Achates Power Opposed-Piston Engine Oil Consumption & Durability Results

The Achates Power opposed-piston (OP) engine has demonstrated important fuel efficiency benefits while achieving ultralow emissions. Competitive oil consumption and durability must also be proven for commercial acceptance.

When it comes to durability, the OP engine starts with some advantages. Cylinder heads, head gaskets, and exhaust valves are the most common sources of mechanical failure in conventional four stroke engines. None of these components are present in OP engines.

Achates Power has developed designs and coorelated analytical tools that enable excellent durability with competitive oil consumption. This paper outlines some of the mechanical design considerations, along with results of accelerated life durability tests includng a 500 hour durability test that was completed with no performance loss, no measurable ring/bore wear and no increase in oil consumption.

Summary

- Achates Power's Opposed-Piston engine demonstrated oil consumption similar to that of conventional four-stroke engines
- OP engine architecture low oil consumption enabling features:
    - Separate oil crankcase from fresh air
    - Less cylinder thermal distortion ensuring proper contact of oil control rings
    - Less interaction of hot combustion gases with engine oil preventing evaporation or contamination
- Initial 500-hour durability tests suggest low oil consumption and durable power cylinder hardware can be achieved for the OP engine

Cylinder Hone Texture

The cylinder hone texture is critical for retaining oil on the cylinder wall and maintaining engine durability. Increased retention, however, generally leads to increased oil consumption. Working extensively with development partners and utilizing modern honing process capabilities, Achates Power has developed a unique hone texture & form that selectively retains oil where needed to provide controlled lubrication, enabling reduced oil consumption alongside increased durability.

Unique OP Engine Architecture

The Achates Power OP architecture is shown in Figure 1, which utilizes four piston rings, two compression (located at the top of the piston) and two oil control (located at the bottom of the piston). The compression piston rings transit the ports as the pistons

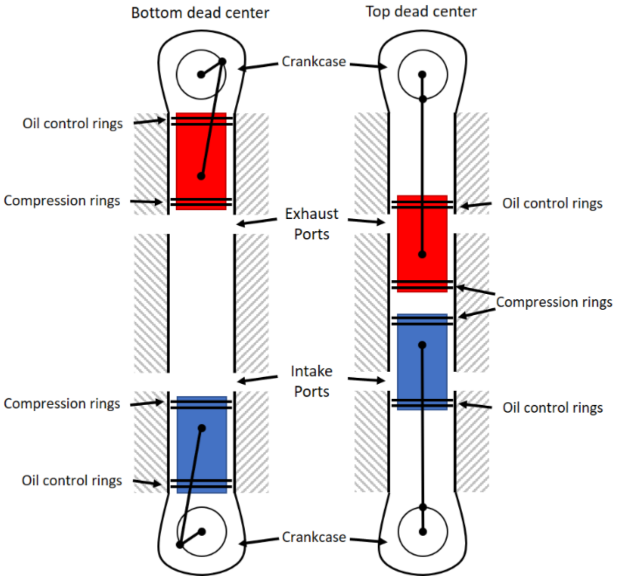

Figure 1: OP engine schematic at bottom dead center and top dead center, not to scale

open and close the intake and exhaust ports while the oil control rings always remain below the ports. This unique configuration has a few advantages.

separate lubrication circuit

First, the closed crankcase scavenging prevents mixing crank oil with fresh air and eliminates the oil consumption mechanism that traditionally plagued two-stroke engines. Rather, oil is circulated in a separate lubrication circuit, like most four-stroke engines.

Oil Control Rings Seal Oil from Manifolds

Second, the oil control rings prevent crankcase oil from escaping into the ports. The oil control rings remain outside the ports, sealing the crank-case from the ports and manifolds.

Reduced Thermal Distortion of Oil Control Rings

Third is lower cylinder thermal distortion. In internal combustion engines, the heat generated by combustion is either extracted as power, vented to exhaust, or lost to coolant and oil. The heat transfer occurring through the cylinder walls causes thermal deformation, which can vary radially and along the length of the cylinder. If the cylinder is exposed to high thermal distortion, it may be difficult to maintain proper contact of the piston rings to the walls. This could lead to high blow by of the trapped cylinder mass, poor oil control from the crankcase to the combustion chamber, and challenges with cylinder kit durability.

In OP engines, the cylinder wall where the oil control rings operate experiences less thermal distortion because combustion is located much further away from where the oil control rings operate and because the hot exhaust gases escape through the ports prior to interacting with the oil control ring running zone as shown in Figure 2. The lower thermal distortion helps the oil rings conform to the bore surface for a given ring tension, improving the oil consumption vs. friction tradeoff. Conventional four-stroke engines have oil control rings immediately adjacent the compression rings & direct proximity to combustion chamber, which operate in a hotter environment that is more prone to greater thermal distortion near the cylinder head.

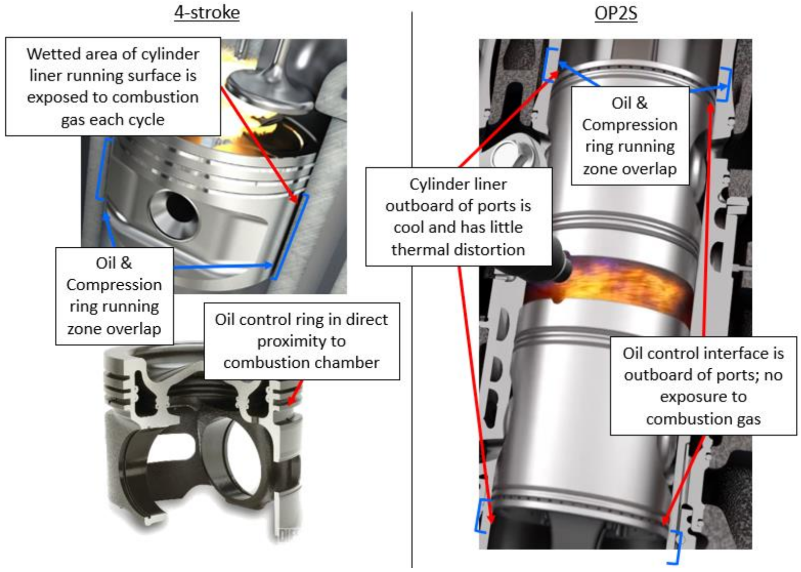

Figure 2: Cross section of conventional four-stroke and OP engine oil and compression ring running zone overlap

The oil ring configuration of an OP engine also reduces the interaction between hot exhaust gases and the oil control ring because the running zone overlap between the oil rings and compression rings are minimized. Reducing the exposure of hot gases to oil minimizes evaporative losses.

Methodology:

A Da Vinci Lubricant Oil Consumption (DALOC) analyzer is used to measure oil consumption real-time through sulfur trace methodology. A 13-mode test was performed on a single-cylinder medium-duty engine equipped with a low oil consumption power cylinder kit. In addition, a 500-hour accelerated durability test was conducted on a 4.9L three-cylinder version of the single-cylinder engine. Commonly available lubricants were used.

Results:

The fuel specific oil consumption[1] (FSOC) for the single-cylinder experiment is shown in Figure 3. In general, the FSOC is below 0.05% for most speeds and loads with a cycle-weighted average of 0.04%. Oil consumption generally increased with load. The results are very competitive compared to four-stroke engines.

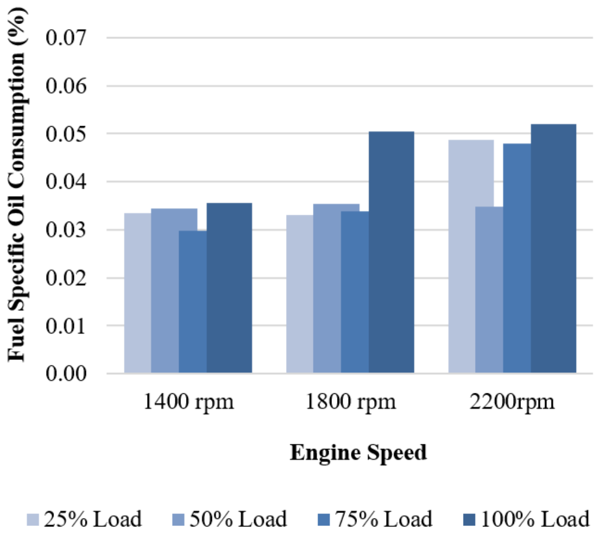

Figure 3: Fuel specific oil consumption for 1.6L single-cylinder OP engine

The 500-hour test was designed to put high stress on the engine to accelerate evidence of wear. The average load over the 500 hours was 81% of peak load. A ten-hour cycle was repeated 50 times and consisted of idle, rated power, mid power, peak torque, and the lowest fuel consumption point (B75 on the SET cycle). After 500-hours, the power cylinders under study experienced zero performance degradation with the engine finishing in good condition. There were not any measurably differences in oil consumption before and after the 500 hour test. These results demonstrate the capability of the OP engine to achieve low oil consumption with durable hardware with good initial durability. While more extensive durability testing must be undertaken for a new OP engine design – as with any new engine design – the results to date provide a good indication that low oil consumption and good durability can be achieved.

Conclusion:

The Achates Power OP engine has previously demonstrated class leading efficiency and emissions, and this paper has demonstrated competitive oil consumption with durable hardware. The fundamental architecture of the OP engine helped solve historical oil consumption challenges on regular two-stroke engines. Design parameters such as cylinder hone, cylinder distortion, piston rings, and piston skirt profiles enabled fuel specific oil consumption

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[1] Fuel Specific Oil Consumption is the ratio of oil consumption to fuel consumption 0.05 – 0.12% FSOC is considered acceptable for a modern commercial vehicle engine.

results below 0.05% while achieving required durability, further increasing the commercial potential of the OP engine architecture.

In addition to the test results reported here, Achates Power has additional experience operating OP engines in an efficient and durable manner. Achates Power has accumulated over 18,000 of run time on its dynamometers across several engine designs. Moreover, Achates Power is working with Cummins on developing the opposed-piston Advanced Combat Engine (ACE) for the U.S. Army. Planned for initial production in 2024, ACE is being developed by Achates Power (San Diego, CA), Cummins (Columbus, IN), and the Army (Warren, MI). Achates Power has developed and demonstrated the capabilities of the OP engines with many other organizations, including: Aramco Services (Novi, MI); Ricardo Engineering (Van Buren Township, MI); the University of Michigan (Ann Arbor, MI); Argonne National Labs (Lemont, IL); Roush Engineering (Livonia, MI); and Peterbilt (Denton, TX).

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