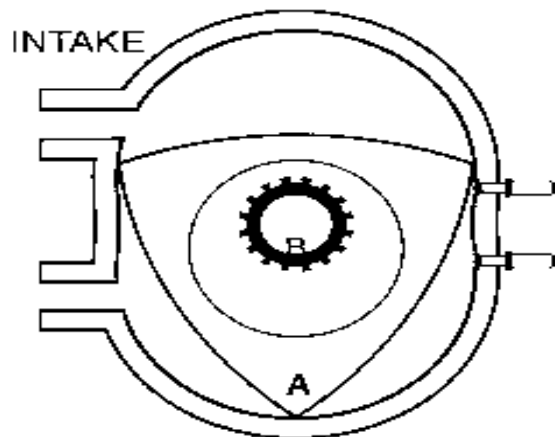


# WANKEL ENGINE

The Wankel engine, invented by German engineer [Felix Wankel](#), is a type of [internal combustion engine](#) which uses a [rotary design](#) to convert pressure into a rotating motion instead of using reciprocating [pistons](#). Its [four-stroke cycle](#) takes place in a space between the inside of an oval-like [epitrochoid](#)-shaped housing and a rotor that is similar in shape to a [Reuleaux triangle](#) but with sides that are somewhat flatter. This design delivers smooth high-[rpm](#) power from a compact size. Since its introduction the engine has been commonly referred to as the rotary engine, though this name is also applied to several [completely different designs](#).

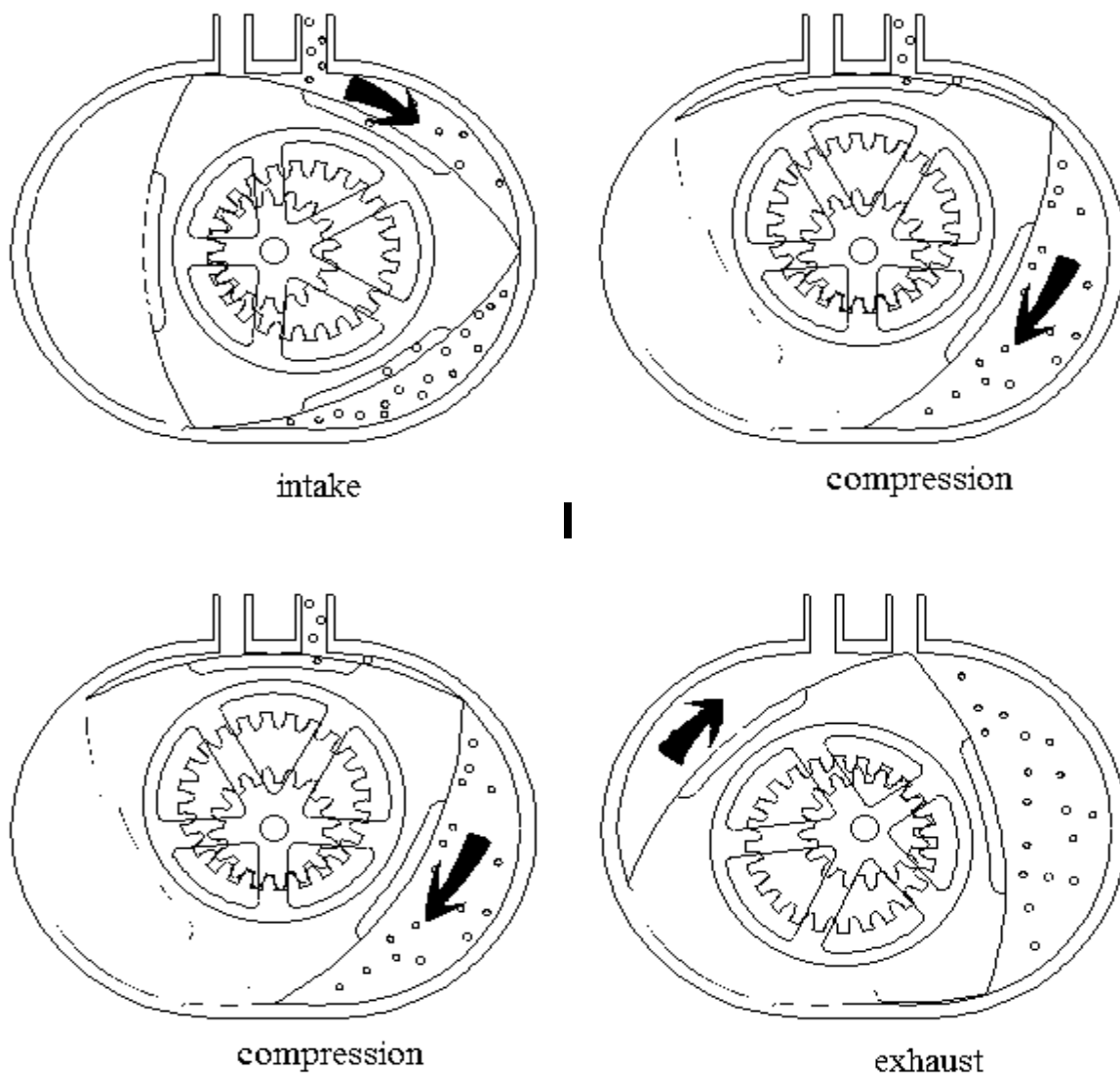
He began its development in the early 1950s at [NSU Motorenwerke AG](#) (NSU) before completing a working, running prototype in 1957. NSU then licensed the concept to companies around the world, which have continued to improve the design.



In the Wankel engine, the four strokes of a typical [Otto cycle](#) occur in the space between a three-sided symmetric rotor and the inside of a housing, although the Wankel cycle differs from Otto cycle in the duration of the expansion part of cycle, that is much longer (Columbia). In the basic single-rotor Wankel engine, the oval-like [epitrochoid](#)-shaped housing surrounds a rotor which is triangular with bow-shaped flanks (often confused with a [Reuleaux triangle](#),<sup>[14]</sup> a three-pointed

[curve of constant width](#), but with the bulge in the middle of each side a bit more flattened

While a [four-stroke](#) piston engine makes one combustion stroke per cylinder for every two rotations of the crankshaft (that is, one-half power stroke per crankshaft rotation per cylinder), each combustion chamber in the Wankel engine generates one combustion stroke per each driveshaft rotation, i.e. one power stroke per rotor orbital revolution and three power strokes per rotor rotation. Thus, [power](#) output of a Wankel engine is generally higher than that of a four-stroke piston engine of similar [engine displacement](#) in a similar state of tune; and higher than that of a four-stroke piston engine of similar physical dimensions and weight.



## Engineering

Felix Wankel managed to overcome most of the problems that made previous rotary engines fail by developing a configuration with vane seals that could be made of more durable materials than piston ring metal that led to the failure of previous rotary designs.

Rotary engines have a thermodynamic problem not found in reciprocating four-stroke engines in that their "cylinder block" operates at steady state, with intake, compression, combustion, and exhaust occurring at fixed housing locations for all "cylinders". In contrast, reciprocating engines perform these four strokes in one chamber, so that extremes of "freezing" intake and "flaming" exhaust are averaged and shielded by a boundary layer from overheating working parts.

The boundary layer shields and the oil film act as thermal insulation, leading to a low temperature of the lubricating film (max.  $\sim 200\text{ }^{\circ}\text{C}/400\text{ }^{\circ}\text{F}$ ) on a water-cooled Wankel engine. This gives a more constant surface temperature. The temperature around the spark plug is about the same as the temperature in the combustion chamber of a reciprocating engine. With circumferential or axial flow cooling, the temperature difference remains tolerable.

Four-stroke reciprocating engines are less suitable for hydrogen. The hydrogen can misfire on hot parts like the exhaust valve and spark plugs. Another problem concerns the hydrogenate attack on the lubricating film in reciprocating engines. In a Wankel engine, this problem is circumvented by using a ceramic apex seal against a ceramic surface: there is no oil film to suffer hydrogenate attack. Since ceramic piston rings are not available as of 2009, the problem remains with the reciprocating engine. The piston shell must be lubricated and cooled with oil. This substantially increases the lubricating oil consumption in a four-stroke hydrogen engine.

## Materials

Unlike a piston engine, where the cylinder is cooled by the incoming charge after being heated by combustion, Wankel rotor housings are constantly heated on one side and cooled on the other, leading to high local temperatures and unequal [thermal expansion](#). While this places high demands on the materials used, the simplicity of the Wankel makes it easier to use alternative materials like exotic alloys and [ceramics](#). With water cooling in a radial or axial flow direction, with the

hot water from the hot bow heating the cold bow, the thermal expansion remains tolerable.

## Sealing

Early engine designs had a high incidence of sealing loss, both between the rotor and the housing and also between the various pieces making up the housing. Also, in earlier model Wankel engines carbon particles could become trapped between the seal and the casing, jamming the engine and requiring a partial rebuild. It was common for very early Mazda engines to require rebuilding after 50,000 miles (80,000 km). This can be prevented in older Mazda engines by always allowing the engine to reach [operating temperature](#). Modern Wankel engines have not had these problems for many years. Further sealing problems arise from the uneven thermal distribution within the housings causing distortion and loss of sealing and compression. This thermal distortion also causes uneven wear between the apex seal and the rotor housing, quite evident on higher mileage engines. Attempts have been made to normalize the temperature of the housings, minimizing the distortion, with different coolant circulation patterns and housing wall thicknesses.

## Fuel consumption and emissions

Just as the shape of the Wankel combustion chamber is resistant to [preignition](#) and will run on lower-[octane rating](#) gasoline than a comparable piston engine, it also leads to relatively incomplete combustion of the air-fuel charge, with a larger amount of unburned hydrocarbons released into the exhaust. The exhaust is, however, relatively low in [NOx](#) emissions; this allowed Mazda to meet the United States [Clean Air Act of 1970](#) in 1973 with a simple and inexpensive 'thermal reactor' (an enlarged open chamber in the [exhaust manifold](#)) by paradoxically enriching the [air-fuel ratio](#) to the point where the unburned hydrocarbons (HC) in the exhaust would support complete combustion in the thermal reactor; while piston-engine cars required expensive [catalytic converters](#) to deal with both unburned hydrocarbons and NOx emissions.

## Advantages

Wankel engines are considerably simpler, lighter, and contain far fewer moving parts than piston engines of equivalent power output. For instance, because valving is accomplished by simple ports cut into the walls of the rotor housing, they have no [valves or complex valve trains](#); in addition, since the rotor rides directly on a large bearing on the output shaft, there are no [connecting rods](#) and

there is no [crankshaft](#). The elimination of reciprocating mass and the elimination of the most highly stressed and failure prone parts of [piston engines](#) gives the Wankel engine high reliability, a smoother flow of power, and a high power-to-weight ratio.

The surface/volume-ratio problem is so complex that one cannot make a direct comparison between a reciprocating piston engine and a Wankel engine in terms of the surface/volume-ratio. The flow velocity and the heat losses behave quite differently. Surface temperatures behave absolutely differently; the film of oil in the Wankel engine acts as insulation. Engines with a higher compression ratio have a worse surface/volume-ratio.

Due to a 50% longer stroke duration compared to a four-cycle engine, there is more time to complete the combustion. This leads to greater suitability for [direct injection](#). A Wankel rotary engine has stronger flows of air-fuel mixture and a longer operating cycle than a reciprocating engine, so it realizes concomitantly thorough mixing of hydrogen and air. The result is a homogeneous mixture, which is crucial for hydrogen combustion.

## **Disadvantages**

Although in two dimensions the seal system of a Wankel looks to be even simpler than that of a corresponding multi-cylinder piston engine, in three dimensions the opposite is true. As well as the rotor apex seals evident in the conceptual diagram, the rotor must also seal against the chamber ends.

Piston rings are not perfect seals: each has a gap to allow for expansion. The sealing at the Wankel apexes is less critical, as leakage is between adjacent chambers on adjacent strokes of the cycle, rather than to the crankcase. However, the less effective sealing of the Wankel is one factor reducing its efficiency, confining its success mainly to applications such as racing engines and sports vehicles where neither efficiency nor long engine life are major considerations.

The time available for fuel to be port-injected into a Wankel engine is significantly shorter, compared to four-stroke piston engines, due to the way the three chambers rotate. The fuel-air mixture cannot be pre-stored as there is no intake valve. Also the Wankel engine, compared to a piston engine, has 50% longer stroke duration. The four Otto cycles last  $1080^\circ$  for a Wankel engine versus  $720^\circ$  for a four-stroke reciprocating piston engine.