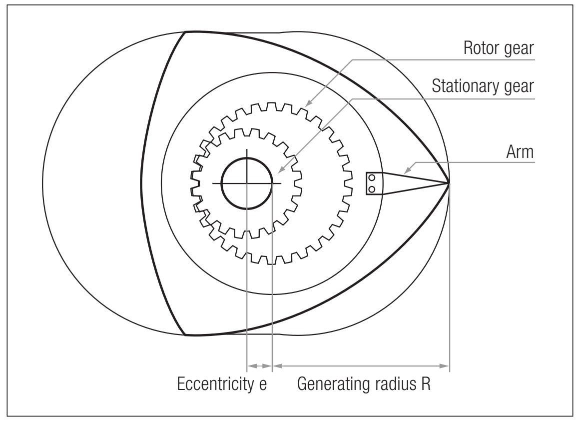
Structure and Working Principles of the Rotary Engine

■ Wankel-type Rotary Engine

Over the past 400 years, many inventors and engineers have pursued the idea of developing a continuously rotating internal combustion engine. It was hoped that the reciprocating-piston internal combustion engine would be superseded by an elegant prime mover bearing a closer resemblance to the "wheel", one of mankind's greatest inventions.

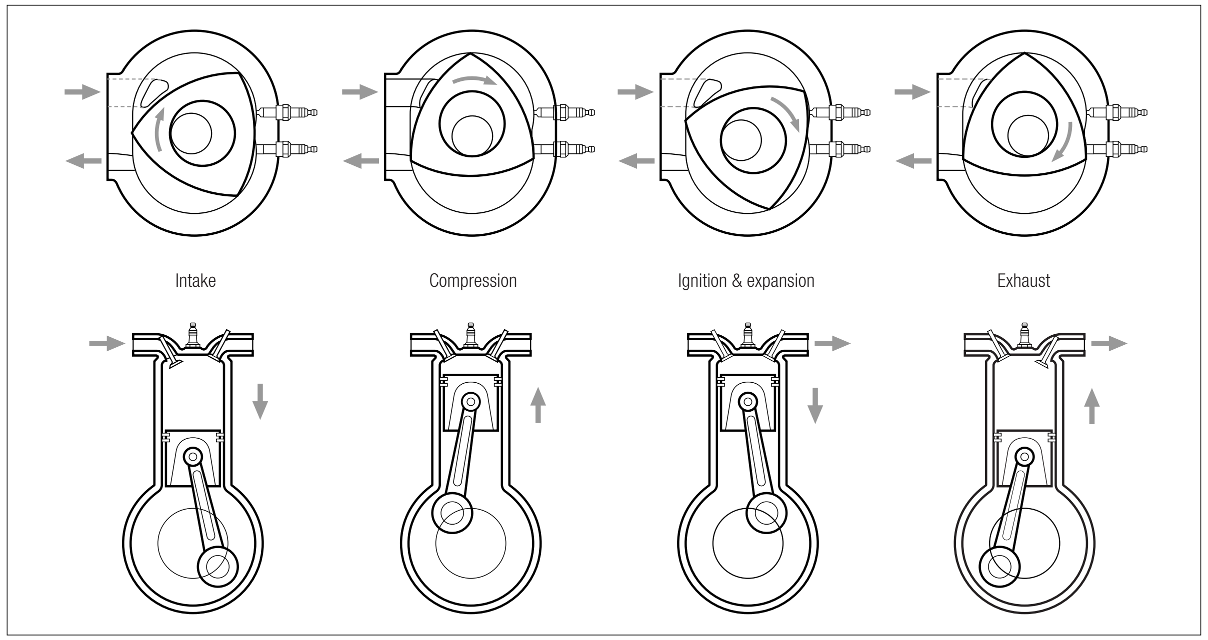


Principle of Peritrochoid Curve

■ Dr. Wankel and his colleagues devised how to configure the trochoid curve as follows: First, fix an outer-toothed gear on a white sheet above a table and mesh an inner-toothed gear on it. Put a pen attached with an arm on the outside of the inner-toothed gear. The gear ratio between both gears is to be set as 2:3. When turning the inner-toothed gear on the other gear, the pen will generate the cocoon-shape trochoid curve.

It was late in the sixteenth century that the phrase, "continuous rotating internal combustion engine" first appeared in print. James Watt (1736~1819), the inventor of the connecting rod and crank mechanism, also took up research on a rotary-type internal combustion engine. For the last 150 years especially, a number of ideas on the rotary engine design have been set forth by inventors. It was in 1846, that the geometrical structure of the working chamber of current rotary engine designs was planned and the concept of the first engine using an epitrochoid curve was configured. However, none of those ideas had been put to practical use until Dr. Felix Wankel developed the Wankel-type rotary engine in 1957.

Dr. Wankel had researched and analyzed possibilities of various types of rotary engines and reached the optimum shape of the trochoid housing . His deep knowledge of the rotary valves used for aircraft engines, the airtight sealing mechanism for superchargers and the incorporation of these mechanisms into his design contributed to practical realization of Wankel-type rotary engine.



Comparison with Reciprocating Engine-1

■ With the rotary engine, the inside space of the housing is always divided into three working chambers and, as the rotor turns, those chambers also move. Four processes of intake, compression, combustion and exhaust are executed successively in a different place of the trochoid housing. This is significantly different from the reciprocating engine, where the four processes are carried out within a cylinder.

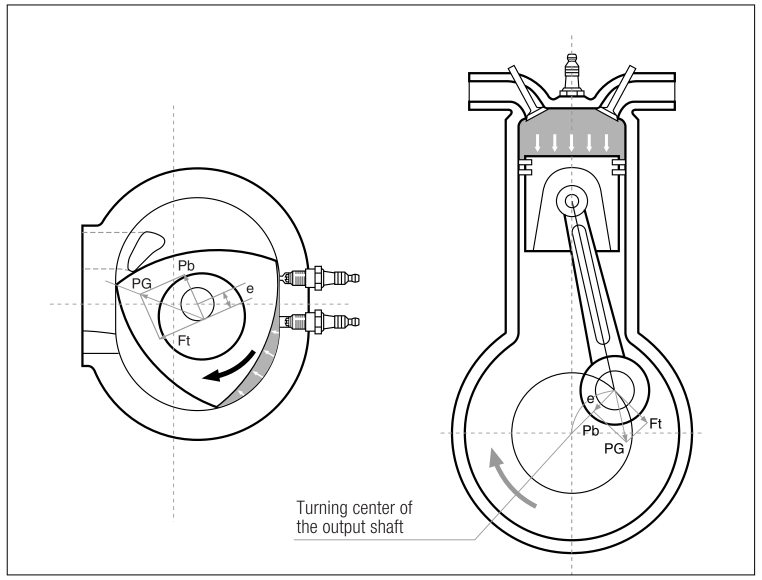
■ Structure and Operation of the Rotary Engine

The rotary engine is composed of a cocoon-shaped housing and a triangular-shaped rotor inside of it. The space between the rotor and the housing wall provides the chamber for internal combustion and the pressure of expanding gases serves to turn the rotor. In order to make the rotary engine work as an internal combustion engine, the four processes of intake, compression, combustion and exhaust had to be performed in succession in the working chamber. Suppose that the triangular-shaped rotor were concentrically placed inside a true circular housing. In this case, the working chamber would not vary in volume as the rotor turned inside the housing. Even if the fuel-air mixture were ignited there, the expansion pressure of combustion gas would merely work toward the center of the rotor and would not result in rotation. That was why the inner periphery of the housing was contoured as a trochoid-shape and assembled with the rotor installed on an eccentric shaft.

The working chamber changes in volume twice per revolution, thus the four processes of the internal combustion engine could be achieved. With the Wankel-type rotary engine, the rotor's apices follow the oval contour of the inner periphery of the engine casing while remaining in contact with the gear on the output shaft which is also in eccentric orbit around the center point of the engine casing. A phase gear mechanism dictates the orbit of the triangular rotor. The phase gear consists of an inner-toothed gear ring fixed on the inside of the rotor and an outer-toothed gear fixed on an eccentric shaft. If the rotor gear were to have 30 teeth inside it, the shaft gear would have 20 teeth on its perimeter so the gear ratio is 3:2. Due to this gear ratio, the rate of turning speed between the rotor and the shaft is defined as 1:3. The rotor has a longer rotation period than the eccentric shaft. The rotor rotates one turn while the eccentric shaft rotates three turns. With the engine running at 3000rpm, the rotor will run at a mere 1000rpm.

■ Comparison with the Reciprocating Engine

In order to get the turning force, both the reciprocating engine and the rotary engine rely on the expansion pressure created by the combustion of the fuel-air mixture. The difference between the mechanisms of the two engines is in the way that the expansion pressure is used. In the reciprocating engine, the expansion pressure generated above the piston's top surface forces the piston down and the mechanical force is transferred to the connecting rod that causes rotation of the crankshaft. In the case of the rotary engine, however, the



Principle of Generating Torque

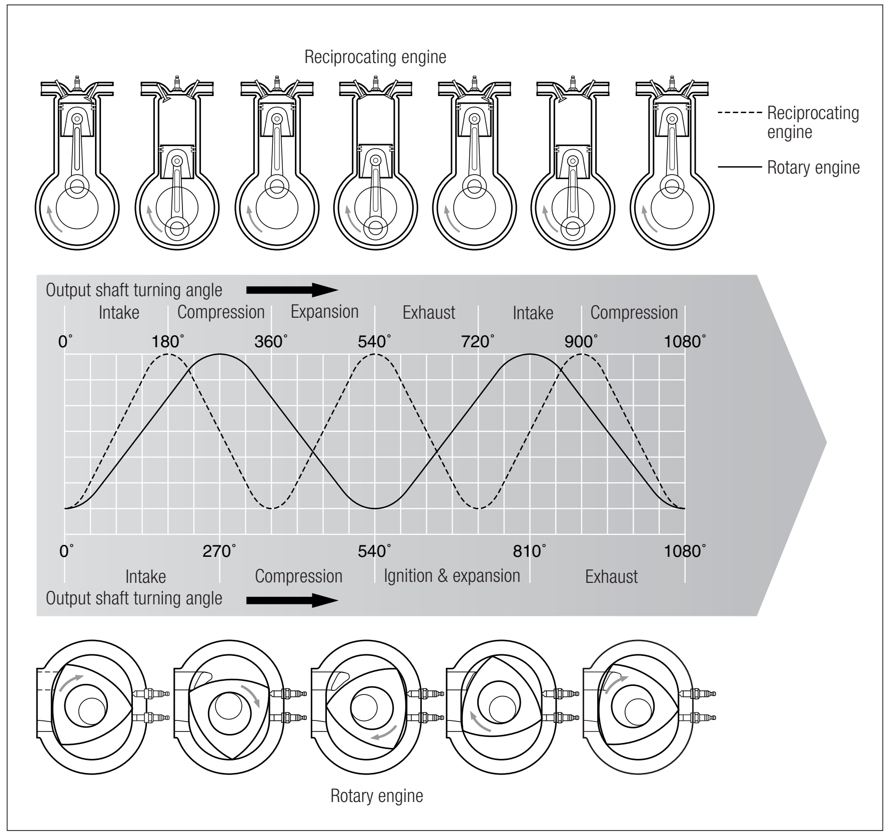
■ With the reciprocating engine, the expansion pressure of the combustion gas is changed to turning motion through the connecting rod and transferred to the crankshaft. While, with the rotary engine, through the effect of the eccentric shaft, the expansion force directly turns the rotor and then the rotor turns the eccentric shaft.

expansion pressure is applied to the flank of the rotor. One of the three sides of a triangle is forced toward the center of the eccentric shaft as a result. (PG in the figure). This movement consists of two divided forces. One being the force toward the output shaft center (Pb in the figure) and the other is the tangential force (Ft) which rotates the output shaft.

The inside space of the housing (or the trochoid chamber) is always divided into three working chambers. Due to the turning of the rotor, those three working chambers are always in motion and successively execute the four processes of intake, compression, ignition (combustion) and exhaust inside the trochoid chamber. Each process is carried out in a different place in the trochoid chamber. This is significantly different from the reciprocating engine, where those four processes are carried out within each cylinder.

The displacement volume of the rotary engine is generally expressed by the unit chamber volume and by the number of rotors. For example, with the model 13B two-rotor rotary engine, the displacement volume is shown as "654cc $\times$ 2".

The unit chamber volume means the difference between the maximum volume and the minimum volume of a working chamber, while the compression ratio is defined as the ratio between the maximum volume and the minimum volume. The same definitions are used for the reciprocating engine. In the figure shown on the next page, the changes of the working chamber volume of the rotary engine and the four-cycle reciprocating engine are compared. Although, in both engines, the working chamber volume varies smoothly in a wave shape, there are two distinctive differences between the two engines. One difference is the turning angle per



Comparison with Reciprocating Engine-2

■ The drawing here shows the volume change of the working chamber along with the working process, respectively for the reciprocating engine and the rotary engine. As seen here, the reciprocating engine runs two turns while completing the four processes, whereas the rotary engine runs three turns. When the output shaft speed is the same, the rotary engine can spend more time for one process than the reciprocating engine.

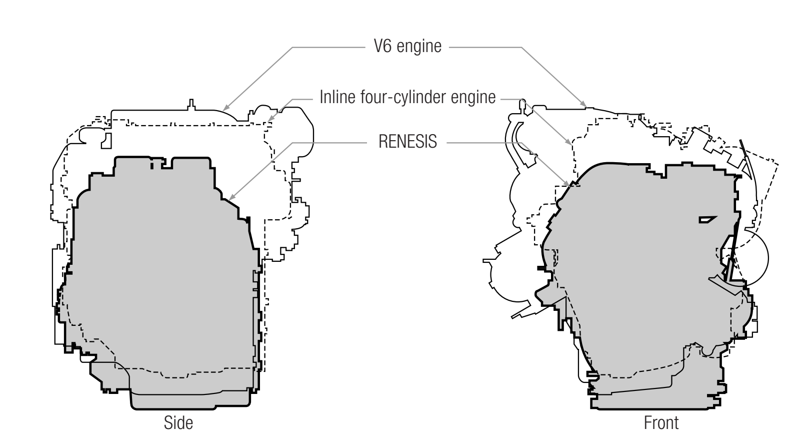
process. The reciprocating engine turns 180 degrees while the rotary engine turns 270 degrees, one and half times that of the reciprocating engine. In other words, in the reciprocating engine, the crankshaft (output shaft) makes two turns (720 degrees) during the four processes, while in the rotary engine, the eccentric shaft (output shaft) makes three turns (1080 degrees) while the rotor makes one turn. In this way, the rotary engine has a longer process time, causes less torque fluctuation and results in smooth operation. Furthermore, even in high speed running, the rotor's rpm is comparatively slower, thus, the more relaxed timing constraints of the intake and the exhaust processes facilitate the development of systems aimed at attaining higher performance.

■ Unique Features of the Rotary Engine

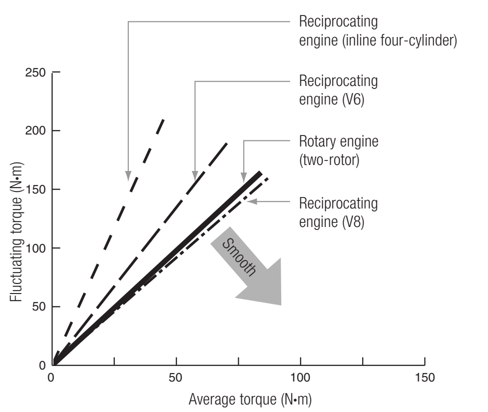
(1) Small Size and Light Weight

The rotary engine has several advantages but the most important ones are reduced size and weight. Where the two-rotor layout is considered equivalent to the inline six-cylinder reciprocating engine in quietness and smoothness of operation, the rotary engine can be designed to be two-thirds of the weight and size while achieving the same level of output. This advantage is very attractive to automobile designers especially in light of the recent trends toward stricter requirements in crashworthiness (collision safety), aerodynamics, weight distribution and space utility thus putting the rotary engine in the spotlight once again.

Comparison of Dimension



Comparison of torque fluctuation Rotary engine and reciprocating engine



(2) Flat Torque Characteristics

The rotary engine has a rather flat torque curve throughout the whole speed range and according to research results, torque fluctuations during operation are at the same level as an inline six cylinder reciprocating engine even with the two-rotor design, and a three-rotor layout is smoother than a V8 reciprocating engine.

(3) Less Vibration and Low Noise

With the reciprocating engine, piston motion itself could be a source of vibration, while the valvetrain generates unwanted mechanical noises. The smooth turning motions of the rotary engine generate considerably less vibration and the absence of a valve actuating mechanism contributes to smooth and quiet operation.

(4) Simple Structure

As the rotary engine converts the expansion pressure of the burnt fuel-air mixture directly into the turning force of the triangular rotor and the eccentric shaft, there is no need for connecting rods. The intake and exhaust ports are opened and closed by the rotor movement itself. The valve mechanism which includes the timing belt, the camshaft, the rocker arm, the valve, the valve spring, etc. required in the reciprocating engine is not required and a rotary engine can therefore be built with far fewer parts.

(5) Reliability and Durability

As mentioned before, the rotor turns at one-third of the engine speed. Therefore, when the rotary engine runs at speeds of 7000 or 8000rpm, the rotor is turning one-third that rate. In addition, since the rotary engine doesn't have such high-speed moving parts as rocker arms and conrods, it is more reliable and durable under high load operations. This was demonstrated by the overall win at Le Mans in 1991.

Major Components of the Rotary Engine

■ The rotary engine has no need of a valve actuating mechanism to open and close the intake and exhaust ports and, compared with the reciprocating engine, is composed of far fewer parts. The photo below shows the RX-8's RENESIS unit disassembled for reference. The major components are:
① rear housing, ② rotor housing, ③ intermediate housing, ④ front housing, ⑤ resinous intake manifold, ⑥ intake manifold, ⑦ electronic throttle, ⑧ stationary gear, ⑨ rotor, ⑩ eccentric shaft, ⑪ exhaust manifold