Greater efficiency potential with a rotating liner engine

Researchers are in the final stages of developing a beta prototype.

GREATER EFFICIENCY IN THE FORM OF HIGHER FUEL ECONOMY VALUES are driving the development of new engine oil specification for passenger car motor oils and heavy-duty engine oils as noted in a previous TLT article.[1] The U.S. Government has established a goal of raising the corporate average fuel economy (CAFE) to 54.4 miles per gallon by 2025.

At the same time, research also has been ongoing to develop higher performing engines that can facilitate the movement toward the CAFE goal. Current internal combustion engines only achieve an efficiency of 33%-40% (for gasoline and diesel engines, respectively) due to the loss of energy as heat and friction. The main source of friction has been found to be in the piston assembly.

KEY CONCEPTS

- A rotating liner engine improves upon the conventional internal combustion engine by enabling the cylinder liner to rotate.
- The initial alpha prototype built from a Quad 4 gasoline engine achieved a 40% reduction in internal friction in motoring tests.
- Work is underway to develop a beta prototype based on a Cummins 4BT diesel engine.

One option discussed in a prior TLT article is a new version of the split-cycle engine.[2] The internal combustion engine uses a four-stroke combustion cycle that includes an intake stroke, compression step, combustion phase and a final phase where the exhaust and spent fuel cylinder leaves the cylinder.

The split-cycle engine contains two sets of paired cylinders connected by a crossover passage. One set takes care of the compression step while the second set is responsible for the power phase of the combustion cycle. Fuel efficiency is anticipated to increase between 25% and 30% for this engine, but this may be under ideal conditions. Other engineers believe that the heat loss of the extended duration of the high temperature events may limit significantly the thermodynamic benefit.

In contrast, the rotating liner engine (RLE) retains the four-stroke cycle of the conventional internal combustion engine, and thus maintains the painful thermodynamic optimizations achieved by the traditional engine, with a key improvement. Dimitrios Dardalis, director of technology of Rotating Sleeve Engine Technologies, Inc., in Austin, Texas, says, "The improvement stems from the ability of the cylinder liner to rotate, which enhances the lubrication of the piston rings and skirts, and allows the re-optimization of the piston assembly in order to reach superior mechanical efficiency and wear characteristics over the longer life of the engine."

The RLE is suitable for use in gasoline and diesel engines, but the focus is on diesel engines where the higher cylinder pressures that help improve thermal efficiency also generate more friction loss in the standard engine.

The key benefit for RLE occurs when the piston is near the top of its stroke during the compression step at a stage known as top dead center (TDC). Dardalis says, "+/- 30 degrees around TDC is a critical period during the cycle when lubrication moves into the mixed/boundary regime where metal-to-metal contact occurs leading to high friction and localized wear. In an RLE, the rotation of the liner leads to the formation of nonparallel microscratches, which in conjunction with the added relative "orbital" motion and the constantly directionally varying shear rate, keep ring and skirt lubrication out of the mixed/boundary regime and in the hydrodynamic region, despite the high cylinder pressure of modern engines and/or reduced lubricant viscosity. The result is a reduction in friction and wear. This is in contrast to the traditional low-load friction reduction attainable with a reduction in lube viscosity, which is typically accompanied by a wear increase, especially at high loads."

Dardalis contends that optimizing the pistons through the use of coatings and ring profiles only provide temporary benefits over a small fraction of the life of the engine, especially when the engine is a heavy duty unit that is expected to be in operation for 5,000-20,000 hours (depending on application and load cycle). Lubricant additives that help minimize the effects of metal-to-metal contact only offer a 10%-15% reduction in the friction coefficient (as opposed to over 90% when contact is minimized), and also

can create problems with poisoning the exhaust after-treatment devices.

The RLE concept was inspired by the development of sleeve valve engines in British aircraft engines used in WWII. Dardalis says, "Sleeve valve engines were British aero-engines of very high output. These engines had a rotating cylinder in the TDC area only, and they had far superior wear characteristics as compared to traditional aircraft engines. Even though mechanical efficiency was not easily measured at the time, there is evidence to support that they were even superior in terms of mechanical efficiency."

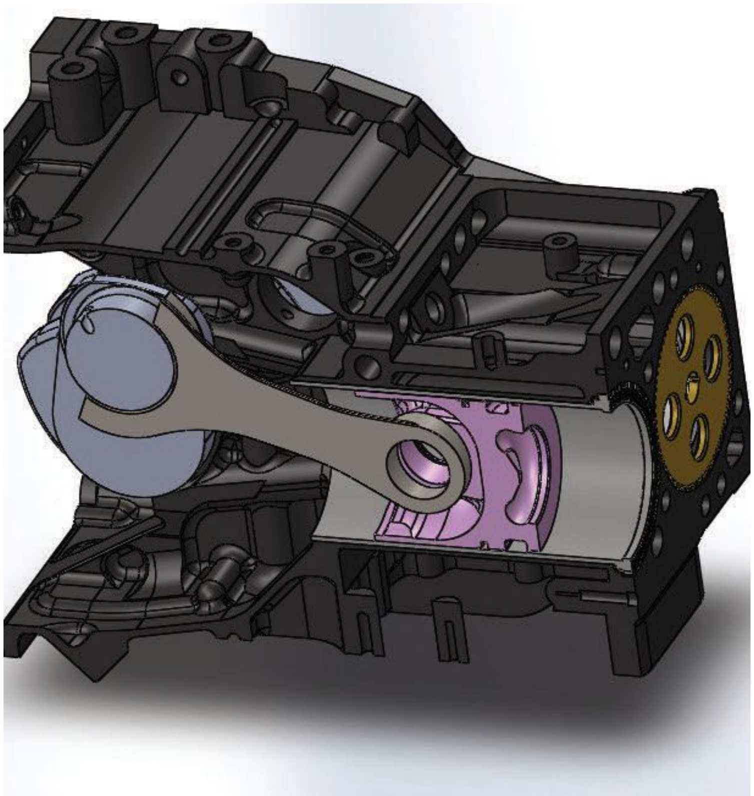

Figure 2 | A computer-assisted design image of the rotating liner engine beta prototype, which is in the final stages of development, is shown. *(Figure courtesy of Rotating Sleeve Engine Technologies, Inc.)*

PROTOTYPE DEVELOPMENTS

Dardalis and his colleagues have prepared an alpha prototype from a Quad 4 gasoline engine, which was converted to a single cylinder RLE. The main technology challenge for the researchers is the sealing mechanism between the cylinder head, which is stationary and the rotating liner.

Dardalis says, "We developed a prototype head-rotating liner seal that has shown perfect sealing performance (i.e., zero or negligible leakage) while remaining in the hydrodynamic lubrication regime throughout the stroke. The power loss of this seal is very low."

Motoring tests conducted on the alpha prototype have shown promising results. Dardalis says, "Despite the low-pressure motoring condition of the relatively low-compression ratio (about 10:1), we saw a 40% reduction in internal friction. This motoring friction, even though not representative of a running engine, is relatively easy to measure (high confidence in the measurements) and was repeatable."

The researchers are now working on a beta prototype that is based on a Cummins 4BT diesel engine converted to a single cylinder, but the design is such that would allow all cylinders to be converted. A three-dimensional, computer-assisted design image of the beta prototype is shown in Figure 2. The prototype is at the final stages of development.

Dardalis states that the RLE will provide significant benefits in fuel economy and work synergistically with current industry trends that include reductions in engine oil viscosity and engine oil size. He says, "At full load, we expect an improvement in fuel consumption of the order of 3%-4%. At idle, we will have as much as a 25% improvement in fuel consumption. We expect a fuel economy improvement in a driving cycle ranging from 6%-9%, depending on driving conditions (a heavily loaded driving cycle will yield about 5%, while low-load urban driving with lots of stop-and-go traffic will yield the larger number). If the technology is coupled with the industries' direction of reduced viscosities, downsizing or other solutions, the synergistic benefits may be even higher."

Dardalis continues, "We expect the fuel economy of the engine to remain identical to the "as new" levels over a much longer time frame, since the wear at the rings and liners will be substantially reduced. This factor will lead to reduced blow-by and enable RLE to avoid the increase friction typically seen as the honing surfaces on the liner of the standard engine polish up and the optimized piston ring profiles are lost due to wear."

Additional information can be obtained from an SAE paper published in 2012[3] or by contacting Dardalis at **dardal@rotatingliner.com**.

REFERENCES

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