The Operation and Performance of the Charge Cooled Rotapower® Rotary Engine vs. Oil Cooled Rotor Rotary Engines

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ABSTRACT

The rotary engine was first brought to the world's attention in the 1950's. This paper chronicles the years of development between then and now. It explains the fundamental differences and advantages of the charge-cooled rotor Rotapower engine over the oil cooled rotor rotary engine, most frequently identified with Mazda.

THE UNIQUE ATTRIBUTES OF THE ROTARY ENGINE, SOLID TECHNOLOGY LOOKING FOR AN APPLICATION

The Rotapower engine is based on the Wankel rotary engine, which was patented in the late 1950's by Felix Wankel. The Wankel rotary was immediately recognized by the international engine community as remarkably simple approach to achieving all the functional characteristics of the efficient but complicated four-stroke piston engine. This recognition led to a worldwide effort to develop reliable and efficient models of this engine initially by Curtiss-Wright, Mercedes Benz, NSU, Fichtel-Sachs, and later by Outboard Marine Corporation (OMC) and Mazda. Curtiss-Wright, John Deere, Rotary Power International and related parties, spent over $1.5 billion on Wankel-type rotary engines, mostly in anticipation of replacing turbine engines in military applications[1]. By 1980, more than 1,500 U.S. patents were issued on Wankel-type engines. These have since expired and can be used by anyone. The total estimated expenditures on rotary engines exceed $3 billion dollars. Mazda alone spent well over $1 billion dollars on rotary engine development and production facilities for their automobiles[2].

In general, the attributes of the rotary engine were outstanding, but in the automotive industry it was competing against the four-stroke piston engine with a 100 year history and hundreds of billions of dollars behind it. In addition, tests suggested that the Wankel rotary had poorer fuel consumption at low power settings. This was attributed to gas leakage past the rotor seals, which at the time was not as good as the piston engine.

By 1974, when the rotary engine was entering limited production, the automotive industry, which drives the four-stroke piston engine industry, was facing two concurrent hurdles:

1. The energy crisis of 1974, which emphasized the need for immediate fuel economy improvements.
2. Pollution reduction mandates were introduced and it was determined that qualifying a new engine along with the existing piston line was more than the automotive industry felt capable of financially undertaking.

As a result, other than limited production projects by Suzuki, Yanmar Diesel, NSU, OMC, and Fichtel-Sachs, only Mazda created a volume production facility and continues to produce engines. However, Mazda, having lost its earlier momentum due to adverse publicity, confined their rotary engine to a sports car (RX-7) and the low engine production numbers never allowed the engine to be produced economically within their high-volume production facility, hence the RX-7 became rather high priced and limited in sales.

The rotary engine is somewhat less fuel efficient at very low power settings, which is where automobiles in the developed countries operate much of the time; i.e. 10% power at 60 MPH, 2% power at 20 MPH. In developing countries, where engines used for transportation operate at the higher end of their power capability, the Rotapower engine offers superior fuel efficiency in most applications. In the U.S. the Rotapower engine is an outstanding alternative to the high emissions two-stroke engine used in some recreational applications. It is also an excellent candidate for hybrid automobile engines or co-generation power plants.

Rotary engines have a remarkable record of reliability. Ingersol-Rand achieved over 40,000 hours without a major overhaul. Rotary Power International (RPI) produces rotary engines (technology acquired from John Deere) that are guaranteed for a minimum of 10,000 hours,[3] and many of the OMC engines produced in the mid-1970's are still running today without an overhaul. Mazda racing engines can operate an entire racing season without an overhaul while their piston competitors are usually overhauled after each race[4].

CHARGE COOLING IS THE MOST COST EFFECTIVE METHOD OF COOLING THE ROTOR

In the Wankel rotary engine the rotor itself can be cooled by one of two means. Oil cooled rotary engines inject oil directly into a cavity within the rotor itself. The planetary motion of the rotor causes the oil to be thrown around the rotor interior with a violent scrubbing action, resulting in good heat transfer from rotor to oil.

The presence of a large quantity of oil subject to high centrifugal forces increases the likelihood that cooling oil will be forced outward between the rotor and the sidewalls. The steel side seals near the rotor flank are designed to seal the combustion chamber but are transparent to oil migrating outward from rotor cooling. For this reason a complex and wear dependent rubber or composite side seal is required in an oil cooled rotor rotary engine.

Contrary to popular belief, this side seal was the source of Mazda's initial oil seal failure problems, characterized by large volumes of blue smoke being produced. This type of seal is designed to exclude oil completely since it does not meter oil. This creates the requirement to meter oil into the intake of an oil cooled rotor rotary engine in order to lubricate the apex seals. Once oil enters the airstream it is problematic how much of it subsequently provides lubrication. The oil quantity required thus increases and the potential for residual deposits within the engine also increases.

A metered oil system, as used in the Rotapower engine closely approximates the lubrication technology of the four-stroke piston engine. With the Rotapower engine, like the four stroke piston, oil is provided directly to the surfaces requiring lubrication as needed, with minimum opportunity to enter the incoming airstream or charge. In the case of the Rotapower engine, the quantity of oil used is determined entirely by the amount needed to lubricate the seal contact surfaces since roller bearings are used throughout the engine and require very little oil.

The oil-cooled rotor is effective at removing heat from the rotor; however, the closed sides and the cored interior make the rotor heavy and complex to cast. In addition the hardware necessary to recirculate the oil, including an oil cooler, pump, filter, seals and complex side housings, all add cost to the engine. Finally, there is a power loss associated with oil sloshing, oil pumping, oil seal drag and hydrodynamic bearing drag resulting in 8% to 12% of the engine power being used to provide this oil cooling.

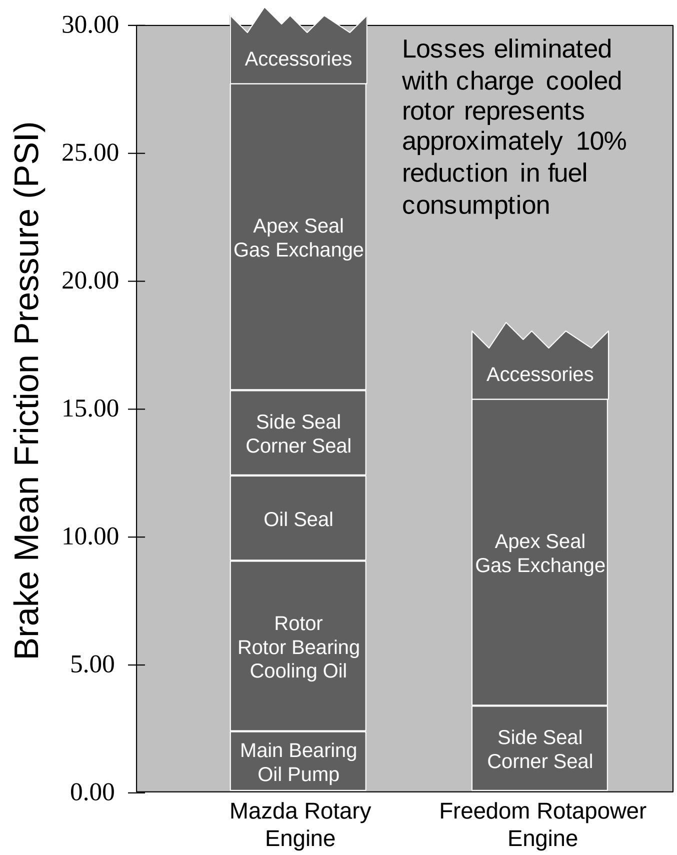

Figure 1: Comparison of Friction Losses between the Mazda 500cc rotary engine and the Freedom 530cc Rotapower engine[5]

In a direct measured comparison, Mazda established that the power loss associated with sloshing in the oil-cooled rotor, the oil pumping losses, the oil seal drag and hydrodynamic bearing drag, contributed about 10% to the total energy loss in a 2x573 cc displacement engine (hydrodynamic bearing loss = .15 kg/cm; rotor oil sloshing and oil seal loss = .4 kg/cm; oil pump loss ~ .3 kg/cm). Apex Seal loss was 1.05 kg/cm and output BMEP was 9 kg/cm.

A charge-cooled rotary engine utilizes the incoming fuel/air mix passing through the rotor, as the method of cooling the rotor. The advantages of this method are:

- The elimination of the oil recirculation hardware, which reduces the engine's weight and cost.
- Elimination of the power loss associated with oil cooling.
- Higher exhaust temperatures result in a naturally occurring thermal reactor that minimizes emissions.

In order to accommodate charge cooling it is imperative that the rotor be designed to minimize heat transfer to the rotor bearing while surviving the high internal temperature gradients. In addition, the rotor bearing itself must be of sufficient quality to withstand this environment.

With the use of roller bearings and a charge cooled rotor, the Rotapower engine has eliminated the 10% loss associated with oil cooling the rotor. The above results also show that the apex seal accounts for an additional 11% loss. The apex seal weight in the Rotapower engine has been reduced and the rotor-housing surface has been improved in the production engine to further reduce seal drag.

REFERENCES

[1] Jones, Charles, "Design of a High Performance Rotary Stratified Charge Aircraft Engine," AIAA Paper 84-1395, June 1984

[2] Kiriu, Rick, Summitono Bank in reference to their commitment to Mazda Motors

[3] Jones, Charles, "A New Source of Lightweight, Compact Multi-fuel Power for Vehicular Light Aircraft and Auxillary Applications - The John Deere Score Engines," 88-GT-271, The American Society of Mechanical Engineers, June 6-9, 1988

[4] Comments from Roger Mandeville, Former Racing Manager of Mazda Racing USA

[5] Yamamoto, Kenichi, "Rotary Engine," Toyo Kogyo Co., 1969