Production of the wankel rotary engine engineering essay

Conceived in the 1930s, simplified and successfully tested in the 1950s, the darling of the automotive industry in the early 1970s, then all but abandoned before resurging for a brilliant run as a high-performance power plant for Mazda, the Wankel rotary engine has long been an object of fascination and more than a little mystery. A remarkably simple design, it boasts compact size, light weight and nearly vibration-free operation.(Hege 2001)

History

Nikolaus August Otto of Germany succeeded in making a practical internal combustion engine in 1876, in 1886 first automobile utilizing an internal combustion engine was made. Since then, the development of the internal combustion engine for automotive purposes has been remarkable.

The history of internal combustion engine mainly consisted of engines that possessed the reciprocating mechanism. But as the matter of fact, there have been numerous challenges made, in the course of development of the internal combustion engine, to create practical rotary engines.(Yamamoto 1981)

Already around 1636, a German called Pappenheim sketched a rotary pump, which was used about 150 years later in Watt's steam engines for the first time in practice. These machines had many difficulties that could not be solved at that time.

Finally a German mechanical engineer, Felix Wankel (1902 – 1988), succeeded to solve the most difficult problem of rotary engines, sealing of the rotor. He could also answer the question of the best shape. A German motor manufacturer, NSU Motorenwerk AG at Neckarsulm, supported him a lot through out his project till in 1967 the first car using a Wankel engine, the NSU Ro 80, was produced.(Hütten 1982)

Development of Wankel engines went on so that in early 1970's the stock of companies holding pieces of Wankel technology were climbing. Major auto executives were publicly predicting, " In ten years, the entire auto industry will be 95 percent rotary"(Hege 2001).

Problem Statement

Because reciprocating engines were not efficient and reliable enough at the time they started out, engineers started searching for an alternative design.

A reciprocating internal combustion engine uses the pressure of expanding gas to move a piston through a cylinder; the piston is connected to a crankshaft by a connecting rod to convert its back-and-forth movement into a much more useful circular motion. Adding the valves system to this, we have a very complicated configuration. Here comes the problem statement of rotary engines, the reciprocating engine's have too many moving parts. Decades ago building an engine that would produce any kind of useful power meant stretching the limits of materials and design. As power goes higher the chances of the parts to break goes higher and this brings reliably down. (Wankel 1965; Hege 2001)

What is the solution? The solution is a new type of gasoline engine, a simpler engine with less moving parts. A rotary engine.

So many concepts came and went, some attracted more attention than others but the only successful design that made it into mass-production is the Wankel rotary engine.

Principles of rotary engine

The Wankel principle is so similar to Otto engine principle, only difference is Wankel uses a trochoidal (almost-triangular) rotor moving around in an epitrochoidal (almost elliptical) hosing to do the four cycles.(Hege 2001)

Here is a brief explanation of how the four cycles happen in a rotary engine:

Fig. 1

Each of the three faces of rotor is undergoing a different phase of a four-cycle engine. In this illustration, the intake is now closed on side A and compression is beginning. Side B has nearly reached the end of the expansion cycle, and side C has finished exhausting and is beginning a new intake cycle.

Fig. 2

Side A is approaching maximum compression.

Side B has opened to the exhaust port, and side C is continuing its intake stroke.

Fig. 3

Side A is at maximum compression. Ignition happens at this stage.

Side B has just opened the exhaust port, and side C is open to the intake port and is drawing in fresh mixture.

Fig. 4

Side A is being driven by combustion.

Side B is forcing out the spent exhaust gas, and Side C is at peak volume and the intake port is about to close.

By the time the eccentric shaft has moved through 360° of rotation, the rotor will only have moved 120°.(Wankel 1965; Yamamoto 1981; Hege 2001)

Source of pictures: http://www. citroenet. org. uk/miscellaneous/wankel/wankel2. html

Specification

Some main specs that Wankel had in his mind are:

A working rotary shape engine that has to accomplish Otto four-stroke cycle in a rotating chamber.

An engine power of at least equal to the existed reciprocating engines.

Smaller in size and lighter in weight compare to reciprocating engines.

Not many moving parts due to the problem of breaking.

Not having a complicated valve system due to the complicacy of it and again to eliminate moving parts.

Parts working in high temperature and high pressure environment.

Overcoming the sealing problem between two sliding metals.(Yamamoto 1981; Hege 2001)

Research and idea generation

Wankel started experimenting by modifying motorcycle engines with different designs, then he worked on a rotary compressor which had the potential of being converted to a four-stroke engine. He had two main problems with his engine; one was the sealing problem which was the main problem of these types of engines and the other was to find the best shape of rotor and housing.

To solve the first problem Wankel started studying piston rings which were still being discovered at the time but nobody understood them better than Wankel. He had learnt a lot about cylinder sealing during his own experiments and was trying to apply what he had learnt to his disk valve design. The problem of sealing a chamber is similar to sealing a cylinder but the shapes are not. Circles are much easier to drill, plug or seal than straight lines or irregular shapes. Wankel tried a large body of shapes and materials under different spring tension to find the best. In most cases spring pressure needed was really quite low because the force of the gas producing most of the pressure needed for sealing.

So Wankel developed other meanings of closing the gaps, for irregular openings, he designed metal strips that would lie, inter-linked with cylindrical joint components.(Fig. 5) Using this system he could seal almost any shaped port. (Hege 2001)

Fig. 5(Hege 2001)

Wankel’s packing body seals which are so similar to piston rings.

They were made of movable parts fitted into finely machined grooves.

A network of strips connected by peg-like trunnions enabled him to seal any shape of opening against a moving surface.

The unique shape of Wankel’s engine is built around the lines drawn by rolling one circle around another. His basic shape is described by choosing a generating circle of radius equal to one half the radius of the basic circle. The resulting shape will be the two-lobe epitrochoid, the shape of the Wankel’s working chamber.(Fig. 6) (Yamamoto 1981; Hege 2001)

Fig. 6(Hege 2001)

As the gear ratio was two to three, rotating the outer gear around the inner traced path of the epitrochoid that made the working housing.(Yamamoto 1981)

The detailed design work

There are some terms Wankel used for his new shape:

Fig. 7(Hege 2001)

A= minor axis; B= major axis; 1, 2, 3= working chambers; C= mainshaft centre; D= eccentric centre; E & F= phasing gears; G, H, I= Rotor apexes; J, K, L= rotor normals; M= point where rotor normals intersect and also intersection of phasing gears; Î³= leaning angle of apex seals; distance D-H= radius of rotor.

Ratio of = = K factor

Wankel also tried three-lobe housing instead of two in his experiments but his early experiments were done without any mathematical analysis. Professor Othmar Baire did the mathematical analysis and found that the possibility of different shapes was practically endless, but Wankel focused on the characteristic of compression potential and the leaning angle of the apex seals.

K factor (the ratio of the radius of the rotor divided by the eccentricity of the engine) plays an important role, once the K factor is determined by the designer, the variations in compression are limited by the engine’s dimension. If the K factor is low, the engine can be very small for its displacement, but its potential compression will be low and the apex seal leaning angle will be very high as the seals must cross a very tight chamber waistline. Most practical Wankel applications have a K factor between 6 and 10 as engineers try to find a compromise between physical size, seal leaning angles and many other considerations that come into play.(Yamamoto 1981; Hege 2001)

First working engine

By solving the main problems of the engine, Wankel with the help of his old friend, Ernest Hoeppner, finally converted his compressor to a working engine, it took them over three years to do so. But this product was hardly close to what we know as the Wankel rotary. The first engine was labeled DKM54 in February 1957, 54 indicating the displacement in cubic meter. But this was just a test prototype which had so many problems such as complicacy of the shapes to seal. But Wankel had spent so many years developing a sealing system for his engine and here was his opportunity to test it. The most important part to seal was the apex seal, because at any time, all three rotor faces are engaged in different portions of engine's working cycles. It is the job of the apex sealing to keep these processes separated from each other.(Hege 2001)

Fig. 8 shows the Wankel's original apex sealing.

Fig. 8(Hege 2001)

Wankel's original apex sealing which used strips of a sealing material, ride in grooves cut into the rotor tips.

They are lightly spring loaded, to assist sealing only in start up.

When the engine is running, the centrifugal force on the seals is enough to keep them pressed against the surface of the inner rotor.

A few month after the DKM54 a larger version was built, the DKM125.(Fig. 9) But neither the DKM54 nor the DKM125 was at all practical because the centre shaft was stationary. Walter Froede, NSU chief engineer, was already working on that problem, while the DKM motor was being built Froede began work on a modified version, he converted the outer rotor to a stationary housing and made the central mainshaft a moving piece which would be the output shaft. The new engine was dubbed the KKM125. (Fig. 10) (Hege 2001)

One of the issues of these types of engines at this time was to evaluate the displacement and classify the Wankel. Not only for the engineers themselves, even for the governments, because they must tax anything that moves. Later it would also become important for racing officials as they tried to decide where to allow the Wankel-engined cars to compete. After lots of discussions everyone agreed to multiply the maximum chamber volume by two and multiply that figure by the number of rotors.

The new KKM125 engine also introduced its own set of problems such as vibration of the engine (it was not as completely vibration-free as the original rotary) and turbulence of oil inside the rotor (the rotor was oil cooled). (Hege 2001)

Froede and his staff worked on all these problems till a well-developed version of the KKM125 developed 26 horsepower at 11, 000 rpm, a respectable output for an engine that only weighed 37. 5 pounds (17 Kg). By mid-1959, a larger version (KKM250) was built and undergoing testing.

Finnaly in 1960, the 250 was installed in a standard NSU Prinz, a basic sub-compact car already in production. It did drive but it was crude and difficult to drive, and it proved that the Wankel could be adapted to automotive use. Later the KKM400 was built, a larger version of the KKm250. It could produce 40 to 50 horsepower. The NSU Sport Prinz was produced which was easier to drive, smoother and more powerful.(Hege 2001)

Fig. 9 Patent drawings for Wankel’s DKM engine(Hege 2001) Fig. 10 Patent drawing for the KKM engine(Hege 2001)

Further development

On October 21, 1958 Curtiss-Wright (an American aircraft and engine manufacturing company) became the first company to purchase a license to produce Wankel engines for $2. 1 million and a 5 percent commission on all Wankel engines that Curtiss-Wright would build or sell. Curtiss-Wright engineers started studying all aspects of Wankel design, they had settled on a design of 60 cubic inches, IRC6, which developed 100 horsepower at 5500 rpm in its first dyno test, in 1959.(Hege 2001)

In 1963, Charles Jones began work on a twin rotor version of RCI60 (sport version of IRC6), it was named RC2-60 U5.

Curtiss-Wright engineers worked a lot on the problems of their engines and finally in 1965 the RC2-60 engine reached a point in its development where it was comparable to piston type automobile engines. A 1966 Ford Mustang was the first test car for the RC2-60 U5 engine. It was tested by Jan Norbye, automotive editor for Popular Science magazine.(Hege 2001)

“ It had a steady idle at 800 rpm and a dab on the throttle sent the revs up to 2000 in a flash. Above 2000 rpm it began to develop a new sound, a sound I had never heard before….

As the engine began to wind, the pitch was lower than turbine’s, although there was something of a turbine in it. Yet it had the evenly pulsating rhythm of a good six in perfect tune…without any indication of reaching top speed when pushed to the 6000 mark. It would seemingly go on and on accelerating forever.”(Jan 1966)(p. 102-107)

Max Bentele (a German engineer working for Curtiss-Wright) designed and developed the first four-rotor Wankel engine (4RC-6) which produced 425 horsepower at 6500 rpm.(Fig. 11)(Hege 2001)

Fig. 11 Patent drawings of Curtiss-Wright’s four rotor Wankel designed by Max Bentele(Hege 2001)

By 1966 Curtiss-Wright had designed, developed and tested Wankel engines from one extreme to the other. They were the first to build a multi-rotor engine, and they had built the largest (1920 cubic inches, 872 horsepower at 1525 rpm) and the smallest (4. 3 cubic inches, 3. 5 horsepower at 4000rpm) Wankels yet.(Hege 2001)

Mazda

In October of 1960, Matsuda president of Toy Kogyo (Mazda) and five of his technical staff went to Germany to work on an agreement with NSU. On October 12 the agreement was signed and a KKM400 prototype engine, with plans and drawings were sent to Toyo Kogyo.

Kenichi Yamamoto (chief engineer of Wankel project) believed that the rotary engine’s problems were because the metallurgy and machining technology of the time were not up to the rotary’s advanced design, so he gathered a small team of metallurgist, designers and engineers to study and work on the problems existed. They approached the problems by experimenting with new materials and techniques for using them, hoping to find the right combination.(Hege 2001)

In 1961 they built their first production model, 110S, after having a pile of about 5, 000 junk rotary engines. It was designed with light-alloy rotor, iron end covers and aluminum trochoidal housing. The surface of the housing was electroplated with chromium. This produced hard, smooth surface for the seals to ride on. The seals were fairly soft, made of a carbon-aluminum composite. They solved most of the problems just by choosing the right material for the job. They also found some new techniques to make the production faster and hence cheaper. (Such as the transplant coating process, which reduces the time that the trochoidal housing has to spend in the chromium plating tank).(Hege 2001)

In 1963 Mazda had its first prototype of production rotary car, The Mazda Cosmo. (Fig. 12)

Figure 2 (source: http://www. earlydatsun. com/cosmo. jpg)

Since then Mazda has been producing many different types of Wankel-powered cars and is the only Wankel rotary producer today (RX-8).

There were so many other companies bought the Wankel’s license such as Fichtel & Sachs AG, Yanmar Diesel Co. Ltd., Daimler-Benz AG, Rolls-Royce Ltd, and etc.(Hege 2001)

Some of products produced by these companies are, NSU RO 80, the Citroen M35, the Mercedes-Benz C111, and etc.

Emission regulations

In 1970, Nixon established two new agencies for the purpose of researching and enforcing government environmental policy, EPA (Environmental Protection Agency), and NOAA (National Oceanic and Atmospheric Administration).

With the passage of Air Pollution Control Act of 1970, emission standards for automotive exhaust were set.(Hege 2001)

Up until now, the Wankel had been considered a relatively “ dirty” engine, with HC (unburned hydrocarbons) output nearly three times that of a piston engine, mostly because of the high surface to volume ratio of a Wankel engine. Other harmful components of auto exhaust are carbon monoxide (CO) and oxides of nitrogen (NOx).

To solve this problem studies started at University of Michigan with the request of Curtiss-Wright.

Experiments at the University of Michigan focused on the use of a thermal reactor and air injection to clean up the exhaust after it left the engine.

A thermal reactor is basically a heat stove, which keeps the exhaust temperature up so that the remaining fuel (HC) is burned up. In most designs, extra air is pumped in at the engine exhaust port to maintain the reaction. Many tests were done on an RC2-60 U5 and the results proved that using the thermal reactor and air pump reduces the HC content by 90 percent, so Curtiss-Wright Wankel engine could be gone in the market with current laws.(Hege 2001)

At he same time Mazda also was working with a thermal reactor and air pump system. They also achieved good results with their twin sparkplug system, as they could shut down the trailing ignition during certain operations (Fig. 13). Results were so positive that in the spring of 1972, they announced their engines would have no trouble meeting 1975 U. S. emission standards.(Hege 2001)

Figure 13(Hege 2001)

Upcoming technology even made the Wankel look even better, therefore American companies like General Motors and Ford were more interested in Wankel engines. But among all these American companies Mazda became the most successful company in selling rotaries in America. While in 1970 Mazda sold only 2000 cars, in 1971 they sold 21000 and in 1972 62000. And they openly predicted selling 300, 000 cars in America in 1975.(Hege 2001) But things didn’t go on as they expected.

The EPA tested Mazda’s cars and the results showed a gas mileage of just over 10 miles per gallon in city driving. Mazda didn’t want to accept this figure and they published their own figures, but in time of high gas prices, the damage was done, and the Mazda rotary had become infamous as a gas guzzler. Other problems of Mazda’s cars were the early breakdown and also not existence of enough rotary mechanics. In January of 1974, sales fell off by over 50 percent from the year before.(Hege 2001) This was almost an end for Mazda rotary as a passenger car but future marketing would be to focus on the rotary’s qualities as a high performance engine.

While other companies were dropping their rotary programs, Mazda held on until it was the only major manufacturer of rotary engines left. They worked on it and improved their engine's gas mileage and reliability and introduced their comeback car in May of 1978, the RX7, a two-seat sport coupe which put the rotary in the performance market where it belonged.

Wankel, as it is, has done well, it made a niche for itself in markets where high power to weight ratios are important. It is getting better and better as the material science advances and it might someday be able to match the efficiency of piston engines.

Source: http://www. citroenet. org. uk/miscellaneous/wankel/wankel2. html

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