

Maintenance Challenges of Wankel Rotary Engines and utility in Aviation Applications

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Abstract

Aero engines are designed in the western countries to suit their operational requirements and climatic conditions. Even though the engines are designed to withstand a broad range of operating parameters, prolonged operation and storage of such engines in high humid and adverse tropical environmental conditions initiates on set of fatigue failure of certain critical components. Hence it becomes mandatory to propose operational changes or routine maintenance changes as appropriate based on the past failure trends to avoid abrupt failures resulting in undesirable consequences. High power to weight ratio is the basic requirement behind the selection of any aero engines. In addition features like less noise, emission and low vibration signature also contribute to some extent during design and selection of propulsion for an aircraft. In analogy to the piston engine cylinder which performs four different jobs like intake, compression, combustion and exhaust strokes, in a rotary engine the uniquely designed housing does these four jobs. This paper mainly deliberate on the working principle and the different strokes of the Wankel engines, performance comparison with reciprocating engines, design and maintenance challenges in Wankel engines, failure of critical components like the “Face and Apex seal” and the real time applications of Wankel engines.

Keywords: Wankel engine, IC engine, Face seal, Apex seal, Downtime, Maintenance.

I. INTRODUCTION

Conventional two-stroke engine[5] poses an unfavorable reputation for rough idle, poor operational efficiency at low speeds, temperamental behavior, and rapid fouling. Two-stroke diesel operation requires a mechanical blower to force-feed air into the engine to ensure optimal aspiration. Because of the tendency to operate best at high speed, they encompass short service lives. Also, lubricating oils blended with fuel for positive lubrication induces incomplete combustion and increases the maintenance of combustion chamber which finally results in reduced engine life. In a piston engine, the same volume of space (the cylinder) alternately does four different jobs, intake, compression, combustion and exhaust. The Wankel rotary engine [7-9] also has the similar strokes in its operation, but all four strokes one happens in its own part of the housing. New developments in Wankel engine design[7] prompted automakers to rethink conventional two-stroke engine concepts and its applications. The main aim behind the development of rotary engines is to overcome the deficiency of the reciprocating engines by developing a compact, high-speed engine with good vibration characteristics. The development process of Wankel engine was badly affected by the downfall of the Germany in the first and the Second World War. The Wankel rotary engine was developed by Dr. Felix Heinrich Wankel[11]. The first model of Wankel engine was sketched in 1924, prototype was finalized in 1929 and a patented double rotor engine[11] was developed in 1934.

The working principle along with different strokes of the Wankel engines, their performance comparison with reciprocating engines and real-time applications are elaborated in the main paper.

II. THEORY OF WANKEL ENGINES

The Wankel Engine is a rotary internal combustion engine with the intake, compression, combustion and exhaust strokes performed by the rotation of a triangular rotor in a modified oval housing.

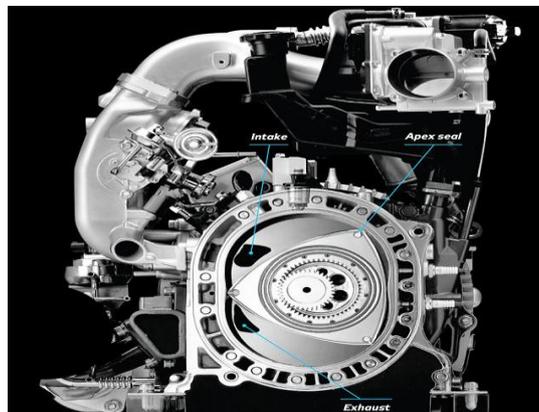


Fig. 1 Cut Section of Basic Wankel Engine

The Wankel engine resembles the conventional ICE in weight, power output, efficiency, and speed. In short, the Wankel tends to save a fragment of more weight and space compared to a conventional IC engine. This saving ranges from a trivial amount in small engines, to a significant amount when compared with large automotive V8 engines[5,11]. Research studies have revealed that for long term operations Wankel engine features are found to be superior than conventional IC engines. Originally the poor combustion-chamber sealing and high fuel consumption plagued the Wankel engines commercial applications[4]. But ongoing development has led to significant improvements in sealing and reduced fuel consumption[11] considerably. The Wankel engine has gained acceptance in some quarters of the automotive market, but currently it is not a contender for industrial applications which warrants more efficiency.

The Wankel engines were commercially used initially by Peugeot[11] and Mazda[11] for the production of race cars. The first sports car with a twin rotary engine is released by Cosmo sport(1967). Mazda race car model RX-8 was equipped with 250 Hp capacity Wankel rotary engine. The Wankel engine are used in automobiles[5,11] due to the following advantages:-

- There is no requirement of valves and connecting rods for control of gas flow.
- Weighs less as compared to piston engine.
- Vibration signature is less as there is only rotary motion during engine operation.
- Volume of engine is almost half as compared to piston engine with same power rating.
- The production costs are lower compared to other conventional IC engines.
- It can reach higher revolutions to deliver required power within short time.

The Wankel engines are similar to the conventional ICE in the basic strokes and operation. Only the reciprocating motion of conventional IC engine is replaced by rotary motion[7] in Wankel engines. Similarities between the conventional IC engine and Wankel engines are,

- The Wankel Rotary engine consists of a three sided rotor moving in a modified oval chamber or rotor housing which is similar to the movement of piston in cylinder head of a conventional ICE.
- The Rotor of Wankel engine is similar to the piston of conventional ICE.
- Both Wankel and conventional ICE produce work at constant volume.
- The weight reduction ratio of Wankel engines is far superior to conventional ICE.
- Four stroke engine has one power stroke, two stroke engine has two power strokes and Wankel engine has three power stroke in one cycle of operation.

III. CONSTRUCTION OF WANKEL ENGINE

There are only three main moving parts in most Wankel engines ie, Two rotors and the eccentric shaft which rotate in one way continuously. Because of the method of movement of rotor the fuel air mixture flows into the housing, the four strokes ie, suction, compression, combustion and exhaust takes place in different areas of the engine. Compression in a rotary engine is created by the rotor in the engine peripheral housing area.

Rotor of Wankel Engine

The rotor of wankel engine consists of a three faces moving in a modified oval chamber or rotor housing. The three faces[9] of the Wankel engine rotor functions as the combustion chambers. The face seals[1] and the apex seal[1] serves functions as the piston rings to give necessary gas tight integrity to the combustion chamber. The rotor encloses epicyclical gear, seals and an eccentric lobe as enumerated in figure.2 below,

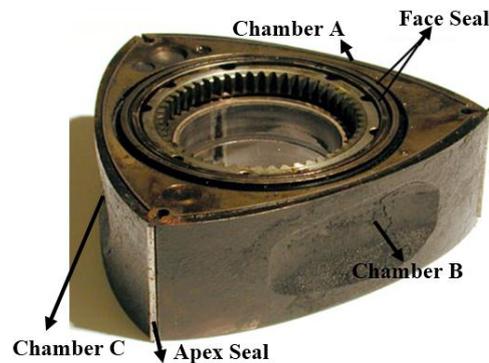


Fig. 2 Rotor of Wankel Engine

The rotor rotates around the center of the eccentric lobe on the output shaft, at the same time rotating around its own axis[1]. This is very similar to the way the earth rotates around the sun while rotating around its own axis. The Wankel engine is sometimes called as a planetary engine for this reason.

Housing of Wankel Engine

There are at least three holes in the walls of the rotor housing. One hole is for the spark plug, One hole is used as intake port and the other as an exhaust port. The movement of the rotor in the housing creates the Epitrochoid curve[8] in the housing.

Epicycloidal Gear

The epicycloidal gear of the Wankel engine transfers the motion of the rotor to the shaft. The epicycloidal gear of the Wankel engine is engaged with the stationary gear which rotates around the stationary gear.

Face and Apex Seal

The purposes of face and apex seals are similar to the cylinder liner of the cylinder heads of a conventional ICE. The apex seals are in contact with the cylinder housing to provide necessary gas tight integrity during combustion stroke and are

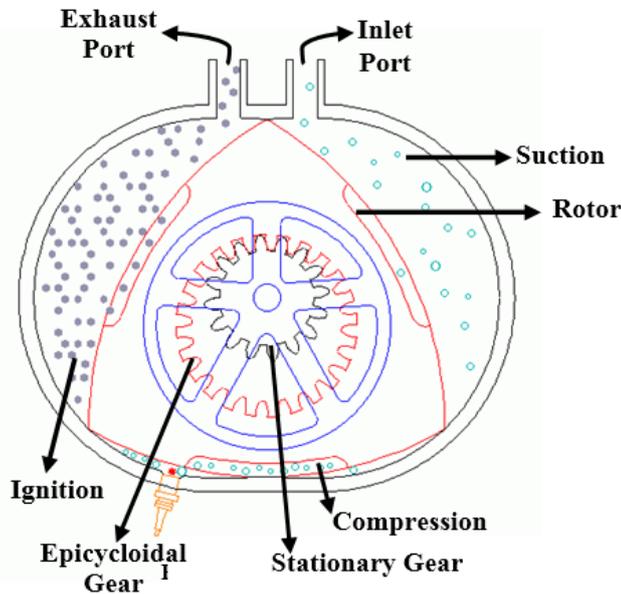


Fig. 3 Construction of Wankel Engine

subjected to uneven wear due to the housing profile. These seals are the major problem leading to the increased maintenance and reduced efficiency of the Wankel engine.

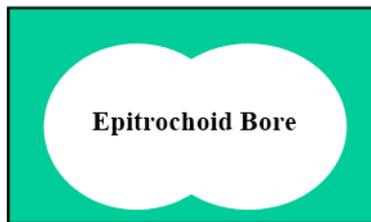


Fig 4 Epitrochoid Bore of Wankel Engine

Wankel Engine Eccentric Shaft

The shafting of Wankel engine consists of the following parts as shown in figure 5.



Fig. 5 Eccentric shaft of Wankel Engine

The Shafting of the Wankel Engine has a lobe which is connected eccentrically to the main shaft. The centre of the Stationary Gear and the centre of Shaft are inline with each other. The center of Epicycloidal gear and the lobe are also in line with each other. The shaft rpm is thrice the rotor rpm.

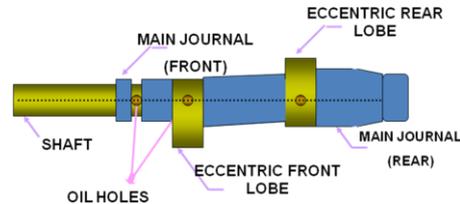


Fig.6 Parts of Wankel Engine Eccentric Shaft

Inlet and Exhaust Port

The inlet port allows the entry of fuel air mixture into the combustion chamber by the rotation of the triangular rotor. The rotor also expels out the exhaust gases from the combustion chamber through exhaust port after combustion .

The main constructional similarities[7] of the rotary Wankel engine and the conventional ICE are,

- The Eccentric Shaft replaces the piston engine's crankshaft and connecting rods.
- The Rotor replaces the piston engine's reciprocating piston.
- The Peripheral Housing replaces the piston engine's cylinder.
- Intake and exhaust ports in the housings eliminate valves, camshafts, cams, lifter rods, and timing belts.

IV. OPERATION OF WANKEL ENGINES

Many engineers and mechanics believe that the rotor translates, reciprocates or wobbles in the rotor housing [9]. The center of gravity of the rotor rotates around the center of output shaft. The motion of Wankel engine rotor is very important from the balancing point of view. The rotor of Wankel engine is balanced around its own axis. The front rotor balances the rear rotor as they are 180 degrees apart. The output shaft leaves a small couple which is finally completely balanced by counter weights.

As the rotor rotates round the stationary gear, the tips of the triangular shaped rotor pass through the ports in the housing. As the first tip passes the intake port in the engine housing the face behind i.e. second tip starts to draw in the fuel air mixture. When the second tip passes through the intake port, the mixture already captured is compressed. As the chamber continues to rotate around the housing it encounters the spark plug and the mixture inside it is fully compressed.

The spark plug fires on the compressed charge which starts to expand imparting pressure energy from the burning mixture to the output shaft. As the rotor continues to

rotate the first tip passes through the exhaust port and the burnt mixture starts to leave the exhaust port. This completes the four strokes for chamber A. In the mean time chamber B and chamber C follows all four strokes in the same sequence simultaneously. The rotor is rotating one third as fast as the output shaft.

The three chamber simultaneous action is the reason for the Wankel engines compactness. Furthermore the forces in each chamber completely acts as a one-piece cast iron rotor. In the contrary, in a piston engine the compression force from the compression chamber (burning mixture) is transmitted to the shaft through connecting rod, crankshaft and couplings which makes the conventional ICE bulky[2,7] and less preferred for aviation applications.

Intake Stroke

The clockwise rotation of the rotor sucks in petrol air mixture into the housing through the inlet port. The chamber A of rotor rotates clockwise and sucks in the fresh gas.

Compression stroke

Chamber A starts to compress the petrol air mixture against reduced volume of the combustion chamber, the while chamber B sucks in fresh gas and chamber C expels the burnt gas.

Combustion stroke

Chamber A is full of fresh charge and it is at high pressure, and the compressed gas is ignited by the spark plug. In the meantime chamber B is in compression stroke and chamber C in suction stroke. This combustion is similar to conventional ICE combustion since Wankel combustion also takes place at constant volume inside the housing.

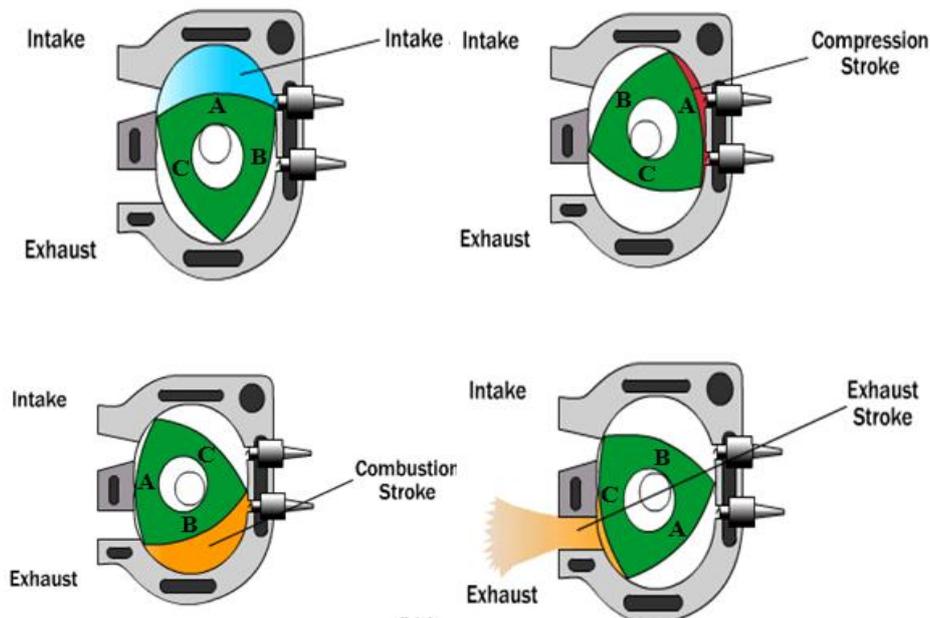


Fig.6 Strokes of Wankel Engine

Exhaust stroke

Finally after combustion, chamber A presses out the burned gases by the rotation of the triangular rotor. Unlike in reciprocating engine the overlapping period is high in Wankel engines.

Unlike Reciprocating Engines there are three power strokes[9,11] in one cycle of rotation of the rotor. The typical rotor and housing construction completes all four strokes within the three faces of triangular rotor. After all the combustion gases have been pressed out, the intake cycle begins wherein petrol air mixture flows through the inlet channel into the combustion chamber. The triangular rotor rotates clockwise and compresses the fresh gas and spark plug ignites the mixture after successful compression. Although the Wankel engine has similarities with a two-stroke ICE, particularly with respect to the working of porting mechanism, by construction it is different from an IC engine.

In the center of the epitrochoidal housing there is an eccentric lobe, the three-edged rotor is designed to turn around the eccentric cam. The rotor and the housing form three spaces, whose volume changes periodically. While the rotor makes one revolution, the eccentric lobe turns three times.

Consider just one of the Wankel engine rotor surface which is horizontal when at TDC (Top Dead Center) and vertical when it is at BDC (Bottom Dead Center). In a piston engine, the "cylinder head" is fixed and does not move during the compression stroke, so that the residual minimum chamber volume at TDC (this exclude the chamber cut inside the piston crown surface) is part of the relaxation volume during the complete stroke, and do not vary. But in case of Wankel engines the residual minimum volume at TDC (Due to epitrochoid constriction geometry) varies during the strokes and the apex seal moves into this minimum volume area. Contrary to piston engines, the minimum TDC residual volume is not at all present in the chamber during the compression stroke, which spoils the applicability of the Pressure-Volume diagram and its efficiency criteria.

V. ROUTINE ENGINE HEALTH MONITORING

In addition to monitoring the vital engine input and output parameters during routine exploitation, to ensure satisfactory performance of the critical engine components routine health monitoring techniques[2] has to be undertaken. The frequently failing parts[3] of Wankel engine are face seal, apex seal and the triangular rotor. The face seal and apex seal provides necessary gas tight integrity to the wankel engine combustion chamber. Hence failure or deterioration of the seals causes incomplete combustion and reduces the efficiency of the Wankel engines.

It is always desirable to ensure the quality of the seals by checking the combustion level of the engine to the desired level in periodic intervals[3]. Failure or deterioration of the seals / triangular rotor causes uneven wear resulting in oil loss from the engine which can be recognized by the increase in the operating temperature or vibration level of the engine. Prolonged exploitation of the engine without undertaking necessary corrective action may result in breakdown of the engine. Hence discharge from the engine exhaust and vibration level of the engine has to be routinely

inspected to ensure the health of the engine[3] by using the under mentioned techniques,

SOAP Analysis

Oil sample may be retrieved from the engine under exploitation and tested for satisfactory level of particle contamination level in the engine as per manufacturers recommendations[6]. If the particle contamination level in the oil is within acceptable level, engine is cleared for further exploitation . If the oil contamination level is beyond the acceptable limits, the engine will be withdrawn from the service for defect rectification[10] or necessary corrective maintenance action[3,6].

Vibration Trending

Vibration monitoring of the engine is to be undertaken on certain periodic intervals and trending is performed to determine the acceptable vibration levels of the engine. If the vibration signature registers beyond acceptable levels, necessary corrective maintenance action may be undertaken as per manufacturers recommendations.

VI. RESULTS AND DISCUSSIONS

The Wankel engine poses various advantages over the conventional ICE both in and operation and construction such as,

- Possess superior power to weight ratio.
- Has three power strokes in 360 degrees.
- Vibration and noise signature is less compared to reciprocating engines.
- Loss of power due to crankshaft and connecting rod is eliminated.
- The intake and exhaust ports eliminate the valves, camshafts, cam, lifter rods & the timing belts.
- Has fewer moving parts and moves in one direction.
- Doesn't require counterweights on the crankshaft.

Because of the inherent advantage of superior power to weight ratio and reduced noise and vibration signatures, wankel engines are used as propulsion plant in UAV (Unmanned Aerial Vehicle). Today's Wankel engines technology is well matured and are utilized widely in automobile and aviation appliances. The power output comparisons of conventional IC engines and Wankel engines are indicated in figure.7.

However Wankel engines possess low fuel efficiency as compared to conventional IC engines making it less preferred for industrial applications. Even numerical model calculations could not account for the level of deficient combustion in the Wankel engine. Three important drawbacks of Wankel engines are,

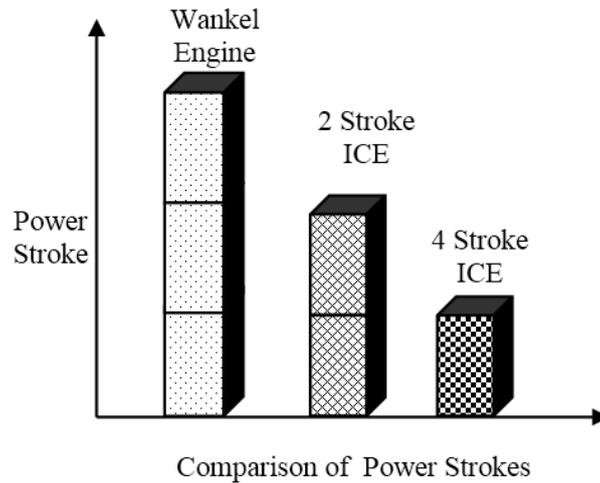


Fig.7 Comparison of Power Strokes in one Cycle of Operation

Low efficiency

Often assumed to be attributed to a slow combustion due to the Wankel rotary elongated combustion chamber geometry .

Oil Leak

The Wankel engine oil leaks result from the fact that the central crankshaft area is part of the oil pan, and a small quantity of oil tends to flow downward by gravity into the lower chamber resulting in incomplete.

Engine Ports Overlap

This is the major limitation of the concept, preventing port design optimization of Wankel engine. Wankel attempts to make 4 strokes with three side's of rotor surface moving in radial direction. There is a very large overlap of the intake and exhaust ports, which truncate the power stroke somewhat before the bottom dead center, resulting in loss of efficiency.

VII. CONCLUSION

Even though the Wankel engines possess inferior efficiencies and emission problems inducing pollution as compares to conventional IC engines, they are preferred in aviation and automobile applications which warrants for superior power to weight ratio and rapid accelerating characteristics. Wankel engines produces three power strokes in one cycle of its operation as compared to two and single power strokes of two stroke and four stroke IC engine. As the Wankel engines possesses very minimal noise and vibration signatures they are preferred in surveillance aircraft like the Unmanned Aerial Vehicles.

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