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The Reliability of the Rotapower® Engine

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ABSTRACT

The rotary engine is a uniquely packaged internal combustion engine invented in the late 1950's by Felix Wankel. The combination of high performance and minimum total moving parts were brought together in a powerplant that now has remarkable reliability. Several companies improved upon the basic foundation first developed by Dr. Wankel. The Rotapower engine capitalizes on this very large historic investment coupled with proprietary improvements that result in a reliable powerplant with impressive power to weight and power to volume characteristics.

WANKEL-TYPE ROTARY ENGINES HAVE A HISTORY OF RELIABILITY

Outboard Marine Corporation (OMC) manufactured approximately 15,000 rotary snowmobile engines during 1973-74[1]. Many of those engines are still running today without an overhaul. Those that failed generally did so because of misuse of the engine in this application; namely a hard climb in late spring in warm weather with an air-cooled engine designed for winter use. Even in this case the engine generally had a "soft failure," whereby it ran until it was stopped and was not able to be started again.

Ingersoll Rand had Curtiss-Wright manufacture a very large twin rotor rotary engine in the late 1960's, for pumping natural gas while running on natural gas. These engines have accumulated more than 40,000 hours without an overhaul.

The Gas Research Institute in Chicago undertook an extensive analytical and experimental study in an effort to find a co-generation engine that could run for 40,000 hours on natural gas without an overhaul. They concluded that the only engine in which this was possible was a rotary engine based on the Wankel principle[2].

The Mazda rotary engine racing team usually overhaul their engines only at the end of the season, while their piston-powered competitors generally overhaul their engines after every race[3]. Mazda did experience an oil-sealing problem in their first production engine. The seal that failed was particular to the oil cooled rotor rotary engine design. This seal prevents the rotor cooling oil from getting into the combustion chamber. Mazda was able to quickly solve this by changing the seal design and material.

RotaPower LLC undertook numerous tests of the OMC engine, in which the rotor was modified to reduce heat transfer to the rotor bearing, while the intake and exhaust systems were redesigned for maximum power. These modified OMC engines proved very reliable in a number of applications. The few engine failures that did occur have been traced to some external element such as improper or inadequate lubricating oil or ingestion of foreign material through the intake. These engines have been run for thousands of hours but due to experimental usage, no one test has exceeded hundreds of hours. The tests undertaken have been very severe, including dynamometer testing using an air-cooled rotor version at 80 hp for over 300 hours. Charge cooled rotor versions of the modified OMC design producing 55 hp have been used in a number of manned and unmanned VTOL aircraft. With over 200 flights in an eight-engined aircraft during six-plus years of flight-testing, the engines ran flawlessly, despite continuously operating at very near their maximum power.

THE WANKEL ROTARY DESIGN IS WHAT MAKES THIS RELIABILITY POSSIBLE

There are a number of features unique to the Wankel rotary engine that enhance its reliability by minimizing wear and potential for component failure. For example, the only rubbing surfaces are the seals. This differs from the piston engine where the piston skirt is inherently forced against the cylinder wall by the angled direction of the connecting rod. Furthermore, since the rotor rotates at one-third the output shaft speed, the actual rubbing or seal sliding velocity is modest. A four-stroke piston engine delivering 50 HP at 6000 RPM has a maximum sliding speed of approximately 50 feet per second. This is similar to the maximum sliding speed of the Rotapower engine, however, with a piston engine the sliding velocity goes to zero at the top and bottom of the stroke. This tends to break the oil film and causes substantial wear of the cylinder at those spots. In the rotary engine the difference between maximum seal speed and minimum seal speed is relatively small, which helps preserve the oil film[4].

The enormous reversal of forces in the piston engine puts a very large inertial load on the bearings. This is handled in the four-stroke piston engine by the use of hydro-dynamically lubricated main bearings that provide some cushioning effect. Hydrodynamic bearings, however, have significantly higher friction losses than do roller bearings. Roller bearings do not tolerate a reversing load and this accounts for bearings being a major failure mode for two-stroke engines where they are generally required. The Rotapower engine uses roller bearings but, due to its pure rotary motion, the bearings never see a damaging load reversal.

Finally, the few moving parts (two in a single-rotor Wankel-type rotary engine) greatly reduce the number of parts likely to fail. A four-stroke piston engine generating the same instantaneous torque characteristics could have as many as 38 moving parts.

THE ROTAPOWER ENGINE IMPROVES ON THIS LEGACY OF RELIABILITY

The rotary engine assets of OMC were acquired in 1985. While the OMC rotary had proven to be surprisingly reliable in the snowmobile application, it had poor fuel consumption and generated large amounts of unburned hydrocarbon emissions. In addition, it was not an engine designed to operate in conditions of elevated ambient temperature. In the rotary engine the power stroke always occurs at one point in the cycle and, unlike the piston engine, it never sees a cooling charge. This makes air-cooling the housing somewhat problematic except at low power. The OMC engine used an air-cooled housing which survived in winter-like conditions while using as much as 10% of its power to drive a cooling fan. OMC did use a charge-cooled rotor, which was an economically attractive alternative to the oil-cooled rotors used by Curtiss-Wright/John Deere/RPI or Mazda. Both RPI and Mazda achieved reliable engines, but the oil-cooled rotor was an expensive approach because of hardware costs and with 10% of its power being used to provide this rotor oil cooling. The OMC design approach to charge-cooling the rotor did present a problem because as their intake charge passes across the rotor it cools one side more than the other. This results in the roller bearing race becoming tapered. A tapered roller bearing generates rotor end thrust and consequently higher end housing wear, as well as bearing end loading which also accelerates bearing wear. RotaPower LLC developed a patent pending induction/rotor system that cools the rotor evenly.

Through its acquisition of the OMC engine technology, it benefited greatly from the estimated $100+ million (in today's dollars) spent by OMC developing this technology. It provided a firm proven foundation to build on and included a large number of engines and hardware to use during the experimental portion of its engine development program.

THE ROTAPOWER ENGINE HAS A UNIQUE SET OF ATTRIBUTES

RotaPower LLC set out to create a rotary engine based on the Wankel principle that would achieve the following:

1. Use a liquid-cooled rotor housing in order to not limit the potential power output. The single rotor engine has been endurance-tested at over 80 horsepower. The original OMC engine produced 42 horsepower in cold weather.
2. Continue to use a charge-cooled or air-cooled rotor because of it's simplicity but develop ways to isolate the rotor bearing from the combustion heat at higher power levels.
3. Make the design modular so that the engine can go from one to a number of rotors by changing only the through-bolts and adding a single casting between each pair of rotor housings.
4. Eliminate any temperature differences across the rotor in order to lengthen engine life.
5. Introduce component changes, including dual spark plugs, to improve emissions and reduce fuel consumption. This led to a patented thermal coating, developed by the company under a previous NASA contract, and current combustion chamber improvements taking place under a U.S. Army contract.
6. A design that injects metered oil directly to the critical rotor bearing, prior to being channeled to the apex seals, by way of the rotor side seals. This eliminates either pre-mixing lubricating oil with the gasoline like OMC or injecting oil into the intake like Mazda. Both of these latter methods result in oil in the incoming charge where it is less efficient in lubricating and consequently ends up as unburned hydrocarbons that also increase particulate production.

7. A design that can use any fuel including diesel, natural gas, and alcohol, as well as gasoline.

All of the above has been achieved without increasing the complexity of the original very simple OMC design. The fundamental difference between the Rotapower engine and the Mazda or RPI engines is the complexity. The cost, volume and weight are very much less in the simple Rotapower design and production cost is comparable to that of a two-stroke engine, based on the previous experience of OMC with their fundamentally low-cost design.

RotaPower LLC is concentrating on specific markets where its 530cc displacement per rotor engine is immediately attractive. These include recreational applications and APU electric power generation. All the components are in place to generate multi-rotor versions of this engine as required for higher horsepower applications. Charge cooled rotor versions of the Rotapower engine generate 50 HP per rotor. Proprietary rotor versions can generate 125 HP per rotor. A four-rotor, long-block model that measures 11” in diameter and less than 26” long weighs approximately 150 pounds with all accessories and is capable of producing 500 HP using alcohol as a fuel.

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