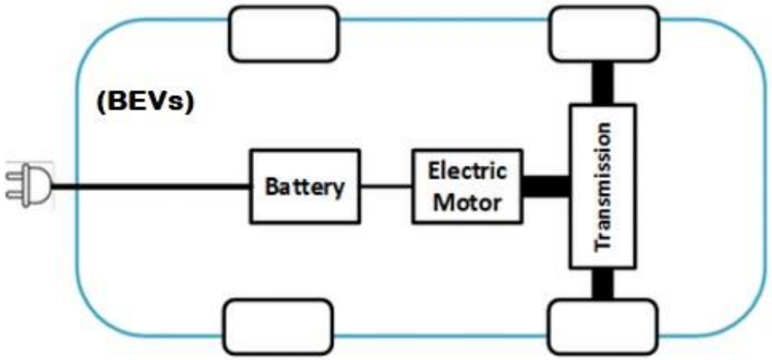
HEVs – Hybrid Electric Vehicles



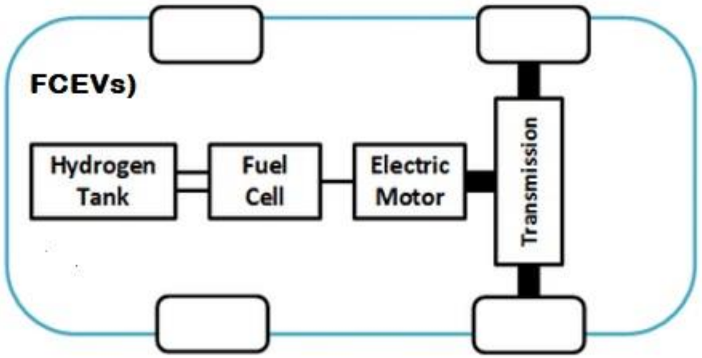
PHEVs – Plug-in Hybrid Electric Vehicles



BEVs – Battery Electric Vehicles

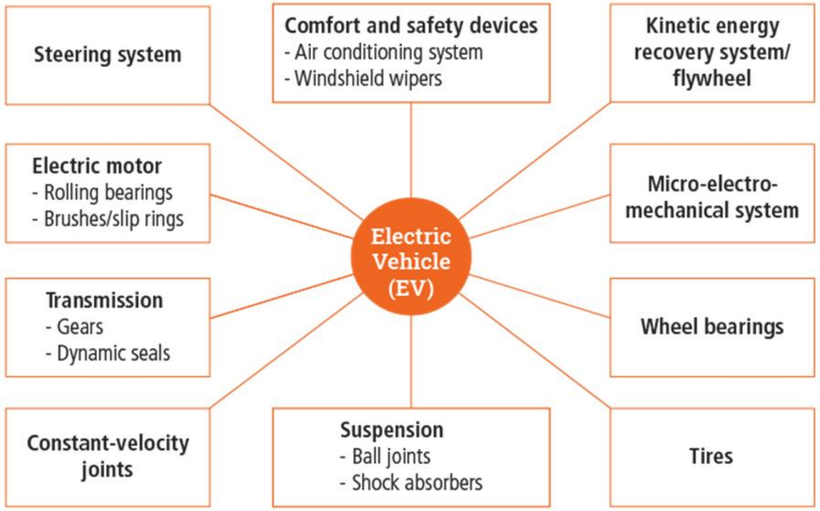


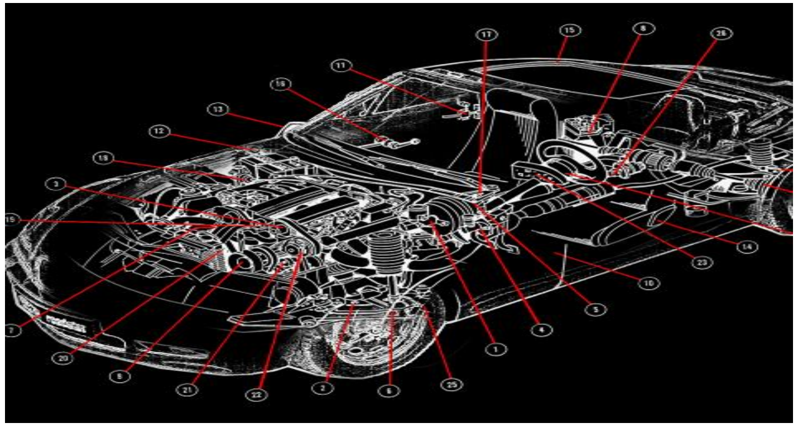
FCEVs – Fuel Cell Electric Vehicles



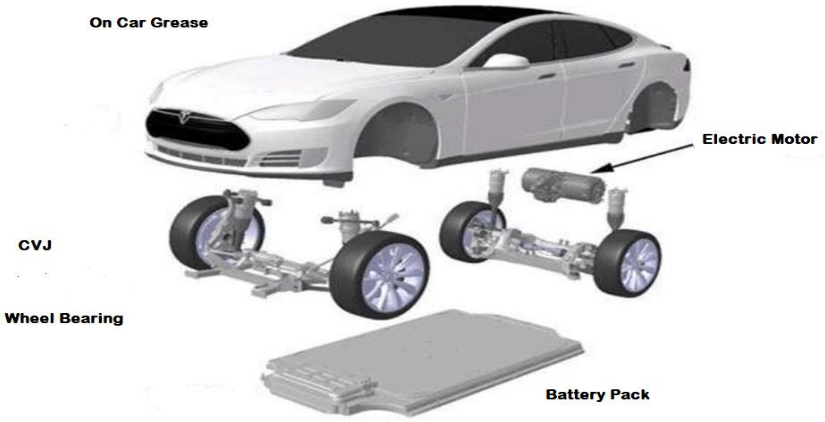
Morsi Nour, Jose Pablo Chaves-Ávila J.P. Magdy, Alvaro Sanchez-Miralles, ”Review of Positive and Negative Impacts of Electric Vehicles Charging on Electric Power Systems”, Energies, 13, 4675, Sep, 8, 2020.

Tribo-components to be Monitored





Parts	Grease Type	ICE	Evs	PHEVs
Wheel Bearing	Multipurpose	Y	Y (fretting-wear)	Y (fretting wear)
CVJ	Multipurpose	Y	Y (High Torque)	Y
On Car	Specialty	Y		
Engine	Specialty	Y	N	Y
Chassis	Multipurpose	Y	-	Y
Brake system	Specialty	Y		
Electric Motor	Specialty	N	Y (High-speed, High-temp)	
Battery	Specialty	Y (min)	Y	



Shah, R., Tung, s., Chen, R., Miller, R., “Grease Performance Requirements and Future Perspectives forElectric and Hybrid Vehicle Applications”, Lubricants, 9, 40, 2021.
Gareth Fish, “Lubricating Greases for Electric Vehicle Applications” The 2nd STLE Tribology & Lubrication for E-Mobility Conference Southwest Research Institute (SwRI), San Antonio, Texas (USA), December 1, 2020.
Jane Marie Andrew, “The future of lubricating Greases in the Electric Vehicle Era”, TRIBOLOG Y & LUBRICATION TECHNOLOGY, 38-44, May 2019.

Grease Specifications – ASTM D4950 (GC-LB)

NLGI originally designed the list of standard test methods and performance targets to meet the needs of automotive service greases, in cooperation with the American Society of Testing Materials (ASTM) and the Society of Automotive Engineers (SAE), from 1969 until it was published in 1989 as ASTM D4950 “Standard Classification and Specification for Automotive Service Greases”.

	Method	Property	Units	Minimum	Maximum	Reproducibility	Proposed Range for Audit Pass
1	ASTM D217	Consistency, Worked Penetration	mm/10	220-250 (#3) 265-295 (#2) 310-340 (#1)		20 units	200-360
2	ASTM D2265	Dropping Point	mm	220℃ min	0.50	12℃	208℃ Min
3	ASTM D1742	Static Oil Seperation	% Loss	10 max	5%	.17m	11.7 MAX
4	ASTM D3527	High Temp -Wheel Bearing Life	H	80 min	120 min	1.2x	60 min
5	ASTM D4290	Leakage Tendency of Wheel Bearing	% max	24 max		3.848√X	42.9 max
6	ASTM D4170	Fretting Protection	mg	10 max	5	1.4√X	14.4 Max
7	ASTM D1743	Rust Protection, Rating	Pass	pass		pass	pass
8	ASTM D2596	4-Ball EP Weld	Weld Point (Kgf)	250		.78x	80 min
	ASTM D2596	4-Ball EP LWI	Weld Point (Kgf)	400		.44x, 16.8 min	.78X, 80 min
9	ASTM D2266	4-Ball Wear Protection, Scar Diameter	mm	.6 max	0.60	.37 mm	.97 max
10	ASTM D1264	Water Resistance at 80°C	% Loss	15 max	+10	1.1(X+4.6)	36.6 max
11	ASTM D4693	Low Temperature Torque at − 40°C	Nm	15.5 max		.55M	24.0 MAX
12	ASTM D4289 (Modified)	Elastomer Compatibility (NBR) NBR28P (ISO 13226) 168 hours at 125 °C	Δ Hardness (Shore A)	-15	+2	11.5 Units	-26.5 to +13.5
	ASTM D4289 (Modified)	Elastomer Compatibility (NBR) NBR28P (ISO 13226) 168 hours at 125 °C	Δ Volume (%)	-5	+30	3.45% points	-8.45 to 33.45

ASTM D4950-14 “Standard Classification and Specification for Automotive Service Greases”, ASTM International, West Conshohocken, PA, www.astm.org.
Dr. Raj Shah, Jacky Jiang, Joseph Kaperick , “Next-Generation NLGI Grease Specifications”, NovDec2019SpokesmanFINAL63-73.

Grease Specifications – HPM (Next Generation)

High Performance Multiuse Specs

Goals

- Define a new grease specification with higher performance & will not replace (GC-LB)

Additional goals

- HPM
- Enhanced Water Resistance (WR)

Property	Test method	Units	Minimum	Maximum
HPM Grease Spec ification				
60x penetration	D217	dmm	220	340
Prolonged worked penetration (Δ10k)	D217	dmm	-10%	+10%
Elastomer compatibility NBR (standard reference elastomer from ISO 13226 or SAE J2643)	D4289* modified with change in tensile & elongation from ASTM D471 (72 or 168 hours at 100°C)	ΔHardness (Shore A)	-15	+5
		Δ Volume percent	-5	+30
Oxidation Stability at 100C	D942	kPa		35
(pressure drop @ 100hrs)		(psi)		(4.9)
Water washout at 79C	D1264	wt%		10
LT Torque at -20°C or -18°C	D1478	mNm (g·cm)		
Starting torque				1000 (10,200)
Running torque				100 (1,020)
Static oil bleed	D1742	wt%		5.0
HT Bleed	D6184	wt%		7.0
(30 hours at 100°C)				
Roll stability	D1831 using 1/2 scale only	dmm	-10%	+10%
(2 hours at RT)				
4-Ball Wear Scar Diameter	D2266	mm		0.60
4-Ball EP	D2596	kgf	250	
Weld point				
Rust rating	D1743	rating	Pass	
Emcor rust test (distilled water)	D6138	rating		0,1
Copper corrosion (24 hours 100 °C)	D4048	rating		1B
HPM Grease + Water Resistance Enhancement (+WR)				
Water washout at 79C	D1264	wt%		5.0
Water spray off	D4049	wt%		40
Wet roll stability (Penetration change)	D8022 using 1/2 scale	dmm	-15%	+15%

ASTM D4950-14 “Standard Classification and Specification for Automotive Service Greases”, ASTM International, West Conshohocken, PA, www.astm.org.
Dr. Raj Shah and Jacky Jiang and Joseph Kaperick NovDec2019SpokesmanFINAL63-73.

Grease Specifications – HPM

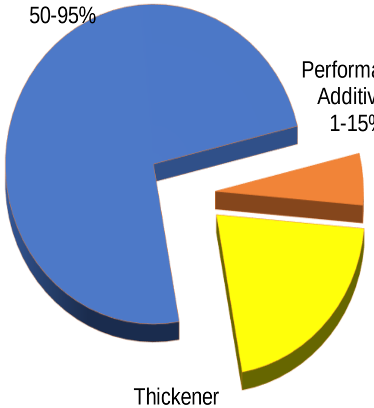
Additional goals

- Enhanced Water Resistance (WR)
- Enhanced Saltwater Corrosion Resistance (CR)
- Enhanced Load Carrying Capacity (HL)
- Enhanced Low Temperature (LT)
- Enhanced Long Life grease (LL)

Property	Test method	Units	Minimum	Maximum
HPM Grease + Corrosion Resistance (+CR)				
Bearing rust 10% synthetic seawater	D5969	rating	Pass	
Emcor rust 100% Synthetic seawater	D6138	rating		1 , 2
Emcor rust ~ 3% NaCl solution (0.5 N solution)	D6138	rating		2 , 3
HPM Grease + High Load (+HL)				
4-Ball Wear - Wear scar diameter	D2266	mm		0.50
4-Ball EP Weld point	D2596	kgf	400	
SRV step Load (Procedure B at 80C)	D5706	N	800	
Fretting wear (weight loss)	D4170 (average two runs)	mg		5.0
Fretting wear scar by SRV	D7594	mm		0.5
HPM Grease + Low Temperature Performance (+LT)				
LT Torque at -40 °C	D1478			
Starting torque		mNm (g·cm)		1000 (10,200)
Running torque		mNm (g·cm)		100 (1,020)
U. S. Steel Mobility @ -18C	LT-37	g/min	10	
Low Temperature Flow Test, Temp for 1400 mBar pressure	DIN 51805-2	Deg C		-30°C
HPM + Enhanced Long Life (+LL)				
4-Ball Wear	ASTM D2266	mm		0.50
Fretting Wear	ASTM D4170	mg		5
Fretting Wear Scar by SRV	ASTM D7594	µm		**TBD**
Roll Stability, 50 Hrs. @ 80°C	ASTM D1831	mm/10		**TBD**
Oxidation Stability	ASTM D942	kPa (psi)		20 (3)
Elastomer Compatibility (NBR)	ASTM D4289 (Modified) 70 Hrs. @ 150°C	Δ Hardness (Shore A)	-15	+5
		Δ Volume (%)	-5	+30
		Δ Tensile Strength (%)	-50	+50
		Δ Elongation (%)	-50	+50

Grease Composition & Formulation - Multipurpose

Oil + Thickener + Additives + Manufacturing Process = Performance Requirements of Lubricating Grease



Base Oils
Mineral oils – 90% of market

- Naphthenic
- Paraffinic
    - GRP – I, II, II+, III

Synthetics IV

- PAO
- PIB

Thickeners - Three-dimensional network of fibers or surface-active particles

Simple Soaps

- *Aluminum*
- *Barium*
- Sodium
- Calcium Stearate (Cup)
- Calcium 12HSA
- Lithium Stearate
- Lithium 12HSA

Complex Soaps

- Aluminum Complex
- *Barium Complex*
- Calcium Complex
- Calcium Sulfonate Complex
- Lithium Complex
- *Sodium Complex*

Non-Soaps

- Polyurea
- Clay

Performance Additives

Anti-wear

- Phosphate Ester
- ZDDP
- **Extreme Pressure**
- Sulfurized additives
- Antimony
- DMTD
- **Corrosion Inhibitors**
- Barium
- Calcium

Oxidation Inhibitors

- Amines
- Phenols

Tackifiers

- Polyisobutylenes (PIB)
- olefin copolymers (OCP)

Viscosity Improvers

- Olefin copolymers (OCP)
- Polyalkymethacrylates (PMA)
- Styrene-butadiene copolymers

Solid Additives

- Graphite
- Molybdenum Disulfide

Color

- Dye
- Identification/Cosmetic

Kumar, A., Bhatnagar, N. and Mallory, B., *NLGI Spokesman*, 81 (2), pp. 12-17, May/June 2017.

Grease Types and Properties - Multipurpose

Parts	Grease Type	ICE	Evs	PHEVs
Wheel Bearing	MP	Y	Y	Y
CVJ	MP	Y	Y	Y
On Car	S	Y		
Engine	S	Y	N	Y
Chassis	MP	Y	-	Y
Brake system	S	Y		
Electric Motor	S	N	Y	
Battery	S	Y	Y	

	Method	Property	Multi-Purpose Finished Greases								
			Sodium	Sodium - calcium	Hydrated Calcium	Anhydrous Calcium	Lithium	Lithium complex	Calcium Sulphonate	Polyurea	Aluminum complex
1	ASTM D217	Consistency, Worked Penetration									
	ASTM D1831	Roll Stability	F		F-G	G	G-E	G-E	G-E	F-G	G-E
2	ASTM D2265 ASTM DD556	Dropping Point	F-G		P	P-F	F-G	G-E	G-E	G	G-E
3	ASTM D1742	Static Oil Seperation	G		G	G	G	G	G-E	F-G	G-E
	ASTM D1742	Oil Separation During Storage	G		G	G	F-G	F-G	G	P-F	G
4	ASTM D3527	High Temp -Wheel Bearing Life	P-F		P-F	P-F	F-G	G-E	G-E	G	G
	ASTM D3336	High-Temp Bearing Performance									
5	ASTM D4290	Leakage Tendency of Wheel Bearing	P-G		P-G	F-E	G-E	G-E	G-E	G-E	F-E
	ASTM D5483	Oxidation Stability by PDSC									
	ASTM D942	Oxidation Stability 100 Hours									
	ASTM D6186	Oxidation Induction Time by PDSC									
6	ASTM D4170	Fretting Protection	F-G		P-F	P-F	G-E	G-E	P-F	G-E	G
7	ASTM D1743	Rust Protection, Rating	P		F-G	G-E	G-E	G-E	G-E	G-E	G-E
	ASTM D6138	Corrosion-Preventive, Dynamic Wet Conditions (Emcor Test)									
	ASTM D5969	Corrosion-Preventive, Dilute Synthetic Sea Water Environments									
8	ASTM D2596	4-Ball EP Weld	F-G		F-G	F-G	F-G	G-E	G-E	G-E	G-E
	ASTM D2596	4-Ball EP LWI	F-G		F-G	F-G	F-G	G-E	G-E	F-G	F-G
9	ASTM D2266	4-Ball Wear Protection, Scar Diameter	F-G		F-G	F-G	G	G	F-G	G	G
	ASTM D2509	Timken Load Carrying Test	G		G	G	G	G-E	G-E	F-G	G
10	ASTM D1264	Water Resistance at 80°C	P		G	G-E	F-E	G-E	G-E	G-E	G-E
	ASTM D4049	Resistance to Water Spray	P		P-F	P-F	F-E	F-E	P-F	F-G	G-E
11	ASTM D4693	Low Temperature Torque at – 40°C					G	G	F-G	G	G
12	ASTM D4289 (Modified)	Elastomer Compatibility (NBR) NBR28P (ISO 13226)	G		G	G	G	G	G	G	G
	ASTM D4289 (Modified)	Elastomer Compatibility (NBR) NBR28P (ISO 13226)	G		G	G	G	G	G	G	G
	US Steel LT-37	Grease Mobility	G		G	G	G	G	G	G	G
	Lincoln ventmeter	Grease Pumpability (Central System)	P-F		P-F	P-F	F-G	F-G	F-G	F-G	F-G

Targets

- noise reduction
- thermal transfer,
- seals
- materials compatibility

Raj Shah, Mathias Woydt, Simon C. Tung3and Andreas Rosenkranz , “Grease, *Lubricants*2022, *10*, 45. https://doi.org/10.3390/lubricants10030045.

Existing & Missing Requirements for Electric Motors

Existing Electric Motors Bearing Specifications - Grease Specifications
- Reduce Friction & Prevent Wear
- Corrosion Protection
- Seal to entry of Contaminants

Existing Testing Requirements - Standardized
- ASTM D217 (60XX) – Consistency – NLGI 1 to 1.5
  (100,000XX) – Shear Stability
- ASTM D3336 – HT Bearing Performance
- ASTM D556 – Dropping Point

Polyurea is the Recommended Finished Grease

New EV Electric Motor bearing Specifications
- to 18,000 r/min L
- Long life
- Low noise
- Conducting or insulating
- Energy efficient

Electric Properties - Greases Required to maintain electrical properties : Conductivity & Resistivity

Conductivity
- Electric **impedance** of a lubricant determines the electric **conductivity** across the lubricated tribo-pairs.
- **Dielectric strength** of the lubricant determines the breakdown voltage across the lubricated tribo-pairs.

Resistivity
- Too low resistivity – leakage current, short-circuits,
- Too high resistivity – damage due to buildup of static charge and arcing & Result in Electrically Induced Bearing Damage (EIBD)

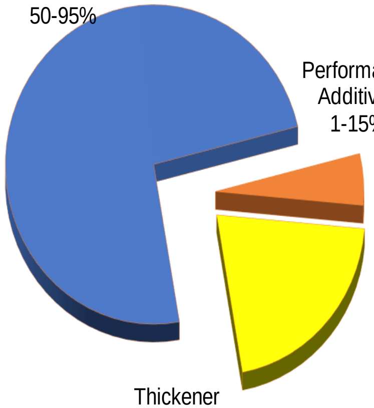
Suggested Testing Requirements
- Measuring electric properties in greases is currently challenging and not standardized
- **Suggestions based on Existing Testing**
  - Volume Resistivity Test Rig
  - EIBD Dynamic Testing Instrument
  - ASTM D149 - Dielectric strength
  - ASTM D257 - DC resistance or conductance
  - ASTM D1816 - Dielectric breakdown voltage of insulating liquids
  - ASTM D2624 - Electrical conductivity of aviation and distillate fuels
  - ASTM D4308 - Electrical conductivity of liquid hydrocarbons

Guide to Electric Motor Lubrication, ExxonMobil Lubricants & Specialties, www.exxonmobil.com, Feb.2002.

Gareth Fish, "Lubricating Greases for Electric Vehicle Applications" The 2nd STLE Tribology & Lubrication for E-Mobility Conference SwRI, San Antonio, Texas (USA), December 1, 2020.George S. Dodos, Raj Shah," COMPOSING THE FUTURE C-H-ORDS OF LUBRICATING GREASES IN THE E-MOBILITY ERA, 32nd ELGI Annual General Meeting Hamburg Germany April-May 2022.

Grease Composition – Specialty

Oil + Thickener + Additives + Manufacturing Process = Performance Requirements of Lubricating Grease



Base Oils
- **Minerals**

Synthetics GRP V
- Esters, POE,
- Polydimethylsiloxane (PDMS)
- Polyphenyl ethers (PFPE)
- PAG
- Silicone
- White Oil

Thickeners - Three-dimensional network of fibers or surface-active particles

Simple Soap
- Calcium 12HSA
- Lithium 12HSA

Complex Soap
- Calcium Complex
- Calcium Sulfonate Complex
- Lithium Complex

Non-Soaps
- Polyurea
- Clay
- Polymer - Polypropylene
- PTFE Teflon®
- Silica

Performance Additives

Anti-wear
- Phosphate Ester
- Zinc Dithiophosphate
- **Extreme Pressure**
- Sulfurized additives
- Antimony
- **Corrosion Inhibitors**
- Barium
- Calcium

Oxidation Inhibitors
- Amines
- Phenols

Tackifiers
- Polyisobutylenes (PIB)
- olefin copolymers (OCP)

Viscosity Improvers
- Olefin copolymers (OCP)
- Polyalkymethacrylates (PMA)
- Styrene-butadiene copolymers

Solid Additives
- Graphite
- Molybdenum Disulfide
- PTFE Teflon®

Elena McDaniel, John Sander & Terry Smith, NLGI SPOKESMAN, OCTOBER 2007
Nancy McGuire TRIBOLOG Y & L UBRICATION TECHNOLOGY, 38- OCTOBER 2017

Grease Types and Properties - Specialty

Parts	Grease Type	ICE	Evs	PHEVs
Wheel Bearing	MP	Y	Y	Y
CVJ	MP	Y	Y	Y
On Car	S	Y		
Engine	S	Y	N	Y
Chassis	MP	Y	-	Y
Brake system	S	Y		
Electric Motor	S	N	Y	
Battery	S	Y	Y	

	Method	Property	Specialty Finished Greases						
			Li/MoS2	LiX/MoS2	Polyurea EM	Clay	PTFE	Silica Dielectric	Polymer
1	ASTM D217	Consistency, Worked Penetration							
	ASTM D1831	Roll Stability	G-E	G-E	F-G	P-F	G	G	G
2	ASTM D2265 ASTM DD556	Dropping Point	F-G	G-E	G	G-E	G-E	G-E	G-E
3	ASTM D1742	Static Oil Seperation	G	G	F-G				
	ASTM D1742	Oil Separation During Storage	G	G	P-F				
4	ASTM D3527	High Temp -Wheel Bearing Life	G-E	G-E	G-E				
	ASTM D3336	High-Temp Bearing Performance	F-G	F-G	G-E				
5	ASTM D4290	Leakage Tendency of Wheel Bearing	G-E	G-E	G-E				
	ASTM D5483	Oxidation Stability by PDSC							
	ASTM D942	Oxidation Stability 100 Hours							
	ASTM D6186	Oxidation Induction Time by PDSC							
6	ASTM D4170	Fretting Protection	G-E	G-E	G-E				
7	ASTM D1743	Rust Protection, Rating	G-E	G-E	G-E				
	ASTM D6138	Corrosion-Preventive, Dynamic Wet Conditions (Emcor Test)	G	G	G				
	ASTM D5969	Corrosion-Preventive, Dilute Synthetic Sea Water Environments	F-G	F-G	F-G				
8	ASTM D2596	4-Ball EP Weld	F-G	G-E	P				
	ASTM D2596	4-Ball EP LWI	F-G	G-E	P				
9	ASTM D2266	4-Ball Wear Protection, Scar Diameter	F-G	F-G	P-F				
	ASTM D2509	Timken Load Carrying Test	G	G-E	P				
10	ASTM D1264	Water Resistance at 80°C	G-E	G-E	G-E	F-E	F-E	F-E	G-E
	ASTM D4049	Resistance to Water Spray	F-G	F-G	G				
11	ASTM D4693	Low Temperature Torque at – 40°C	G	G	G				
12	ASTM D4289 (Modified)	Elastomer Compatibility (NBR) NBR28P (ISO 13226)	G	G	G				
	ASTM D4289 (Modified)	Elastomer Compatibility (NBR) NBR28P (ISO 13226)	G	G	G				
	US Steel LT-37	Grease Mobility	G	G	G				
	Lincoln ventmeter	Grease Pumpability (Central System)	F-G	F-G	F-G				

Missing Targets

Lubrication efficiency in the presence

- electrical current and electromagnetic fields generated by electric modules, sensors and circuits

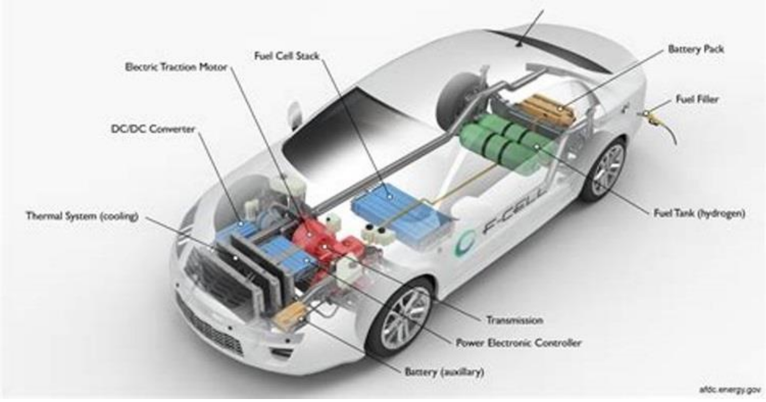
Gabriel Calderon Salmeron, Johan Leckner, Fabian Schwack, Rene Westbroek, Sergei Glavatskih,“ Greases for Electric Vehicle Motors: Thickener Effect and Energy Saving Potential”, Tribology International 167 (2022) 107400.

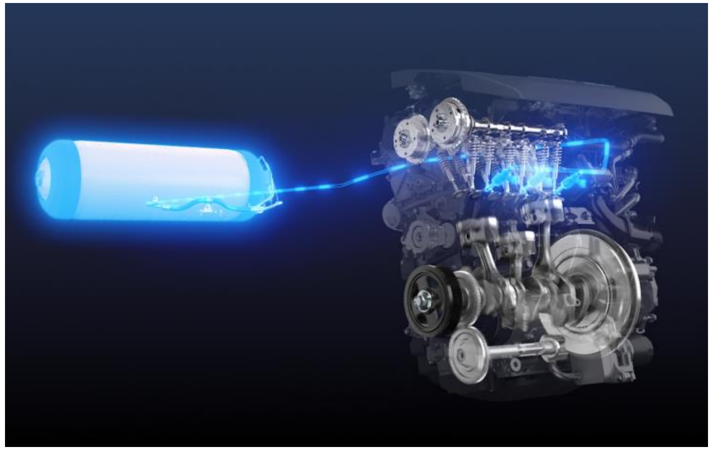
Heinz P. Bloch ,Robert Aronen, “How to extend motor life with PFPE grease”, Plant Services, June 17. 2015 https://www.plantservices.com/articles/2015/how-to-extend-motor-life-with-pfpe-greases/

Disruptive - Types of EV

1. HEVs – Hybrid Electric Vehicles
2. PHEVs – Plug-in Hybrid Electric Vehicles
3. BEVs – Battery Electric Vehicles
4. FCEVs – Fuel Cell Electric Vehicles
5. HCEs – Hydrogen Combustion Engines

Toyota Mirai





The Toyota/Yamaha **5.0-litre naturally-aspirated H**ydrogen-burning V-8 Produces up to **335kW** of Power and **540Nm** of Torque

https://www.topspeed.com/toyotas-hydrogen-combustion-engine-has-the-potential-to-make-evs-obsolete/.
https://global.toyota/en/newsroom/corporate/35209996.html.

Conclusion

- Multipurpose Grease Specifications and Formulations Meet the EV Requirements
- Current Specialty Grease Specifications and Formulations meet residual ICE Requirements
- Additional Development needed in the Specifications and Formulations of Specialty for Conductivity & Resistivity – Gap for Electric Motors
- Future or Disruptive EV Technology will Continue to Influence and Require New Specifications and Formulations

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