The Manufacturability of the Rotapower® Engine

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ABSTRACT

There are many elements of the charge cooled Wankel type rotary engine that make it inexpensive to produce. OMC was able to show that they could produce this type of engine at a cost competitive with their carbureted two-stroke engines.

THE PRODUCTION CHARGE COOLED WANKEL WAS FIRST INTRODUCED AS A POTENTIALLY CLEAN, LOW COST, POWERFUL REPLACEMENT FOR TWO-STROKES.

In the late 60's Outboard Marine Corporation (OMC) recognized the market value of an advanced, more powerful engine. This interest was intensified by a growing concern that emission issues would necessitate a clean burning, environmentally friendly powerplant. OMC clearly understood the obvious advantages of the rotary engine over the reciprocating two-stroke engine. These included low vibration, high power and very compact design. Even more important, since the rotary operates on the four-stroke Otto cycle, it had better fuel consumption and much lower emissions. Four-stroke engines also have a broader torque curve and are less sensitive to exhaust backpressure, which provides much better muffling. OMC's knowledge of, and experience with, oil-cooled rotor rotary engines, through an engine development contract with Curtiss-Wright, convinced them that this design approach would not be economically feasible[(1)]. Instead, a charge-cooled rotor version was chosen, not only for cost but because servicing a charge-cooled engine in the field is much simpler.

The snowmobile was chosen as OMC's first test application because it was separate from their marine market and presented a demanding application (extended operation at maximum power). OMC established the requirement that their rotary engine must equal or surpass any competitive reciprocating two-stroke engine in terms of cost, performance, packaging, manufacturability and effect on the environment, before it could be substituted for the two-stroke engine in any application. In 1972, OMC introduced their rotary powered Evinrude RC-35-Q and Johnson Phantom snowmobiles.

OMC also investigated liquid cooled housing marine models. OMC's four rotor outboards raced six times in the summer and fall of 1973, winning every race in U class (unlimited). At the Galveston Speed Classic, they placed 1^{st}, 2^{nd} and 3^{rd}, lapping the entire field three times (a fourth OMC boat rolled). It was rumored that they once made a straightaway pass at 165 mph.

THE CHARGE-COOLED ROTOR WANKEL TYPE ENGINE HAS A LOW PART COUNT

When choosing an engine for a particular application or comparing the part count between engines, the required power and torque characteristics of the engines must be considered. The displacement per piston and number of pistons a particular engine has, determines this. Horsepower can be gained by either increasing the displacement size of the cylinders or by adding cylinders. More cylinders provide better airflow to each cylinder and allow the engine to run at a higher RPM. However, more cylinders add parts and hence cost. As more cylinders are added the engine tends to have less vibration and better torque characteristics. More cylinders may have a higher value in the eyes of the end user.

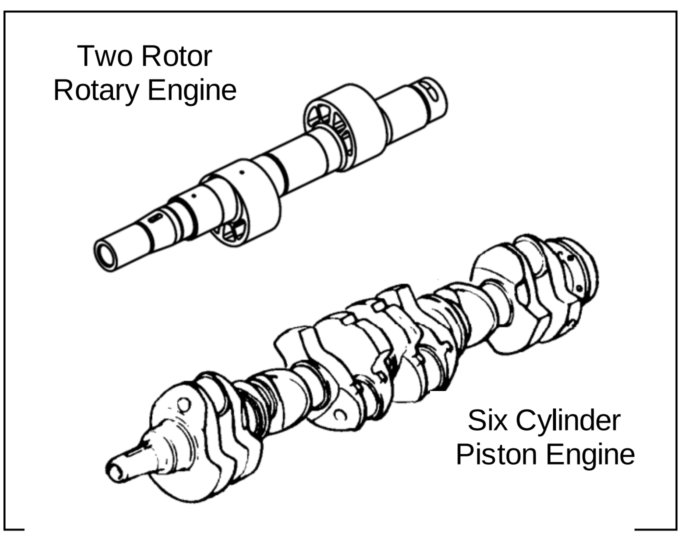
Rotary engines, by design, breathe very well and are not limited in RPM except for apex seal speed, which should be below 50 ft/sec., typical of piston ring wear speeds. Since the rotary engine power stroke has a duration of 270 degrees of crankshaft rotation and each rotor fires once per crankshaft revolution the rotary engine had the same peak-to-mean-torque ratio as a three-cylinder four-stroke piston engine. A two-stroke engine has a shortened power stroke so that as a practical matter it also requires approximately three cylinders to match the torque characteristics of a single rotor engine. Therefore any part count should compare a single-rotor rotory engine with a three cylinder, two or four-stroke piston engine. When comparing the number of moving parts, the two-rotor rotary has three, the crankshaft and two rotors. This equals only 23% of the total moving parts of a six-cylinder two-stroke and only 2% of those for a six-cylinder four-stroke piston engine. The rotary crankshaft is a very simple component while the rotor and its seals are no more complex to manufacture than a piston and rings.

PART COUNT (Engines with similar torque characteristics)				
	ROTAPOWER (Two charge cooled rotors)	MAZDA WANKEL (Two oil cooled rotors)	2-STROKE PISTON (Mercury V6)	4-STROKE PISTON (Toyota V6)
Major Parts	8	8	16	28
Moving Parts	3	3	13	134
Total Parts	163	242	225	312

THE OMC PRODUCTION EXPERIENCE WAS ONE OF LOW COST DESPITE BEING PRODUCED IN RELATIVELY SMALL QUANTITIES

The Research Group at OMC built many different rotary engines including a 50cc single rotor, 825cc single rotor, 1300cc double rotor marine engine, the 530cc snowmobile engine and a four rotor 2120cc-360HP racing outboard. The only engine that was placed into production was the air-cooled snowmobile engine. Forty thousand (40,000) of these engines were built from 1972 through 1974. During the same period OMC built 1.5 million two-stroke engines.

OMC undertook an extensive cost comparison between their rotary engine and a two-stroke engine of similar power. The two-stroke engine used in the comparison was produced at seven times the volume of their rotary engine. In a direct comparison, without accounting for these production differences, the cost of the rotary was only 8 to 13% higher than their two-stroke. OMC concluded that if they were produced in similar volumes the production costs would be nearly identical.[2]



CRANKSHAFT COMPARISON

The costliest components in the OMC production process were the rotor housing and the rotor. The seals for the engine were not expensive, according to OMC's production manager[3]. OMC confirmed that the crankshaft for the rotary was much cheaper to manufacture than the two-stroke crankshaft. The electrical and the fuel systems were also less expensive. Assembly was comparable to the two-stroke engine. OMC generally used standard machine tools to produce the engine. Additional production equipment included a plasma spray capability to plasma coat the wear surface of the rotor housing and an automated machine for cutting side seal slots in the rotor.

The highest process cost associated with the rotor housing was the plasma coated wear surface. The surface was first machined and then went through an elaborate preparatory process before being plasma-sprayed. The potential for damage during processing was significant. After plasma spraying, the housing sides were flat ground to remove over-spray. Then it was finish-ground on a housing wear surface grinder (trochoid grinder) and, finally, it was lapped to 4 to 5 micron finish. The plasma coating was difficult to apply evenly and therefore the resulting coating was put on approximately twice as thick to ensure meeting the required thickness of the finish coating after grinding. This resulted in extended grinding with a diamond wheel. The raw materials for the plasma coating (tungsten-carbide) were relatively costly and the over-spray resulted in an additional 50% loss of the sprayed material.

IMPROVEMENTS IN MANUFACTURING PROCESSES FURTHER REDUCE THE ROTAPOWER PRODUCTION COST

Casting Technology

In the years since OMC's first production run of rotary engines, several manufacturing processes have matured that will further reduce the production cost of the Rotapower engine. The most significant of these is the lost foam casting process. This method of casting was just being developed as OMC was discontinuing their snowmobile engine production. However, OMC did introduce the lost foam process in their two-stroke engine production and continued to experiment with it as part of their continuing liquid cooled rotary engine development through June 1986[4].

Lost foam casting uses a foam pattern packed in sand. The addition of the molten metal burns away the pattern, leaving the "as cast" part. Because the part is first replicated in foam, rather complex shapes can be cast. Cores, which represent internal features, are placed inside the foam. As a result, the core is fully supported during the pour process, eliminating the typical problem of sifting cores.

This process allows the parts to be cast very close to "as-designed" dimensions. The result is the elimination or reduction of secondary machining operations and very low rejected parts. OMC used sand casting for both their Wankel engine rotor housing and crankshaft, which is slow and inaccurate. They used shell molding for the rotor and this is also replaceable by the faster and more accurate lost foam process.

Coating Technology

Wear coating technology has significantly matured since the OMC production and can provide very economic alternatives for co-deposit plating in which a composite coating is created by, for example, plating nickel along with carbides. In the past this process was patent-controlled by Mahle in Germany. Variations of this technology are now used extensively. Recently the automotive industry has begun using this type of plating process to coat cylinder walls for low friction, high strength wear surfaces.

This technology can be directly applied to the application of the wear coating to the Rotapower rotor housing. The advantages are several. The plating process is much faster and simpler than the plasma spray process used by OMC. Control of the thickness of the surface coat is greatly enhanced, which substantially reduces both the amount of material used and the time associated with grinding the surface coat to the desired thickness.

THE FUTURE OF PISTON ENGINES GROWS INCREASINGLY COMPLEX WHILE THE ROTAPOWER ENGINE CONTINUES TO SIMPLIFY

The original basis for OMC's interest in the rotary engine was the expected stricter emissions standards. The standards anticipated by OMC are now a reality. Engines are coming under increasingly stricter emission limit mandates.

The technology growth path to comply with these mandates proposed by most piston engine manufacturers focuses on direct fuel injection. As a result of the harmful particulates created by direct injection, some type of particulate trap will be required as well.

The cost of direct fuel injection significantly increases the cost of the engines. A catalytic converter is also expensive, if required, with its use of precious metals such as platinum. Weight and space are additional considerations in view of the importance of these in both recreational and auxiliary power unit (APU) applications.

By comparison, even a carbureted, charge-cooled Rotapower engine already meets the emission requirements being mandated for both industrial and recreational engines[6]. Several opportunities exist to simplify the Rotapower engine further while improving its performance. For example, results from a NASA-sponsored study, "Evaluation of Thermal Barrier and PS-200 Self-Lubricating Coatings in a Wankel engine" (patented by Moller International) make a lubricationless engine possible[7]. Recent developments have shown the potential to eliminate the traditional ignition system and replace it with an inexpensive proprietary non-powered igniter that utilizes the unique geometry of the Rotapower engine.

In an era where emission compliance seems to translate to complexity and cost, the charge-cooled Rotapower engine offers four-stroke performance at the cost of the simple carbureted two-stroke engine.

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