Mobil SHC™ 918 EE

The first turbine oil to meet GE's new energy-efficient turbine oil specification

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*GEK 121603 – Lubricating Oil Recommendations Energy Efficient Oil for Gas Turbines with Bearing Ambients above 500 degrees Fahrenheit
**For more details about the warranty, see your local ExxonMobil sales representative or contact the Technical Help Desk at 1-800-MOBIL25 or visit mobil.com/contact-us

Section 1:

Mobil SHC™ 918 EE introduction

Introducing breakthrough turbine oil performance

Next-generation Mobil SHC™ 918 EE turbine oil is the first and only oil in the world to meet GE's new rigorous GEK 121603 energy-efficiency specification. It was designed in collaboration with GE to help gas turbine operators:

- Experience energy-efficiency benefits.
- Lower production costs* while maintaining performance and reliability.
- Lower emissions per megawatt-hour

Patented formulation is based on Mobil DTE™ 932 GT technology.**

*Actual results can vary depending upon the type of equipment used and its maintenance, operating conditions and environment, and any prior lubricant used. The energy efficiency of Mobil SHC™ 918 EE relates solely to the fluid performance when compared to conventional ISO 32 VG turbine oils.
Mobil DTE™ 932 GT at over 70K hours in GE Frame 7FA – **no varnish, no varnish mitigation

Applications

GE Frame 7FA, 7HA multi-shaft and Frame 6FA.01 turbines

- Not for steam turbines or GE Frame 7EA, 5, or 3 gas turbines
- GE Frame 7FAs opportunities approved by GE

Section 2:

Lowering your cost to produce through energy efficiency

Here's how the savings add up:

In a Frame 7FA.03 169 MW gas turbine operating at 5,000 hours with 38.6% nominal cycle efficiency, Mobil SHC™ 918 EE can deliver:*

- $39 K incremental sellable electricity* (or 136 kW free electricity), or
- $9,200 in reduced fuel consumption per year*
- 455 tons in CO_2 reduction per year

Mobil SHC™ 918 EE delivers:

Up to $48,200 increased profitability per year*

*Frame 7FA.03 169 MW gas turbine operating at 5,000 hours with 38.6% nominal cycle efficiency, Typical operating values at plant who conducted field trial. Based on $0.0567/kW-hr cost to produce and $2.50/MMBtu, LHV.

Mobil SHC™ 918 EE can deliver:

$39,000

incremental sellable electricity per year*

or

$9,200

in reduced fuel consumption per year*

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*Frame 7FA.03 169 MW gas turbine operating at 5,000 hours with 38.6% nominal cycle efficiency, Typical operating values at plant who conducted field trial. Based on $0.0567/kW-hr cost to produce and $2.50/MMBtu, LHV.

Section 3:

GE relationship, rig testing and test stand

Developed in collaboration with GE

- Experimental formulations
- GE rig testing
- GE test stand
- Field demonstrations

Traditional fluid	Optimized fluid
ISO 32	ISO 18

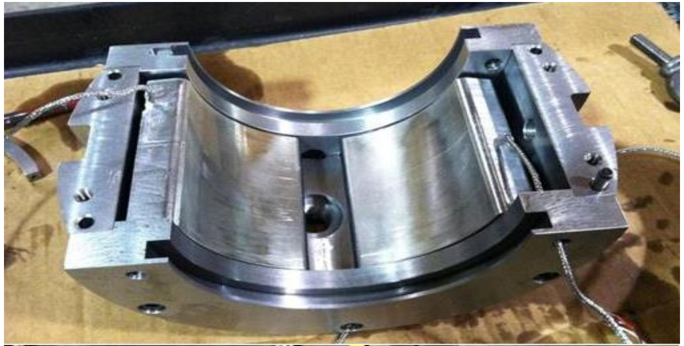
Volatility	Flashpoint
Specific heat	Density

GE-designed low-loss bearing (LLB) rig

GE and ExxonMobil collaboration led to low-loss bearing rig testing and protocols (based on ASTM D 7721) to demonstrate bearing efficiency improvement.

- Tested candidate oil using “A-B-A-B” approach over four days, run at four speeds and six loads
- Scaled-down journal bearing with standard four-tilting pads
- Captured substantial raw data points to conduct statistical analysis

GE Low-Loss Bearing Test
Approximate 16% bearing efficiency improvement



GE-designed low-loss bearing (LLB) rig data

A series of A – B – A – B tests were run at varying RPM (four speeds) and loads (six loads). This table represents a comparison of heat loss at one of the four speeds. Test data offers the most representative test speed and loading according to GE.

VG 32 vs VG 18 at constant oil flow oil and inlet temperature under varying loads

	Load (PSI)	46.7	75	125	200	300	400	AVG
VG 32	Calculated loss (HP)	39.6	42.3	44.7	45.7	47.9	49.2	44.9
VG 18	Calculated loss (HP)	35.1	36.3	36.2	37.3	39.5	40.8	37.5
Delta	Calculated loss (HP)	4.53	5.96	8.44	8.47	8.36	8.4	8.4
% Delta	**Calculated loss (HP)**	**11.43%**	**14.09%**	**18.90%**	**18.52%**	**17.46%**	**17.07%**	**16.39%**

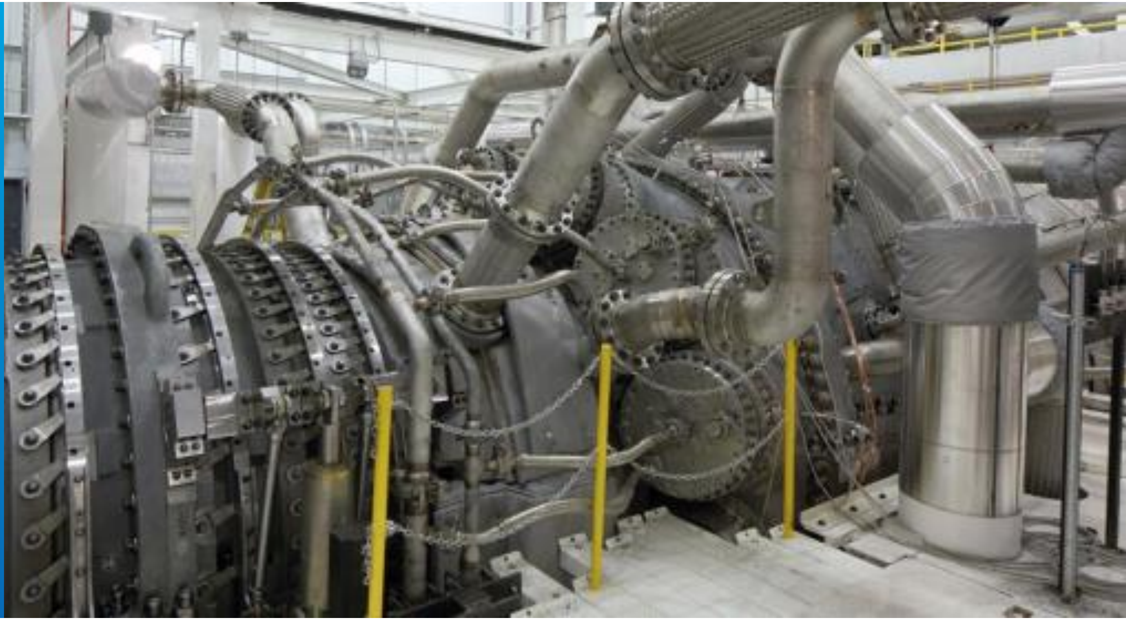
Additional supporting test parameters: Flow (GPM), Oil Inlet and Drain by RTD (F), Brg Metal Temp, Torquemeter Loss (HP)

The table above shows data at 9,550 RPM, which according to GE is the most representative speed with most representative loading at 300 psi.

GE 7HA test stand results

Bearing power loss reduction: 16%

- No significant difference in vibration at critical speeds or steady state
- Bearing Metal T showed reduction: 8°F



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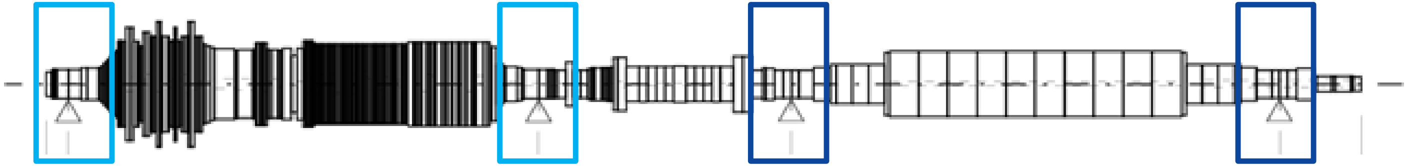
Section 4:

Field demonstrations and test results

GE Frame 7FA field demonstration



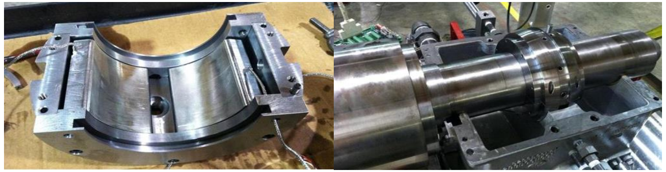
GE 7FA is a four-bearing machine.

- Two generator bearings
- Two gas turbine bearings

		VG 32 Oil			Mobil SHC™ 918 EE		
Load (MW)	**Bearing number**	**BMT (degrees Fahrenheit)**	**Oil drain (degrees Fahrenheit)**	**Power loss (KW)**	**BMT (degrees Fahrenheit)**	**Oil drain (degrees Fahrenheit)**	**Power loss (KW)**
168.2	GT No. 1	208	155.8	468	201	151	399
	GT No. 2	187.7	155.9	217	179	151	184
	GEN No. 1	212.1	156.3	103	198	152	90
	GEN No. 2	212	158.3	111	197	152	90
			Sum =	899		Sum =	763
						Delta (KW)	136

Bearing efficiency test summary

GE Low-Loss Bearing Test
Approximate 16% bearing efficiency improvement



GE Test Stand
Approximate 16% bearing efficiency improvement

GE Frame 7FA Field Demonstration
Approximate 15-16% bearing efficiency improvement

Source: sirgen.com

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*Actual results can vary depending upon the type of equipment used and its maintenance, operating conditions and environment, and any prior lubricant used. The energy efficiency of Mobil SHC™ 918 EE relates solely to the fluid performance when compared to conventional ISO 32 VG turbine oils.

Mobil SHC™ 918 EE produced a

.08%

heat rate reduction*.

*This result was based on a field trial. Actual results can vary based on operating conditions and prior lubricant used.

Field demonstration results

Bearing power losses of 0.5320% can be reduced to 0.4505% — providing a **15-16% bearing efficiency improvement.***

Field trial for 2+ years in 7FA.03 with no varnish mitigation technology

GE Frame 7FA Efficiency Calculator

	P_{VG32} (HP)	Reduction (%)*	P_{VG18} (HP)
Gas Turbine			
No. 1 Journal + Thrust	627.6	15.0	533.5
No. 2 Journal	291.0	15.0	247.4
Generator			
Drive End	138.1	16.0	116.0
Collector End	148.9	16.0	125.1
Total (HP) =	**1,206**		**1,022**
Additional Power (KW) =	---		136
Bearing Power Losses (%) =	0.5320		0.4505
Heat Rate (Btu/kWh, LHV) =	8839		8832
Heat Rate Improvement (%) =	---		**0.08**
Machine Output (MW) =	169		169.136
Efficiency Gain (%) =	---		0.0314
	P_{VG32}		P_{VG18}
Gas Turbine Efficiency (%) =	**38.6**		**38.6314**
Electricity Cost ($/KW-hr) =	---		**0.0567**
Hours Operation (hrs/year) =	---		**5,000**

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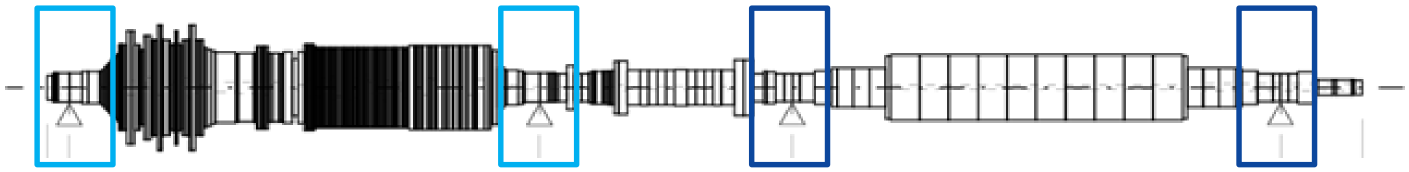
*Bearing efficiencies based on GE frame 7FA.03 field demonstration. Actual results can vary depending upon the type of equipment used and its maintenance, operating conditions and environment, and any prior lubricant used. The energy efficiency of Mobil SHC™ 918 EE relates solely to the fluid performance when compared to conventional ISO 32 VG turbine oils.

GE Frame 7FA field demonstration



GE 7FA is a four-bearing machine.

- Two generator bearings
- Two gas turbine bearings

Baseline gas turbine efficiency = ~38.6%

- Baseline bearing power losses = ~.53%
- Mobil SHC™ 918 EE bearing power losses = ~.45%
- **Bearing power loss delta = 15-16%**

Efficiency impacts:

- Bearing power losses: thermal energy loss due to friction and heat transfer
- Heat rate: thermal energy in divided by electrical energy out (inverse of efficiency)
    - **Lower heat rate = improved energy efficiency (i.e., less fuel)**

Improved energy efficiency = reduced fuel

Reduced power loss in bearings → Reduced heat rate → Reduced fuel consumption

Customer impact:

Fuel savings = (Heat rate reduction) X (Operating Hours) X (Natural Gas Price) X (Baseline Output in MW) X (NPV factor*)

Fuel savings = (7.2 Btu/kWh) X (5,000 hours) X ($2.50/MMBtu) X (169 MW) X (0.005)

10-year NPV fuel savings = $76,000**

*Net Present Value (NPV) factor assumes 10-year project with 10% discount factor
**Fuel savings based on customer field trial data

Section 5:

GEK 121603 – Energy Efficient Oil for Gas Turbines*

*GEK 121603 – Lubricating Oil Recommendations Energy Efficient Oil for Gas Turbines with Bearing Ambients above 500 degrees Fahrenheit

Exclusive endorsement

GE created the new GEK 121603 turbine oil specification for energy efficiency. Mobil SHC™ 918 EE is the **only oil** that meets the specification!

Lubricating Oil Recommendations *GEK121603*

Table 1. Recommended Properties – New Oil

Test method	Test	Recommended Value
ASTM D4052	Specific Gravity at 15.6°C	0.76 to 0.88
ASTM D1500	Color	≤2
ASTM D97	Pour Point (°C)	≤-12
ASTM D445	Kinematic Viscosity @ 40°C (centistokes)	16.5 to 20
ASTM D974	Acid Number (mg KOH/g)	≤0.2
ASTM D665	Rust Prevention — B	Pass (4 Hours)
ASTM D92	Flash Point — Cleveland Open Cup (°C)	≥215
ASTM D130	Copper corrosion (3 hour/100°C)	≤1B
ASTM D892	Foam Sequence 1 ml/ml	≤50/0
	Sequence 2 ml/ml	≤50/0
	Sequence 3 ml/ml	≤50/0
ASTM D943	Turbine oil oxidation test (hours)	≥5,000
ASTM D2272	Oxidation Stability by Rotating Vessel (minutes)	≥500
ASTM D2272	Oxidation Stability by Rotating Vessel (modified per ASTM D2272 Appendix XI)	≥85% of time in unmodified test
ASTM D3427	Air Release	≤5
ASTM D2270	Viscosity Index (V I)	≥95
ASTM D5182 or ISO 14635-1	FZG Gear Rig Test Failure Load Stage*	≥8
ASTM D5185	Zinc Content ppm — Spectroscopy	≤5

*Test is required for geared turbines; may be omitted for non-geared turbines.

Energy Efficiency claims must be confirmed by GE-approved rig testing and GE-approved gas turbine field demonstration. Geared generators must have confirmed performance in GE-approved gear box manufacturer.

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Section 6:

Summary

Mobil SHC™ 918 EE lowers your cost to produce.

- Mobil SHC™ 918 EE , developed in collaboration with GE, delivers energy-efficiency benefits:
  - Resulting in $76,000 in 10-year NPV savings*
  - 455 tons in CO_2 reduction per year*

Make the switch today

Learn more at mobil.com/efficientturbines

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*Actual results can vary depending upon the type of equipment used and its maintenance, operating conditions and environment, and any prior lubricant used.

Section 7:

Backup

Mobil Serv℠

Experts you can trust

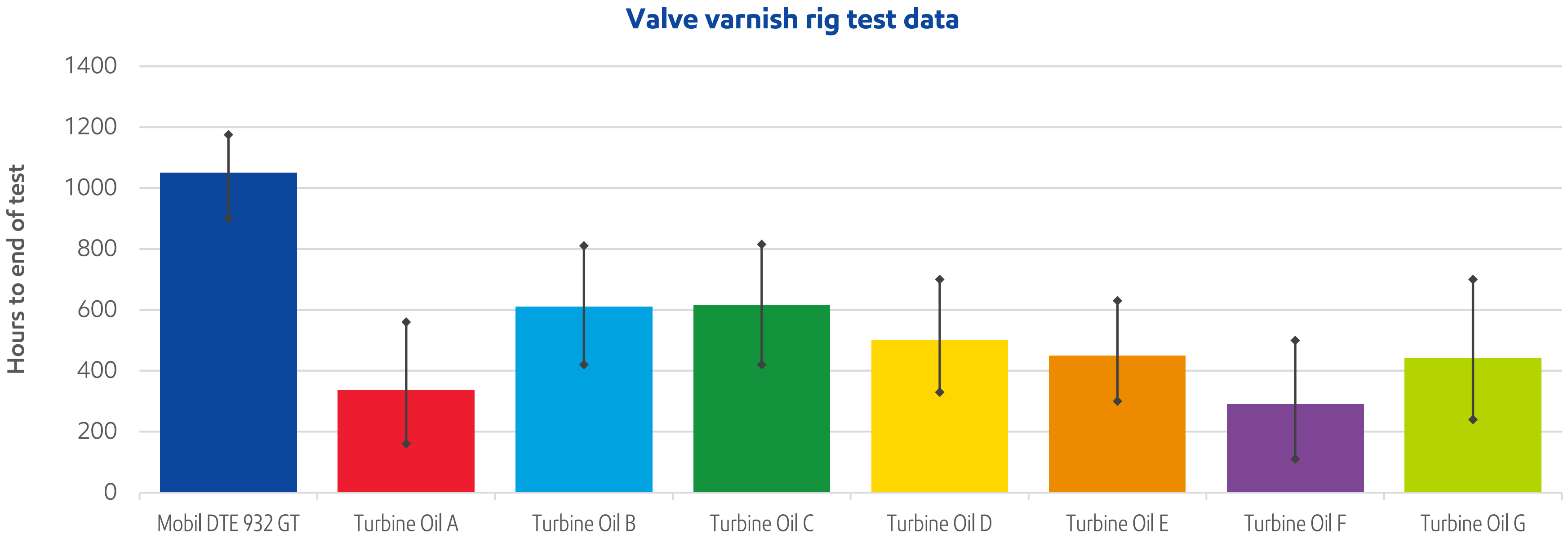
Mobil SHC™ 918 EE is backed by the Mobil Serv℠ promise and more than 150 years of ExxonMobil expertise. Mobil Serv experts work with you as committed partners to help you reach your goals.

Tap into best-in-class expertise developed through trusted OEM relationships, groundbreaking research and an extraordinary legacy of lubrication achievements. Contact your sales representative for more information.

Mobil SHC™ 918 EE vs. GEK 121603

Test (ASTM)	Method	Units	Min	Max	Mobil SHC™ 918 EE
D4052	Specific Gravity @ 15.6C		0.76	0.88	0.8371
D1500	Color			2.0	L0.5
D97	Pour Point	°C		-12	-33
D445	Viscosity 40C	cSt	16.5	20	18
D974	Total Acid Number			0.2	0.07
D665	Rust Prevention – B, 4 hour		Pass		Pass
D92	Flash Point (COC)	°C	215		231
D130	Copper Corrosion	Rating		1B	1A
D892	Foaming Tendency Seq 1	mL		50	10
D892	Foam Stability Seq 1	mL		0	0
D892	Foaming Tendency Seq 2	mL		50	10
D892	Foam Stability Seq 2	mL		0	0
D892	Foaming Tendency Seq 3	mL		50	10
D892	Foam Stability Seq 3	mL		0	0
D943	Turbine Oil Oxidation Test	hrs	5000		>10,000
D2272	Oxidation Stability by Rotating Pressure Vessel	minutes	500		2006
D2272	Oxidation Stability by Rotating Pressure Vessel (mod)	minutes	85% of unmodified test		106.7%
D3427	Air Release, Time to 0.2 Pct Air	minutes		5.0	0.7
D2270	Viscosity Index		95		125
D5182	FZG Gear Failure Load Stage*	stage	8		10

Mobil SHC™ 918 EE based on Mobil DTE™ 932 GT technology



Mobil DTE™ 932 GT at over 70K hours in GE Frame 7FA – no varnish, no varnish mitigation technology

Valve varnish rig test – proprietary

Evaluates varnish control

- Provides relative assessment of performance of turbine oils under simulated service conditions

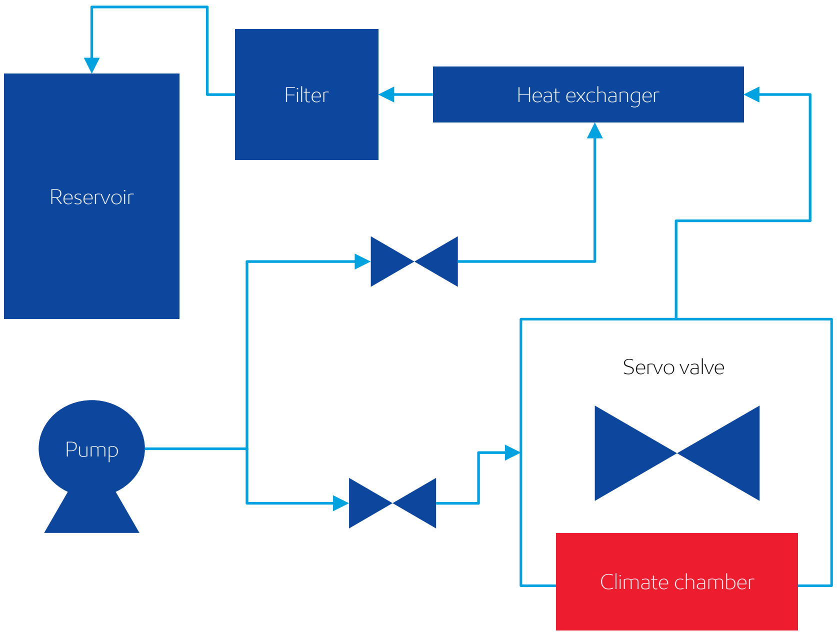
Rig configuration

- Oil circulation system containing a reservoir, pump, heat exchanger, filter and control valves
- Utilizes cyclic on/off operation to simulate real-world conditions

Used exclusively by ExxonMobil to help develop high-performing turbine oils

More relevant than glassware tests because it replicates real-world conditions

- Analysis confirms varnish deposits generated in the rig test and in the field are chemically similar.



Varnish causes unit trips/no-starts

Inlet Guide Vane (IGV) — Ring and gear

- IGV servo is prone to varnish due to supply tube cooling.
- IGV servo actuates the jackshaft which operates the ring and gear for air flow control.

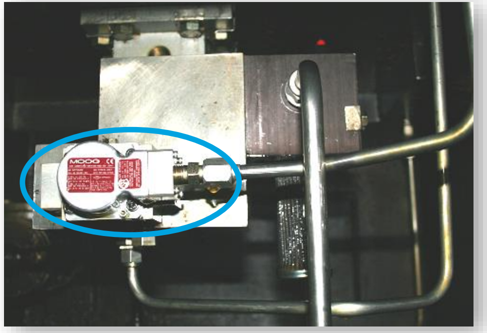
Servo Valve – Spool

Clean

Varnished

Gas Ratio Servo

- Air-to-fuel ratio control servo valve sticking can cause unit trips or no-starts.



Energy efficiency calculations

GE Low-Loss BRG. Rig, GE Test Stand and field demonstrations

Test objective

Obtain and compare temperature-based calculated power losses.

Calculated power losses using the following equation:

$$Calculated\ Loss\ (hp) = c_p \cdot Q \cdot (T_d - T_i)/c_f$$

$$c_p = Specific\ Heat\ (BTU/gal \cdot {}^{\circ}\mathrm{F})$$
$$Q = Oil\ Flowrate\ (gal/min)$$
$$T_d = Drain\ Temperature\ ({}^{\circ}\mathrm{F})$$
$$T_i = Inlet\ Temperature\ ({}^{\circ}\mathrm{F})$$
$$c_f = Conversion\ Factor\ from\ BTU/min\ to\ hp\ (42.445)$$

Performed complete statistical analysis over full data set

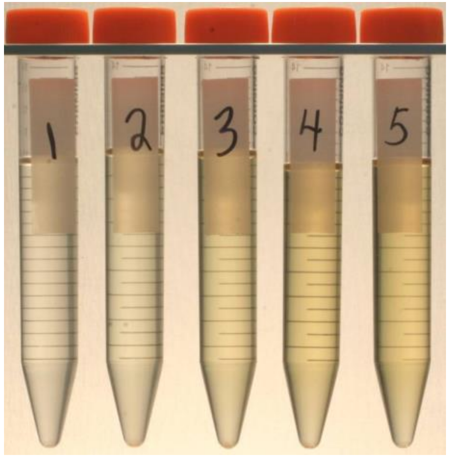
- Understand instrumental variability and validate efficiency conclusions
- Establish reproducibility of data and associated error bars

Mobil SHC™ 918 EE — compatibility

Compatibility testing conducted per ASTM D7155 Standard Practice

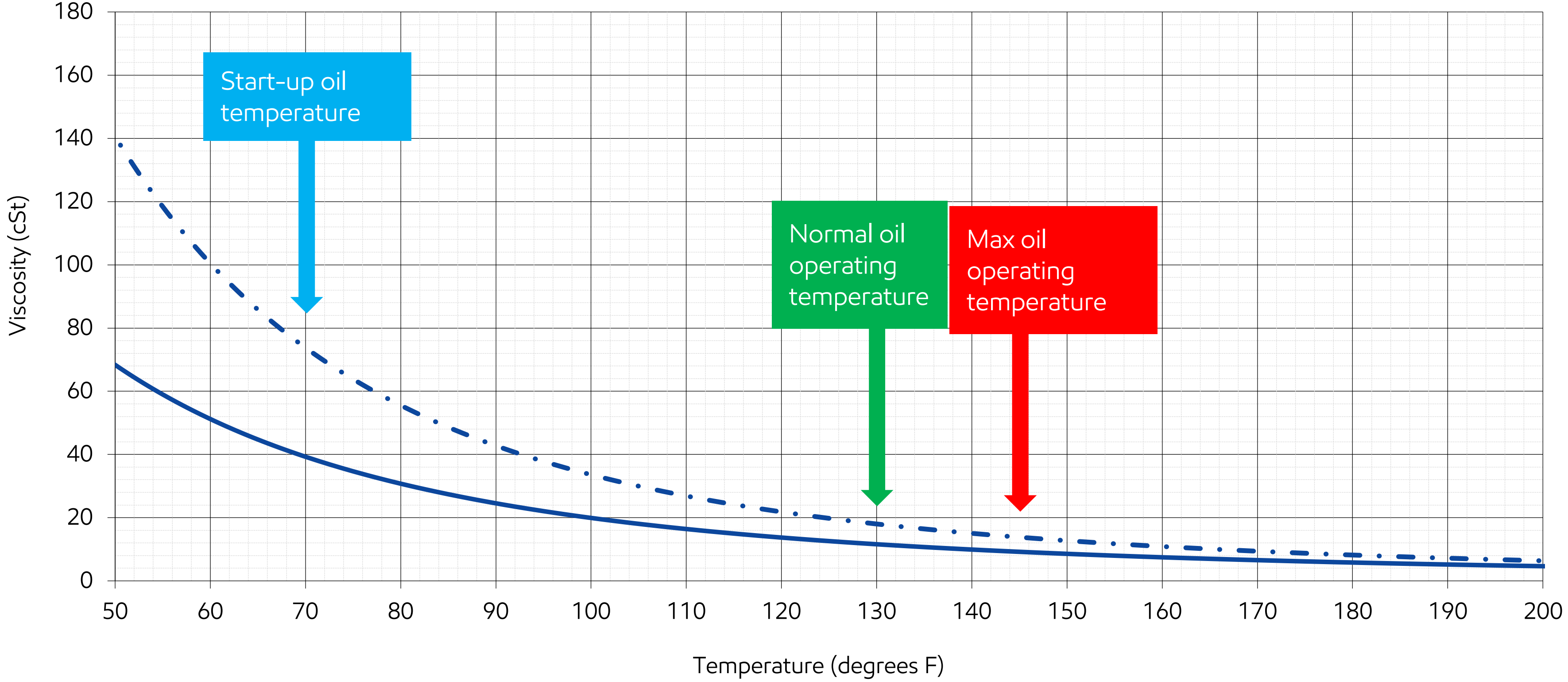
- Mobil SHC™ 918 EE is fully compatible with:
- Mobil DTE™ 932 GT
- Mobil DTE™ 724
- Mobil DTE™ 832
- Shell VSI 32
- Not compatible with Mobil DTE™ 732
- Hydrogen Absorption similar to Mobil DTE™ 932 GT
- Optimum Mobil SHC™ 918 EE performance is gained through system flushing with Mobil SHC™ 918 EE .

Freeze/Thaw Storage Stability



1 & 2: M-DTE 724 **3:** 50/50
4 & 5: M-SHC™918 EE

Mobil SHC™ 918 EE viscosity comparison to an ISO 32 oil



GE Frame 7FA – HP loss comparison

Mobil SHC™ 918 EE requires less horsepower versus water-soluble-based PAG fluids at constant dT (21 degrees Fahrenheit).

dT is temperature differential between bearing oil inlet and outlet.

$$Calculated\ loss\ (HP) = (Cp) \cdot (Q) \cdot (T_o - T_i)/42.445$$

$$Heat\ Capacity, Cp = Btu/gal\text{-}F$$
$$Q = gpm$$
$$T_o/T_i = F$$

Horsepower loss example comparison (GE 7FA.03):

Mobil DTE™ 732		Mobil SHC™ 918 EE		Water-soluble-based PAG Turbine Oil	
Q=615		Q=615		Q=615	
dT=24		dT=21		dT=21	
Specific heat/BTU/gal-F	3.42	Specific heat/BTU/gal-F	3.33	Specific heat/BTU/gal-F	3.96
HP loss	1188	HP loss	1013	HP loss	1205
HP loss vs DTE 732, %	0	HP loss vs DTE 732, %	14.7%	HP loss vs DTE 732, %	-1.4%

*Actual results can vary depending upon the type of equipment used and its maintenance, operating conditions and environment, and any prior lubricant used. The energy efficiency of Mobil SHC™ 918 EE relates solely to the fluid performance when compared to conventional ISO 32 VG turbine oils.

GE Frame 6FA field demonstration data

6FA Noblesville Oil Test

Test date Point	Load (MW)	Bearing Number	Oil inlet (°F)	BMT (°F)	Oil drain (°F)	Oil flow (gpm)	Oil grade (cSt)	Specific heat Btu/gal-°F	Power loss (HP)	Power loss (KW)
Baseload run		GT no. 1*	130.0	191.6	150.9	190	VG32	3.43	321	239
3/28/2016	69.5	GT no. 2	130.0	193.6	153.1	60	VG32	3.43	112	84
3:18 pm		GB HS no. 1	130.0	209.3	179.4	37	VG32	3.43	148	110
49 °F		GB HS no. 2	130.0	202.5	179.4	37	VG32	3.43	148	110
		GB LS no. 3	130.0	197.0	179.4	37	VG32	3.43	148	110
		GB LS no. 4	130.0	194.7	179.4	37	VG32	3.43	148	110
		GB Mesh	130.0	—	179.4	262	VG32	3.43	1,046	780
		GEN no. 1	130.0	177.0	156.9	37	VG32	3.43	80	60
		GEN no. 2	130.0	185.9	160.6	37	VG32	3.43	91	68
								Sum =	2,242	1,672

*Inactive thrust = 60 GPM, Active thrust = 70, No. 1 journal = 60 GPM

	BMT VG32	VG18	Delta
	191.6	183.1	8.5
	193.6	183.8	9.8
	209.3	202.8	6.5
	202.5	196.3	6.2
	197.0	191.0	6.0
	194.7	186.1	8.6
	—	—	
	177.0	171.1	5.9
	185.9	177.7	8.4
		avg (°F)	7.5
GB	1,211	1,151	-5.7%
GT-Gen	451	388	-14.0%

6FA Noblesville Oil Test

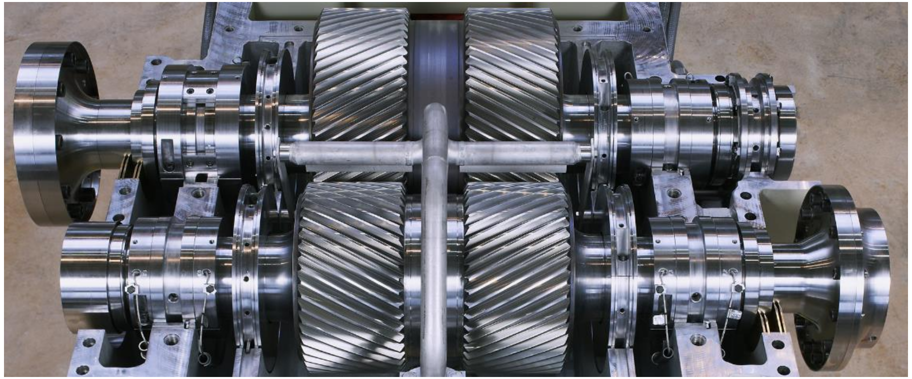
Test date Point	Load (MW)	Bearing Number	Oil inlet (°F)	BMT (°F)	Oil drain (°F)	Oil flow (gpm)	Oil grade (cSt)	Specific heat Btu/gal-°F	Power loss (HP)	Power loss (KW)	
11/17/2017	69	GT no. 1*	130.0	183.1	148.9	190	VG18	3.33	282	210	
3:57 pm		GT no. 2	130.0	183.8	150.2	60	VG18	3.33	95	71	
50 °F		GB HS no. 1	130.0	202.8	178.0	37	VG18	3.33	139	104	
		GB HS no. 2	130.0	196.3	178.0	37	VG18	3.33	139	104	
		GB LS no. 3	130.0	191.0	178.0	37	VG18	3.33	139	104	
		GB LS no. 4	130.0	186.1	178.0	37	VG18	3.33	139	104	
		GB Mesh	130.0	—	178.0	262	VG18	3.33	987	736	
		GEN no. 1	130.0	171.1	152.8	37	VG18	3.33	66	49	
		GEN no. 2	130.0	177.5	156.6	37	VG18	3.33	77	58	
								Sum =	2,064	1,539	7.9%
										131	Savings (KW)

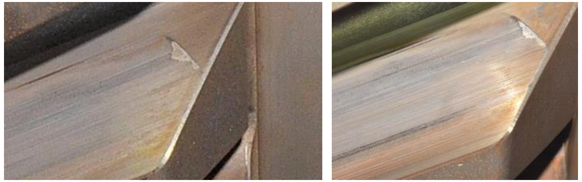
*Inactive thrust = 60 GPM, Active thrust = 70 GPM, No. 1 journal = 60 GPM

Gear load capability requirements for GE Frame 6FA

- Gear load protection of FZG (FLS) 8 required
- Renk gear test rig collaboration
- EB Germany supports testing/oil storage and distribution

Successfully completed Renk gear box testing





11/8/17 07/30/18

No increase in gear wear since start-up

Thank you