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IMPROVE LIP SEAL PERFORMANCE AND INCREASE SAND RESISTANCE WITH A LOW-COST GRAPHITE SHAFT COATING

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ABSTRACT

Lip seals are vital components that serve two primary purposes – keep liquids/lubricants in and keep sand/contaminants out. An additional task is to confine pressure. Test study results indicate that self-polishing Additive Abradable Graphite Coatings (AAGC's) will protect sealed rotating components from sand, and extend lubricant maintenance interval on gearboxes, PTO's, and the like.

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1. INTRODUCTION

There are over 100,000 trucks of various configurations in all branches of the US military, and more than twice as many light armored and combat vehicles. All of these vehicles use multiple radial shaft seals to contain lubricants and prevent contaminants from mixing in.

The military often operates in places with especially challenging environmental conditions, where sand, dust, saltwater and temperature extremes increase the challenges and criticality of maintaining proper sealing of gear cases, engines, blowers, pumps and other equipment. Penetration of foreign materials and/or water into sealed areas degrades the life of internal components via wear and corrosion modes.

Despite advanced sealing technologies for shaft sealing, sand and water penetrate in the field and damage components. One measure to improve life of equipment despite poor sealing is to change the lubricant often. Contaminants and wear debris are flushed away with the used lubricant fluid. Fresh lubricant provides safe operation of the equipment, but only until seals are breached again. This process is extremely costly due to consumables, manpower, parts and downtime.

A huge reduction in sustainment costs related to seal failure will occur if a low cost retrofit-able sealing improvement solution was available. Retrofitting such a solution during normal service cycles would provide a quick payback with expected savings from longer Time Between Overhauls (TBO) and service life of equipment.

Better sealing systems would improve readiness and generate huge operational savings through extended service intervals, reduced lubricant consumption, less logistical burden on all military vehicle fleets including amphibious, tactical, and combat vehicles. These benefits would extend to Maritime, and aviation applications stand to benefit from Abradable Powder Coating technology as well. Overall readiness and sustainability efforts would benefit hugely, allowing focus on other systems.

If shaft seals were breached 90% less by sand, component wear rates and sand related field failures would drop and service intervals could be extended. Resources would be freed up for all warfighters who are operating in sandy or amphibious environments.

Such an improvement could be applied to a range of equipment including, but not limited to, compressors, blowers, pumps, turbines and indeed most devices that have a rotating shaft seal. "Other applications under a wide range of operating conditions. These conditions can vary from high-speed shaft rotation with light oil mist to low speed reciprocating shaft in muddy environments. Radial lip seals can be found sealing lube oil in high speed crankshaft applications for gasoline and diesel engines that operate from the tropics to the arctic, in submarines, oil tankers, spacecraft, windmills, steel mills, paper mills, refineries, farm tractors, appliances and automobiles. In fact, they can be found in anything that has a rotating shaft." [1]

From small engines to enormous systems, an order of magnitude improvement in seal performance would increase readiness and cut sustainment costs for military including applications from desert action to long storage intervals.

A novel use of Additive Abradable Graphite Coatings (AAGC's) holds promise to deliver major improvements in sealing with low cost and without mechanical risk to shafts, seals, lubricants or internal components. This paper details the test apparatus, conditions, and results of simple rotating seal testing. Testing was done under a number of conditions which are detailed later.

The findings of this brief study represent improvement potential for many of the challenges in sealing outlined in "Parker Rotary Shaft Seal Design.[1]" This reference describes a broad array of sealing challenges, illustrates many seal designs, and the required designs and materials to make robust seals. Despite the vast innovations in sealing, sealing remains a problem and plays a key roll in the service life of most mechanical equipment. AAGC Seal Seat Technology would likely benefit many of the designs based on this work.

The following observations were made based on the data presented. AAGC lip seal seats on shaft exhibited a groove bedded into the thick coating after operation. The benefits of the AAGC, Shaft Seal Seat include:

1. able to retro-fit into most equipment; 2. after wear-in, graphite coating supports the edges of the seal; 3. keeps the seal true in pressure excursions; 4. keeps sand away from the active sealing interface; 5. extends the labyrinth seal to limit access of external fluid to the active sealing interface; 6. seals pressure and vacuum better; 7. reduces effective shaft runout by wearing unevenly towards centerline of seal.

Additionally, AAGC's soak up oil and hold it in pores and grains of the coating to insure adequate lubrication at the seal-shaft contact interface. One could expect that this characteristic would reduce dry start problems, especially after long periods of vehicle storage.

The process is cost effective for high volume manufacturing applications and can be done in a retrofit mode to all types of shafts. It involves surface preparation, powder coating, and heating to lock in the properties of the graphite coating. An entire coating operation can be housed in a 40-foot shipping container, making deployment quick and easy.

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2. PROBLEM STATEMENT

Shaft seals are critical components in most mechanical systems, and represent a key factor in the service life of equipment. They hold clean lubricants and gasses in. They keep dirt, sand and water out. Without robust seal performance, any field device will suffer reduced readiness, poor reliability, and elevated sustainment cost due to short TBO's (Time Between Overhaul).

Penetration of sand into the sealing area causes shaft wear, degrading shaft strength and opening leak paths prematurely. Sand which reaches internal components can cause extreme wear damage, and even short-term catastrophic failures.

Sealing fluids in and keeping contaminants out is more challenging when pressure differentials occur between the inside and outside of the case, since lubricant can be pumped out and dirt and contaminants are pulled in. Temperature extremes and vibrations further exacerbates the difficulties of maintaining a seal.

Multi-lip seal designs, advanced seal materials, and creative geometric features are employed to improve seals. Increasing interference can improve sealing, tight seals generate more heat and may not be durable. There is a limit on tightness between the shaft and the lip seal, because high lip load can also create a groove.

Seal failures and premature degradation of equipment are common field issues and drive maintenance costs up for all types of equipment.

Fig. 1: Power transmission unit scrapped after seal failure

A common failure mode is migration of fluids across the seals, after which sealed components are not protected. Bearings depend on clean, moisture free lubricant, and most equipment requires a specific lubricant level for optimal operation and life.

Figure 2a shows milky lubricant which has been emusified with water near and at the seal to shaft interface during testing vacuum and pressure cycles.

Fig. 2a: White ring around seal signifies water and oil mixing

Lubricant leaks detrimentally entrap dust and sand to the fragile seal-shaft interface areas. Figure 2b shows an example of leaked lubricacnt collecting sand at and probably under the seal. This process grinds sand particles to finer sizes and increases the likelihood of gear case penetration of abrasive bodies.

Fig. 2b: Darker shaded sand shows that seal is leaking with uncoated shaft

Lubrication also has an effect on a seal's lifespan. Insufficient lubrication between the seal and shaft, and the seal becomes hot and less flexible. Leakage can occur where the seal is no longer able to follow the shaft. Improper shaft finish or dry start-ups can also contribute to excessive heat, seal and shaft wear.

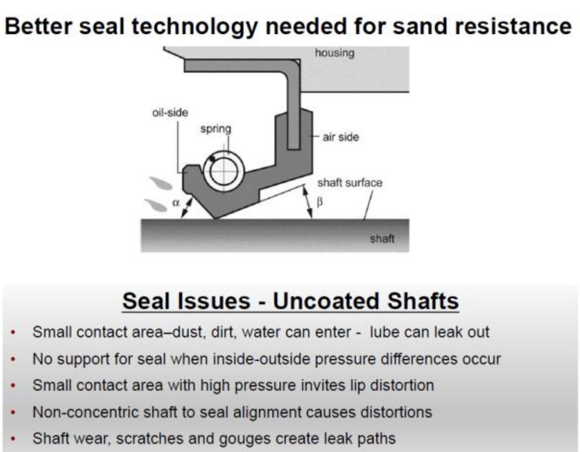

Fig. 3a: Common seal design issues

3. SOLUTION

AAGC's offer a safe, reliable, low cost method of improving sealing performance and life, and requires no change to the existing seal and shaft designs. A thick, graphite-based coating is applied in a patch where the lip seal seats on the shaft. Approximately 10 mm ring of AAGC coating is applied to the shaft in the area where the seal will contact. The soft coating is applied approximately 100-150 microns thick, and it is heavily loaded with graphite and other solid lubricants.

Upon assembly and initial operation, the lip seal beds into the softer coating, effectively forming a permanently lubricated groove in the graphite coating. The walls of the groove mirror the seat shape and provide support to the seal while extending the contact point to form a labyrinth seal.

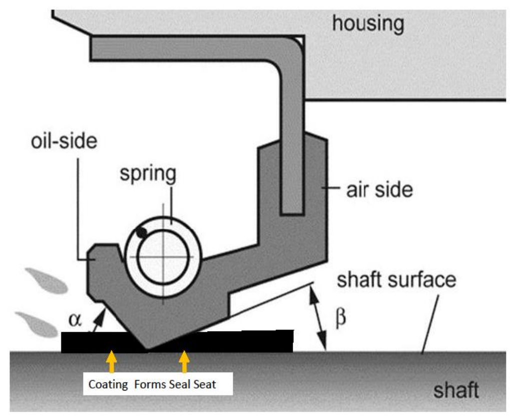

Fig. 3b: Shaft coated with AAGC to form an abradable seal seat

Figure 4 shows an example of the pattern worn into the abradable seal seat. Notice the discrete features in the worn AAGC seat material according to the exact contact pattern. More importantly, after wear-in a thick edge of graphite serves as guide ring to support the seal in pressure, vacuum, and fluid surging and turbulence conditions. The edge also forms an additional labyrinth seal to keep contamination away from the active seal interface. The AAGC material absorbs oil and holds it in porosity, so the seal to shaft interface maintains lubrication. Stored equipment could benefit by avoiding dirt accumulation and dry start-ups. Notice the oil sheen on the lipophilic, or ‘oil-loving’ graphite coating.

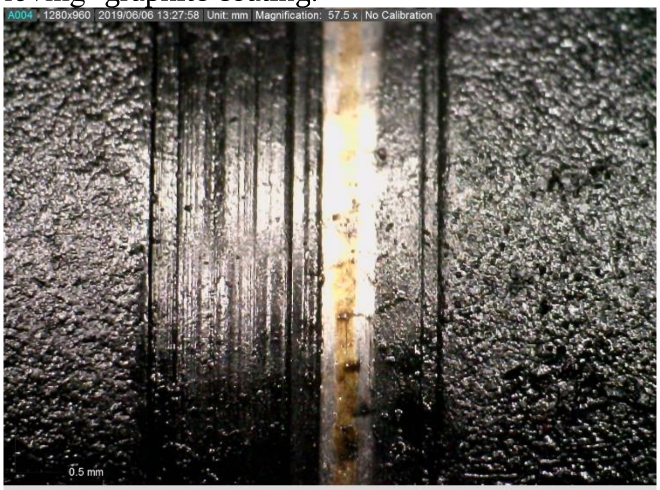

Fig. 4: Seal profile worn into AAGC seal seat material.

4. RADIAL LIP SEAL TESTING

The objective of this work was to conduct preliminary quantitative rig testing evaluations on a simple seal design in order to measure the effect of an Abradable Graphite Seal Seat on seal performance and life.

A seal testing rig was constructed to subject the seals to alternating sand and water during repetitive cycles of pressure/vacuum, in heat/cold and with/without vibration from a pneumatic vibrator which measured at 3-4 m/sec^2 on the face of the chamber cover. Instrumentation was configured to measure lubricant level, temperature, pressure, and vacuum. New synthetic 5W-30 engine oil was added at the start of each test after thorough cleaning of the chamber.

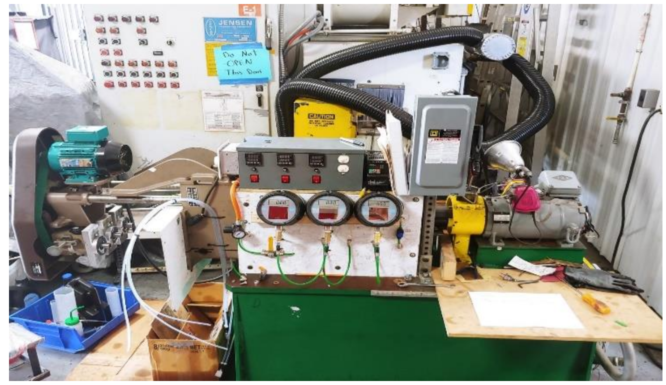

Fig. 5: Oil seal test rig

Fig. 6: Seal Test Chamber- heat, cold, pressure, vacuum, vibration, sand, water conditions controlled

A .875” nitrile single lip seal with an SZ design including a garter spring was chosen as a simple, common seal.

Seal Specifications per Manufacturer:

Seal Type – SZ single lip seal (as in Fig. 7)
Nitrile material
Maximum Runout = .008”
Maximum Temperature = 225ºF
Pressure limit = 7PSI
Shaft speed = 5.47ft/s (166.7 ft/sec)
Shaft roughness

- Ra = 10-20 micro inches
- Rz = 80-120 micro inches

Steel spindles of .875” OD were machined and runout was checked and normalized during all tests. As machined, the ground spindles had surface profile of Ra = 7.6 uin. The coated spindles had a 4-mil thickness (0.008” diametric increase) of AAGC applied the length of the spindle so multiple tests could be done on each.

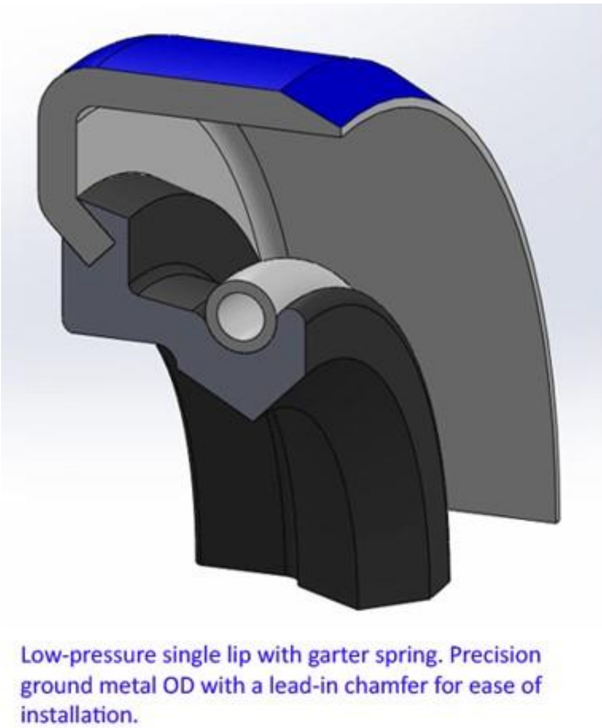

Fig. 7: Cross section of Type SZ Seal

Fig. 8: Uncoated and coated spindles next to .875” SZ seal

A test matrix was developed that would run both coated and uncoated spindles through identical conditions of pressure and vacuum while being subjected to sand and water exposure. Table 1 lists the experimental conditions done on 12 runs for each seal.

Table 1 – Experimental Run Conditions Matrix

Run Number	Temperature (°F)	Tip Speed (cm/s)	Vibration
R1	100	41	No
R2	100	165	No
R3	250	41	No
R4	250	165	No
R5	100	41	Yes
R6	100	165	Yes
R7	250	41	Yes
R8	250	165	Yes
R9	0	41	No
R10	0	165	No
R11	0	41	Yes
R12	0	165	Yes

- Each run includes 4 cycles. Each cycle includes 3 minutes of pressure and 3 minutes of vacuum, with Sand and Water exposure
- Pulsed streams of water were sprayed with a plant mister squirt bottle aimed directly at

the seal at 30 sec, 90 sec and 150 sec into each 3 minute pressure or vacuum cycle. At the 60 sec and 120 sec mark in each cycle, 50 ml of playsand was poured into a funnel and through a tube which directed the sand at the shaft to seal interface.

- Ri is an initial static leak test done on each seal while shaft is in static condition over a 2 minute dwell time.
- Each run condition was repeated for 3 seals with coated shafts and 3 seals with uncoated shafts.
- The methodology allows for direct performance and life comparison of a basic seal operating on an uncoated shaft versus an identical shaft with 100 microns (radial) of AAGC in the seal seat area.

5. RESULTS and DISCUSSION

Figures 9a and 9b show that spindles with AAGC Seal Seats had much lower leak rates under pressure and vacuum conditions than uncoated shafts. Taller bars mean higher leak rates. AAGC Seal Seats made a remarkable improvement in this study.

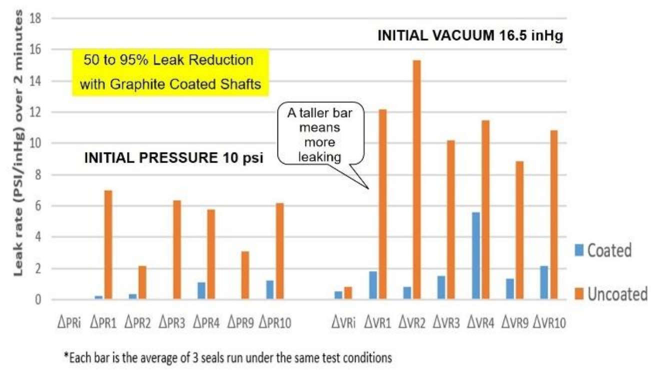

Fig. 9a: 2-minute vacuum/pressure drop results for runs Without Vibration

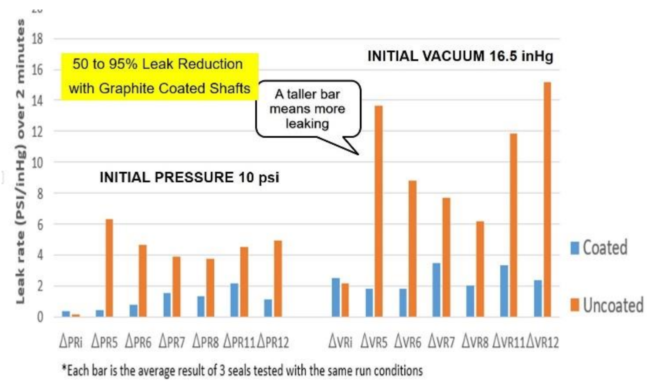

Fig. 9b: 2 minute vacuum/pressure drop results for runs With Vibration

Figures 10a and 10b show the amount of sand which was collected inside the seal and in the oil after Run R2 for the uncoated and AAGC coated shafts respectively. R2 results were typical of the other runs and were arbitrarily chosen for presentation here. The red arrow points to white sand that penetrated the seal on the uncoated spindle.

Fig. 10a: Uncoated shaft – sand gets in

Fig. 10b: Coated shaft – sand stays out

The coated spindle prevented all but a few grains from getting past the seal.

Water was also sprayed onto the seal during each cycle. At the end of each cycle, the case oil was checked and changed. Figures 11a and 11b illustrate case oil quality after Test Segment R2.

The uncoated spindle allowed severe deterioration of the oil in the because water passed the seal and emulsified with the oil (Fig. 11a). The lubricating properties of the oil are quickly lost when water mixes in, so internal components face high wear and corrosion from seal leaks.

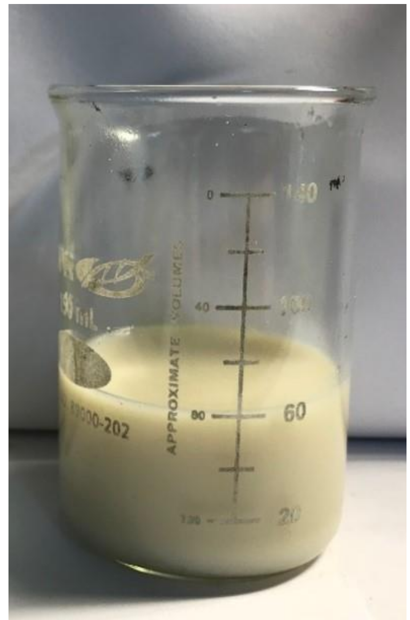

Fig. 11a: Milky oil indicates water emulsified into the oil. This will ruin engines and other equipment quickly.

The oil in the AAGC Seal Seat runs remained clean because very little water can access the active seal zone or penetrate it, even under vacuum.

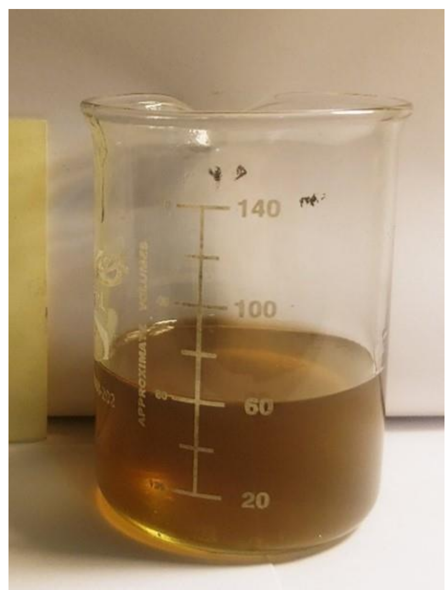

Fig. 11b: Clear oil shows that Graphite Seal Seat prevents water penetration

Dry Ice was packed around the test chamber to simulate cold environment for runs R9-R12. The cooling power was limited. During tests, oil temperature was directly measured to be nominally 0 ºF.

Figures 12a and 12b photos shows order of magnitude change in water penetration and formation of ice in the test chamber after R12 for an uncoated shaft and a AAGC Seat Seal shaft repectively.

Fig. 11a: Box filled with long ice crystals after uncoated shaft test (R12)

Fig. 11b: Box chamber had minimal ice slush after coated shaft test (R12)

6. CONCLUSIONS

For a simple SZ nitrile seal, these tests indicate that the presence of an AAGC Seal Seat coated onto the shaft, yielded dramatic sealing improvements including:

1. keeping sand out,
2. reducing air, water and oil leak rates by 50-95% under pressure and vacuum
3. preserving oil quality
4. improving sealing in cold, mild and hot conditions
5. improving sealing with and without vibration

These results indicate that the Army could enjoy significant improvements in readiness by utilizing AAGP Shaft Seal Seats in vehicles and auxiliary equipment. There is also a huge potential for cost avoidance related to sustainment, operation, and extended service life of a wide variety of mechanical equipment. AAGC Seal Seat coatings can be retrofitted (at depots for example) into many if not most rotary shaft seal applications during scheduled service with this low cost technology.

Simple addition of the seats onto shafts, with other design changes required would enable significant and cost-effective sealing improvements in many seal applications.

Recommended Next Steps:
Case Study for Cost Avoidance Model.
Temperature Chamber Equipment Testing.
Vehicle field testing.

References

1. Parker Rotary Seal Design Guide https://www.parker.com/literature/Engineered%20Polymer%20Systems/5350.pdf