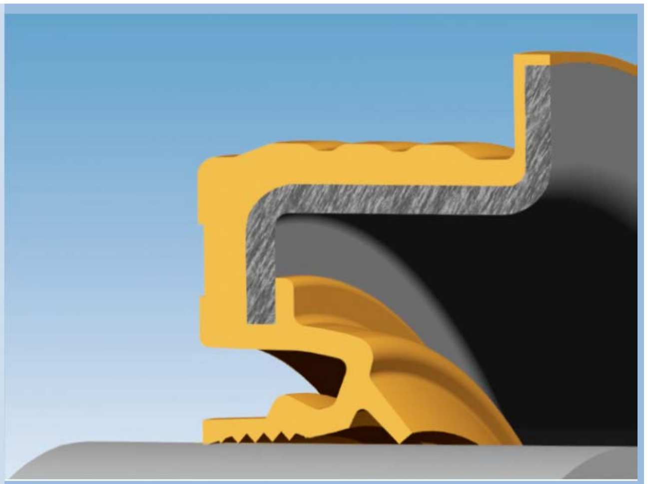
Freudenberg
Sealing Technologies

ESS® Radial Lip Seal Technology Answers CO_2 Reduction and Fuel Economy Challenges



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Abstract

- **Awareness on the impact of emissions from ICE powered automobiles is increasing and is leading to new legislation aimed at progressively improving overall vehicle performance.**
- **Automakers and suppliers have been closely collaborating to implement technologies that decrease overall emissions and improve vehicle efficiency.**
- **Various technological advances have been made in the engine to optimize combustion, advantageously utilize gas recirculation and charging. One other area of interest has been reduction of friction between moving components.**
- **In particular, innovation in rotational and reciprocating sealing systems has led to designs that significantly reduce the power requirements.**
- **Currently used sealing technologies while providing with a satisfactory function, introduce frictional losses, which sometimes could be quite significant. Yet, there is only so much room for the friction minimization of existing designs without degrading the sealing performance.**
- **ESS® seals utilize sealing mechanism different from the standard sprung rotary shaft seals allowing further friction reduction. They do not employ springs thus reducing radial load and therefore friction and wear.**
- **Multiple challenges related to performance and durability have all been successfully addressed with ESS® sealing technology.**
- **This technology was proven to be flexible enough to evolve in response to new challenges being introduced by evolving ICE engine**

Factors Driving Automobile Evolution

- **Population growth**
- **Climate change**
- **Fuel cost**
- **Globalization of the world economy**
- **Competitive pressure**
- **Commodities price and availability**
- **Public acceptance**
- **Governments regulations**
  - CARB, EPA,UN/ECE, LEV and ZEV programs

Factors Influencing Dynamic Sealing

Market Pressures

- Reduction of CO_2 and other noxious gas emissions
- Reduction in fuel consumption
- Reduction in cost of ownership
- Global customer base
- Increase in warranty (in some cases – life time)
- Increase in comfort: NVH
- Increase in safety

Automobile Evolution

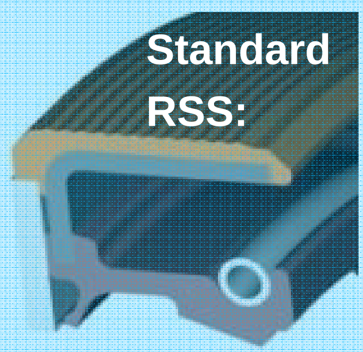
- Increase in engine efficiency
  - Higher engine temperature
  - Increased engine RPM
  - Use of turbo / super chargers
  - Start and stop systems
  - Cylinder deactivation
  - Hybridization
- Increase in vehicle efficiency
  - Low friction drivelines, transmissions, wheel bearings
  - Vehicle electrification
  - Reduction in vehicle weight
- Global vehicle platforms
- Reduction in engine noise
- Improvement in NVH

Dynamic Seals must provide reliable function at broader ranges of temperature, pressure, oil aggressiveness, and alignment tolerances.
Reduced friction and lighter weight can come as an additional benefit.

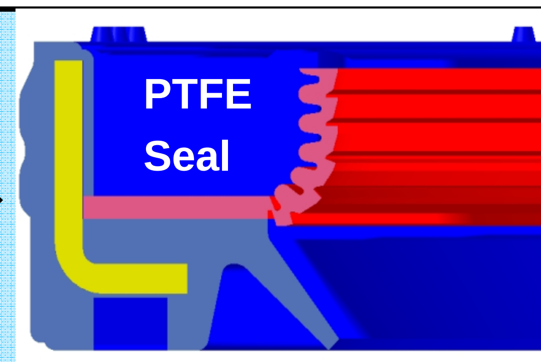
Sealing Industry Development History

Material Evolution

Engine	→	**Silicone Rubber**	→ **ACM**	→ **FKM, PTFE**
Drive Line	→	**NBR**	→ **ACM**	→ **HNBR, AEM, FKM, PTFE**



Seal Design Evolution →



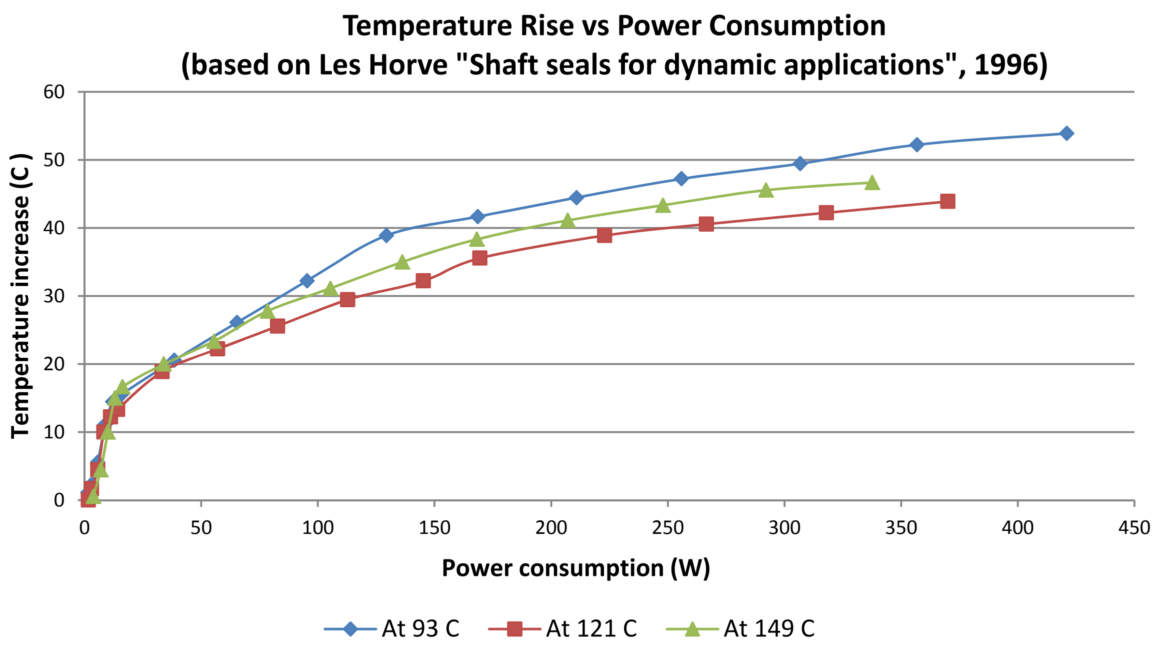
Seal material evolution was driven by increased temperature and oil aggressiveness. The progress has become incremental and approaching material limit in recent years. Seal design evolved to accommodate new materials

Seal Friction

- **Seal performance critically depends on the seal temperature**

$$T_{seal} = T_{application} + T_{underlip}$$

- **Under lip temperature rise $T_{underlip}$ is a function of the frictional heat**



Design and material evolution of dynamic seals is driven by the requirement to reduce seal temperature, and therefore the seal friction

Ways For Seal Friction Reduction

Seal Friction Force = COF x Radial Load

- **Coefficient of friction reduction**
  - Rubber compound optimization
  - Friction reducing coating
  - Design change to improve lubrication
- **Radial load reduction**
  - Design change to reduce radial load (i.e. preformed PTFE seal)
  - Elimination of spring with subsequent improvement to rubber stress relaxation properties
- **Optimization of lubricants**

Friction Reduction is Achieved by Design and Material Change

Why Dynamic Seal Seals

For Static Sealing

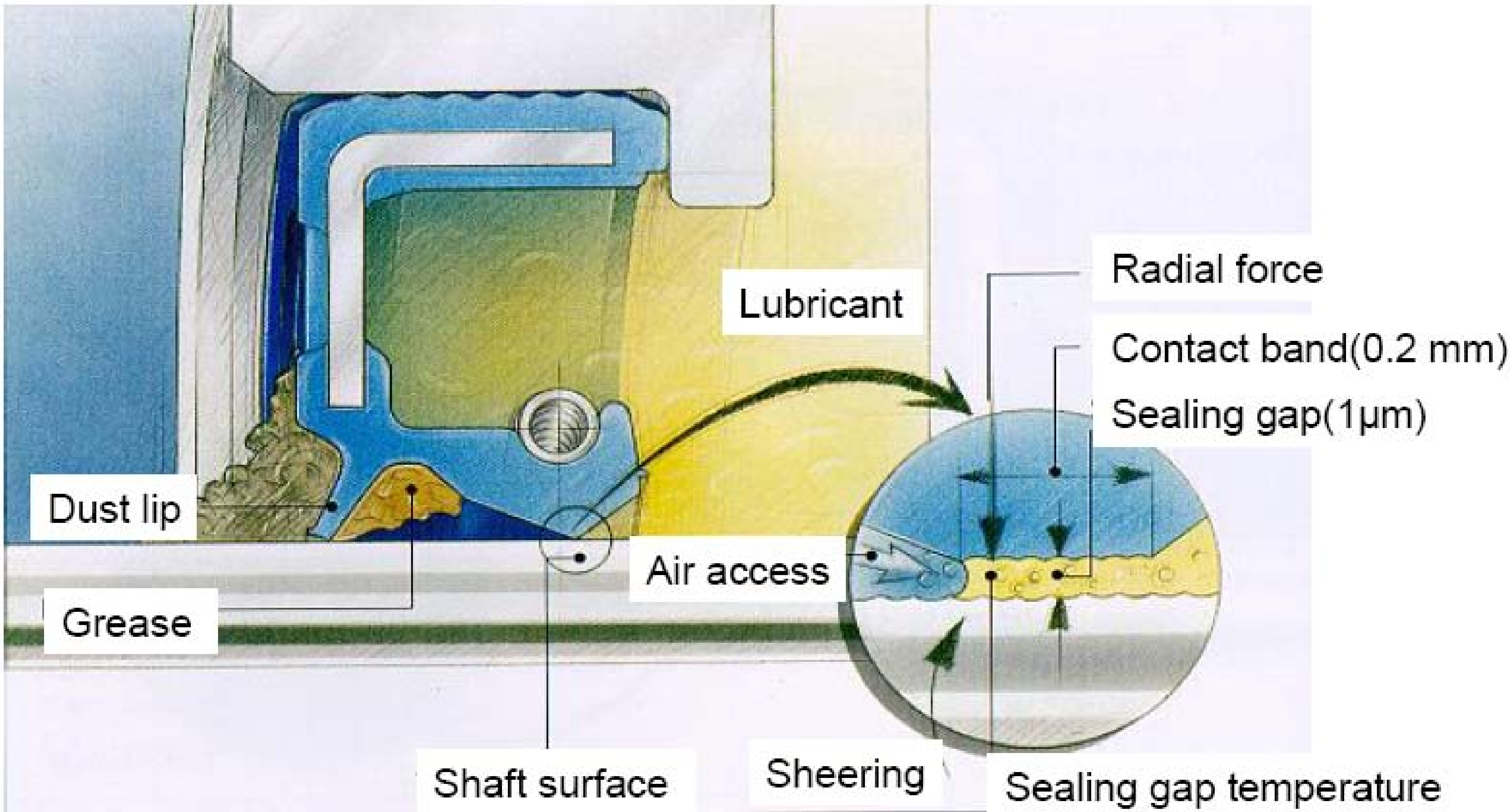
Contact Pressure And Capillary Pressure	>	Fluid Pressure

For Dynamic Sealing a lubricating film has to form between contacting surfaces to eliminate excessive wear and

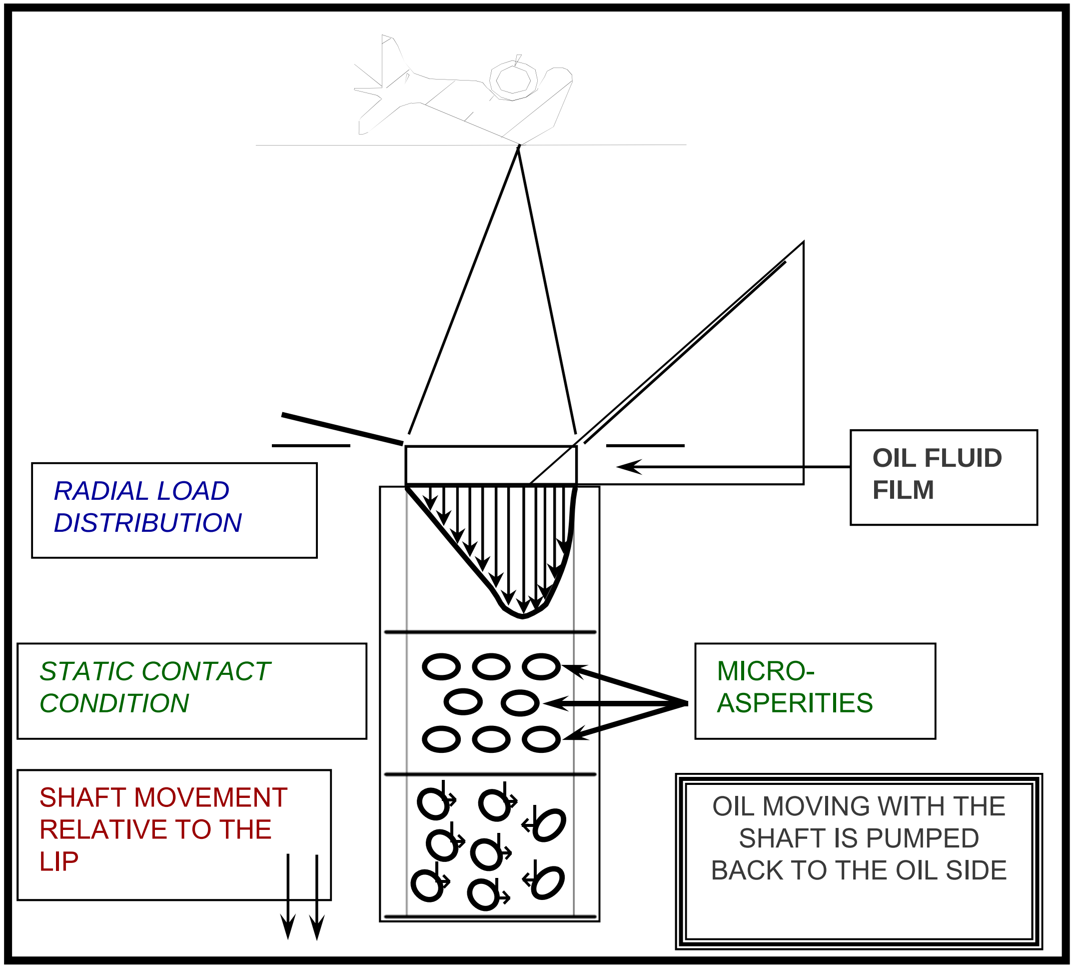
Reverse Pumping	>	Leakage Rate Potential

Both sets of conditions must be satisfied uniformly around the shaft circumference in the full range of required environmental conditions, geometric constraints, and shaft speeds

How Standard Lip Seal Works

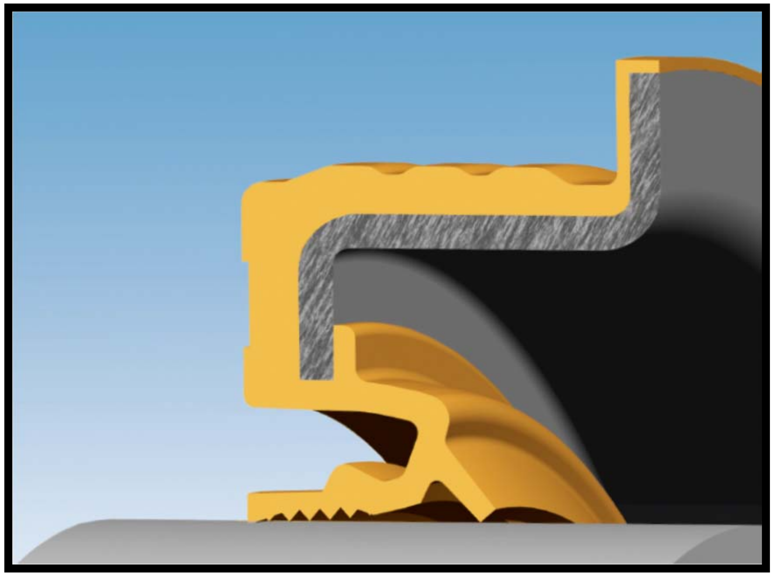


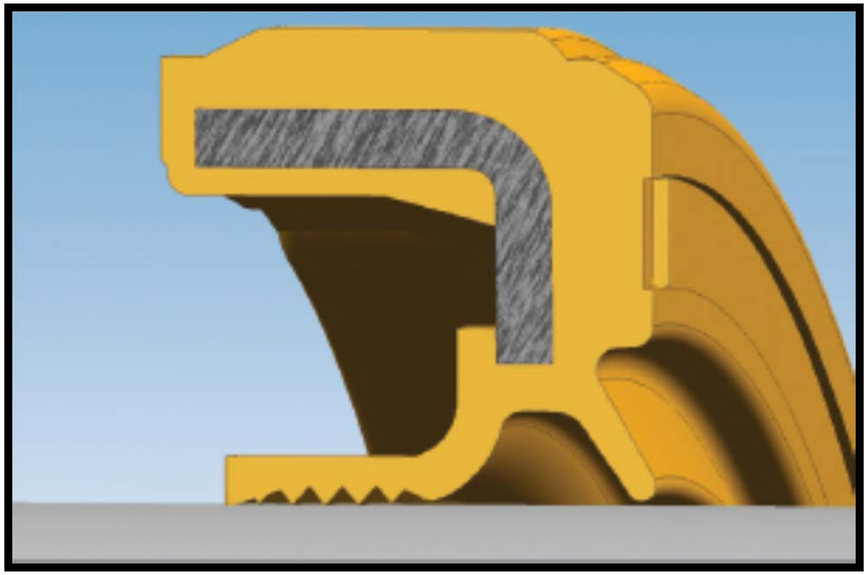
Sealing Mechanism – Micro Asperities



There is a Limit to Friction Reduction in Standard Seals

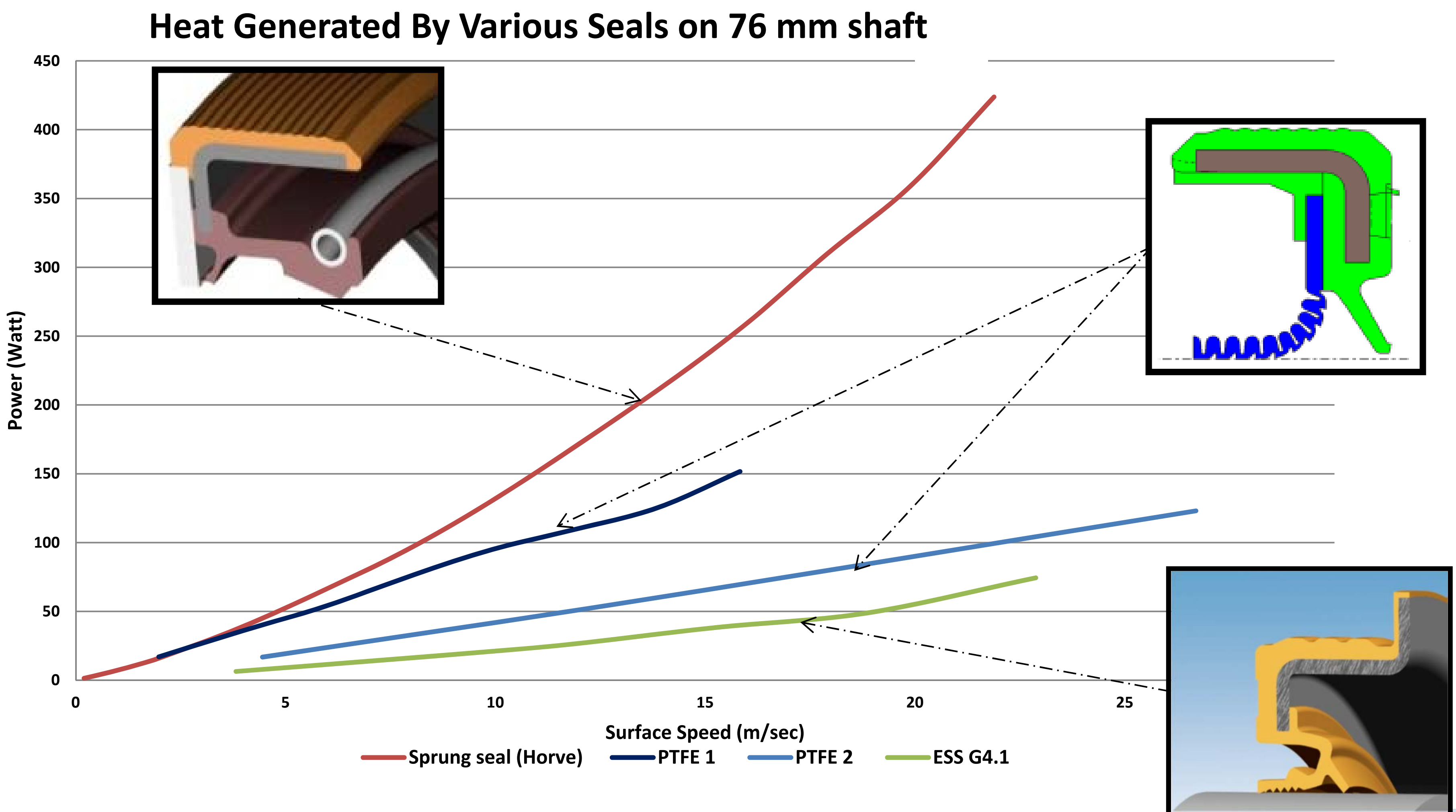
ESS® Seal Design Enhances Performance





- **Significantly reduces friction between the seal lip and the shaft.**
  - **Reduces power consumption, improving fuel economy and CO_2 emission**
  - **Lowers seal lip temperature thus virtually eliminates coked oil failure mode and reduces heat aging (hardening) of rubber**
- **Maintains sealing at high shaft misalignments (0.5 mm DRO & 1.25 mm STBM)**
- **Can eliminate air leakage at engine assembly plants without use of special lubricants.**

ESS® Seal vs. Other Sealing Technologies



ESS® vs. Other Sealing Technologies

Seal Design, 93 mm Shaft	Power @ 2500 rpm (Watts)	30% Engine Efficiency (gal/hr)	Gallons of Gas Used By 1 Seal After 3,000 Hours	Pounds of CO2 Emitted After 3,000 Hours
Energy Saving Seal	19.5	0.00185	5.35	107
PTFE 1 / 2	95.3 / 47.4	0.00905 / 0.004503	25.92 / 12.89	518.4 / 259.5
Sprung FKM Lip Seal (Horve)	131	0.012445	37.3	746.7

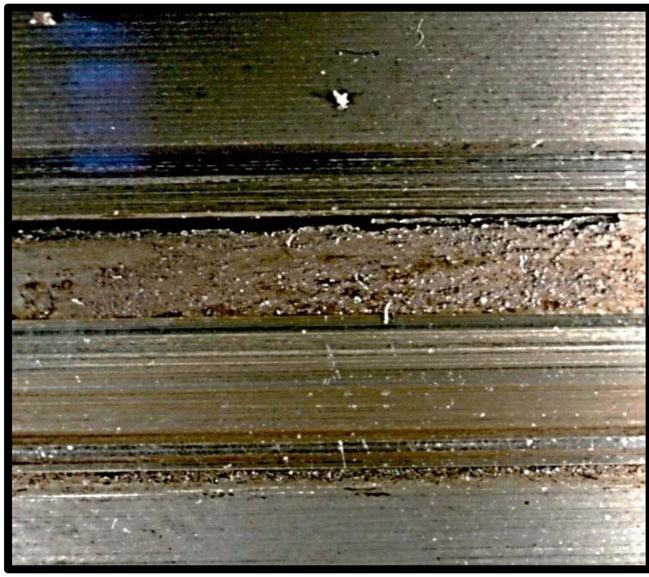
- **ESS® seal design enhances sealing performance and provides significant reduction of friction between the seal lip and crankshaft**
- **In life time approximately 30 million gallons of gas saved, with an equivalent reduction of 300,000 tons of CO_2 per 1 million engines**

Seal Radial Load

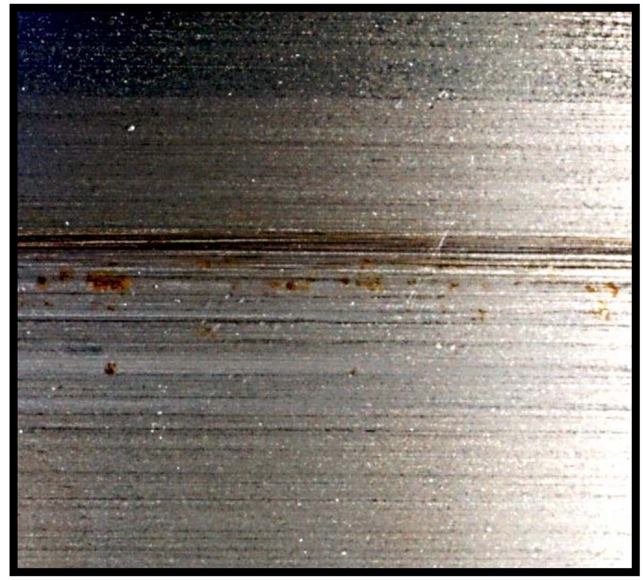
	FKM w/ Sprung Lip	PTFE	ESS®
Minimum Radial Load (N)	15	45	5
Maximum Radial Load (N)	35	100	15

Energy Saving Seal technology applies the lowest radial load on the crankshaft of all available seal designs, while still providing sufficient sealing capability.

Shaft Wear



More than10 µm grooving on HRB 95 shaft after 2300 hour of durability of PTFE seal

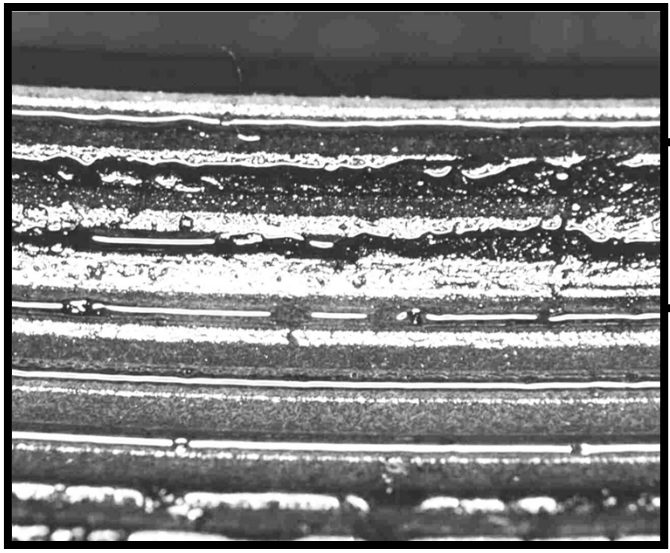


- Less than 1 um grooving on HRB 95 shaft after 2300 hour of durability testing of ESS® seal

Low radial load virtually eliminates wear even of low hardness shafts

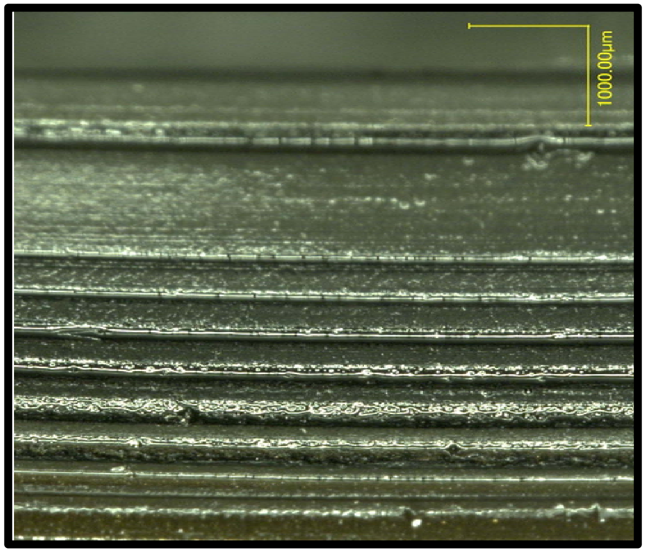
Low Radial Load Leads To Reduced Lip Temperature

Oil Side



Oil coking build up on PTFE spiral grooves at end of durability testing

Oil Side



No oil coking build up in ESS spiral grooves at end of durability testing

The ESS® design virtually eliminates coked oil failure mode

Improved Follow Ability

1st Gen PTFE Seal (FNGP) – 44.77 mm shaft.

DRO (TIR) \ STBM (TIR)	0	0.25 mm	0.5 mm	0.635 mm	0.75 mm	1.016 mm	1.27 mm
0	N/L						
0.25 mm		N/L					N/L
0.5 mm			N/L			N/L	
0.635 mm				N/L			
1.016 mm	Wet @5000	Wet @ 4000	Wet @ 4000	Leaks	Leaks	Leaks	Leaks

ESS Seal (FNGP) – 44.77 mm shaft.

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0	N/L						
0.25 mm		N/L					N/L
0.5 mm			N/L			N/L	
0.635 mm				N/L			
1.016 mm	N/L	N/L	N/L	N/L	N/L	N/L	N/L

Seal Robustness

Test Name \ Test Parameters	Required (hrs)	DRO (mm)	STBM (mm)	Max Oil Temp. (C)	Max Speed (m/sec)	Max Pressure (kPa)	Max Vacuum (kPa)
Durability	2016	0.2	0.5	135	36	4	4
Dust	480	0.2	0.5	140	24	0	0
Slurry	96	0.2	0.5	150	24	0	0

Other Requirements

- Air Leakage and Pumping
- Oil Specification

ESS® Seals are Robust Against All DV Testing

Design Validation ≠ Application Conditions

Risks

- **Unrecognized application conditions**
  - Shaft defects and hardness have lesser effect on ESS® seal than on a standard seal
  - Contamination on the shaft or the seal is a lesser factor for standard seals than for ESS® seals
- **Changing application conditions**
  - Broader use of turbo and super chargers produced crankcase vacuum at levels significantly higher than in free aspirating engines. The first iteration of ESS® seals having lower radial load showed susceptibility for the main lip lift off and consequent noise. Standard seals are less susceptible to vacuum
  - New technologies, such as cylinder deactivation create pressure spikes all seals are vulnerable to. Although, ESS® seals are less sensitive to higher pressure than standard seal, certain measures need to be taken to prevent lip inversion under pressure
- **Only limited number of DV testing is practical, therefore some hidden failures can still not be recognized**
- **DV testing exaggerates real application conditions thus shifts failure modes**

Supplement DV Testing with Failure Mode Testing

New ESS® Technologies Invented, Developed, and Validated by FNST

Air Pumping Reduction

- "Edge Band" pumping feature addresses air pumping issue. For a limited time the seal can work even if the shaft changes the direction of rotation

External / Assembly Contaminants

- "Mid Lip Band" design prevents contaminants from disrupting seal performance
- "Four Bar" design not only prevents contaminants from disrupting seal performance but also lowers air pumping since it combines an "Edge Band" feature

Pressure Inversion Preventer

- Multiple design variants were invented to extend pressure range of G4.1 seal design

Vacuum Noise Elimination

- FNST developed and validated three new ESS® designs solving the noise problem

COF reduction

- FNST invented, developed, and validated new pumping feature further reducing COF of ESS® seals

ESS design concept was proven flexible enough to solve all currently recognized sealing challenges

Thank you for listening