MX-30 e-SKYACTIV R-EV[1] Press Material

8C Rotary Engine Production: Tradition and Cutting-Edge Manufacturing Technology

【Contents】

[1] Mazda MX-30 e-Skyactiv R-EV (125 kW / 170 PS): WLTP fuel consumption (combined) 1.0 l / 100 km; WLTP CO2 emissions (combined) 21 g / km. WLTP electric energy (combined) 17.5 kWh / 100 km.

Introduction

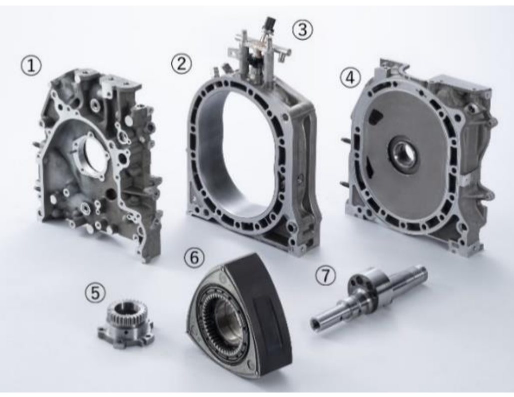
■ MX-30 e-SKYACTIV R-EV & the rotary engine

The MX-30, Mazda's first mass-production battery electric vehicle released in 2020 is based on the concept of "living true to yourself." It has offered a genuinely pleasant drive, congenial design, and distinct cabin space created with warm materials—all elements that make time spent with the car and experiences enjoyed alongside it creativity-inspiring for owners. The MX-30 e- SKYACTIV R-EV is a series plug-in hybrid that continues to deliver the same customer value as the original MX-30 while simultaneously offering owners new ways of using their car as a battery electric vehicle. The MX-30 e-SKYACTIV R-EV has an 85 km battery electric driving range[*1] sufficient for a wide range of everyday driving needs as well the ability to use a generator to enable long distance drives. On top of this, the entire driving range is motor-powered.

The rotary engine was chosen to power the generator system. Mazda began developing the rotary engine in 1961, an effort which took six years to successfully mass-produce the world's first rotary in 1967. A crisis precipitated in the 1970s when the rotary engine was almost withdrawn from the market, even so Mazda engineers believed in the rotary engine's potential and continued their relentless challenge. Although production of the Mazda RX-8 was discontinued in June 2012, R&D on the rotary engine continued in the determination never to allow the light on this technology to extinguish. Now, after almost 11 years, the rotary engine has returned to generate power in the age of electrification.

■ Rotary engine structure and production

The rotary engine's chief components are a triangular-shaped rotor, cocoon-shaped rotor housing, and side housings hold these workings. In the chamber between the housing and rotor, the mixture of fuel and air combusts, turning the rotor as the pressure swells.



① Side housing (front)
② Rotor housing
③ Direct injector
④ Side housing (rear)
⑤ Stationary gear
⑥ Rotor
⑦ Eccentric shaft

*1: Electric-only driving range: 110 km for European WLTP city mode and 85 km for European WLTP combined mode. Range values are for when EV mode is selected. These values are based on specific test conditions and actual electric-only driving range will vary depending on actual driving conditions. Additionally, in situations such as if the driver needs to accelerate suddenly and purposefully depresses the accelerator pedal significantly beyond a certain point (equivalent to the kickdown switch function on a standard automatic transmission vehicle), the rotary engine generator will activate and generate the energy for the required output.

Every rotary engine that Mazda has turned out has been produced at the Mazda Hiroshima Plant. This tradition is carried on by the new 8C rotary engine for the MX-30 e-SKYACTIV R-EV. Production comprises processes for materials where iron and aluminum are used to cast the rotor, housing, and other key components, machining that grinds and polishes materials and machines functionally-necessary groves, holes, and other cuts necessary for components to function, plating which further treats surfaces to make them stronger and more durable, and, then the components are finally assembled and auxiliary devices mounted to construct one engine. Each rotary engine goes through many processes for each component over the course of production.

Even though Mazda discontinued production of the MAZDA RX-8 in June 2012, the manufacturing facilities have continued to be utilized with periodic maintenance to produce and supply replacement parts for the 13B rotary engine. Nevertheless, it has actually been 11 years since we launched production of a new rotary engine with a different structure and performance requirements. In embarking on this endeavor, we faced three significant challenges.

■ **Launching production of the first rotary engine in 11 years**

The first challenge we faced was the pursuit of balanced precision. The 8C rotary engine has a displacement of 830cc and one rotor. Compared to the 13B rotary engine with a displacement of 654cc and two rotors, the generating radius, which comprises the area to top of the triangle from the center of the rotor's gyration, was extended from 105mm to 120mm and the switch made to a single rotor. While this is the size necessary for one rotor to generate the output required for a generator, the radius of rotational motion is larger but without another rotor to cancel out vibration. One would be hard-pressed to say such a structure is advantageous in terms of vibration. Hence, what we sought to achieve was a more precisely balanced rotor. Throughout the 8C rotary engine production process, this goal was consistently pursued in each step of casting, machining and assembly in an effort to realize a smooth rotation.

The second challenge was to make it stronger. Today as the world transitions toward full-scale electric vehicle use, weight reduction is key for ensuring EV driving distance and allowing the battery-powered EV to be used in a wide range of daily situations. Creating a side housing out of aluminum was a challenge that we faced with the 8C rotary engine in an attempt to reduce total vehicle weight. Mazda adopted an aluminum side housing only for the 10A rotary engine mounted on the first version of the Cosmo Sports car, but later all mass-production rotary engine side housings were made of cast iron. Although we anticipated a weight reduction of approximately 15 kg just from the engine alone by making the side housing out of aluminum, we were faced with the problem of how to ensure the strength of surfaces along which the rotor slide at high speed without a decrease in material strength. Engineers conducted simulations to replicate techniques for casting SKYACTIV engine cylinder heads, which were similarly made of aluminum, to optimize the side housing casting, partnering with a new thermal-spraying technology to ensure the necessary strength. This is how aluminum side housing was revived after roughly 60 years.

The third challenge was flexibility. Today in the transition to electrification, progress is made in different degrees in different markets. Besides battery EVs, there are a variety of other options available, such as hybrid vehicles (HEV), plug-in hybrid vehicles (PHEV), and so on. Demand for these types of power units varies depending upon regulations and other factors. To create a new rotary engine in this age, what production technology engineers insisted upon when designing the machining process for the 8C rotary engine was not only to possess the ability to machine with greater precision than ever before, but also to put in place a flexible line with the potential to accommodate changes in demand for electrification. In other words, the aim was to arrange a production line that would be able to machine not only components for the 8C rotary engine, but also other components and other vehicle models.

In launching production of the first new rotary engine in over 11 years, challenges were faced by not only production technology engineers, but also the plant where actual production would take place. Based upon proprietary technology handed down in-house over the years, new manufacturing approaches and methods, which were developed with SKYACTIV technology, were incorporated. These supported quality achieved with intuition handed down unchanged by craftsman. The story of those challenges is presented along with the newly adopted production technology.

8C rotary engine production process and technology

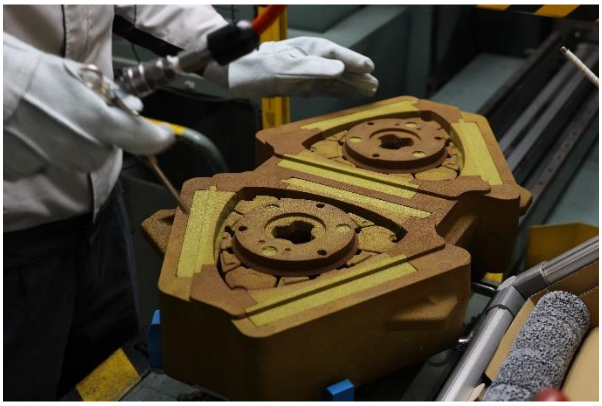
1. Materials process

■ **Rotor: Casting iron with the precision of a grain of sand**

The triangular-shaped rotor, which some see as symbolic of rotary engine, is produced in a casting process where molten iron is poured into a mold to harden. The mold is prepared by baking sand, which contains a special adhesive called resin-coated sand, at a high temperature and using a process suitable for casting complex shapes like rotors. The pursuit of a precise weight balance of the rotor begins with casting this mold.

The mold into which molten iron is poured is prepared by combining multiple sand molds. The sand mold for creating the hollow section of the rotor, known as the core, is the one of the most important steps and the dimensional precision of rotors cast using this mold varies significantly. With the 8C rotary engine, we reworked the structure of the metal mold for forming the core and switched from a mechanical link mechanism to an actuator slide type, which improved clearance between the sand mold and the metal mold from 0.4mm to 0mm.


Metal mold for fabricating the rotor core


Multiple sand molds combined by hand to construct a casting mold

Moreover, the work of pouring the molten iron into the casting mold was automated for the 8C rotary engine. Previously, the work of pouring red hot molten iron at a temperature of approximately 1400°C into a sand mold was done by skilled craftsmen who poured the iron at a consistent speed while adjusting the angle of the ladle (container used for carrying and pouring liquid metal, a metal which has been melted during the casting process). However, working in close proximity to high-temperature molten iron is physically demanding. That makes it more difficult to ensure stable quality during this process. With the new 8C rotary engine, a model-based technology is utilized in reassessing casting methods to develop technology where this work is performed mechanically. This makes it possible to achieve high-precision casting with a difference in temperature of ±10°C at each part that occurs after the iron is poured, enabling variation to be controlled that might occur due to any variation in deformation resulting from heat shrinkage.

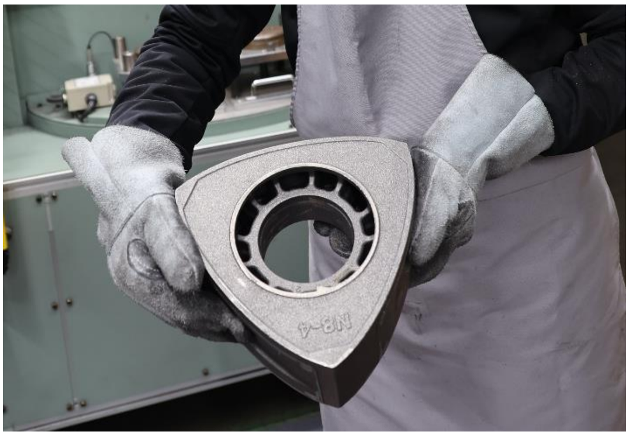
Pouring molten iron into a mold

Rotor material taken out from a mold

In addition, we adopted a new pre-verification technology. This makes it possible to predict the precision of the rotating balance during the casting process. Previously, verification was only possible once the rotor was actually rotated during the final process of machining. A 3D scanner is used to create a 3D model of the sand mold, a step pivotal for fabricating the rotor. The data is then studied so the balance may be analyzed virtually without casting or other processing.

3D scan of a sand mold

Each particle of sand for forming the sand mold has a diameter of roughly 0.2mm. The degree of precision serving as the standard when casting the rotor for the 8C rotary engine is ±0.3mm. All 8C rotors sent from the materials process to the subsequent machining process are expected to meet this standard.Hitoshi Kojima, the work station foreman, said, “Beginning right from the material stage, we are casting iron at a precision of one particle of sand.”



Completed rotor material

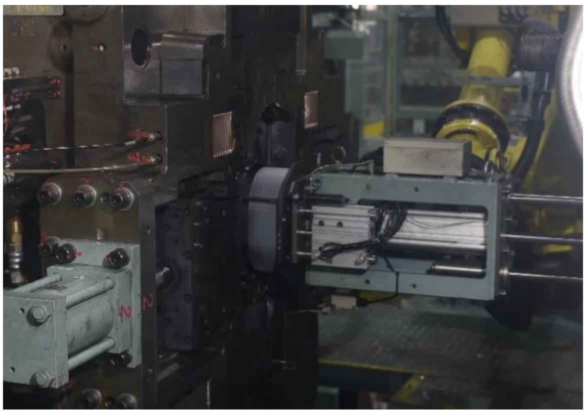
■ **Rotor housing: New die casting machine for high-precision casting**

Production of the rotor housing, the equivalent of a cylinder block in a reciprocating engine, begins with formation of the steel sheet metal comprising the inner wall surface that comes into contact with the top of the rotor. First, to ensure adhesion with the aluminum on the outer surface, fine grooves are cut like a grater. These are called toothing. The sheet metal in which toothing cuts have been made, is snipped so it is the length of the circumference of the inner wall surface . After the joints are welded, it is formed into the shape of a cocoon.


Ground sheet metal


Cocoon-shaped sheet metal

This sheet metal is set into a die casting mold, after which molten aluminum is injected along the outer circumference to cast the rotor housing. With the 8C rotary engine, a cutting-edge diecast machine has been newly introduced that fills the metal mold with molten aluminum in a process that is precisely controlled. A die casting mold, corresponding to the interior of a metal mold is a high vacuum, is used along with a multi-articular robot to fill the mold with molten aluminum. Using even more intricate controls, a highly precise cast may be made.


Setting sheet metal into a die casting mold


Cast rotor housing without any unnecessary parts

- **Side housing: Applying SKYACTIV engine technology to convert to aluminum and achieve high-strength**

With the exception of the 10A mounted on the first edition Cosmos Sports car, the side housing, which comes into contact with the sides of the rotor rotating at high speed and shaped to hold the rotor, is manufactured using cast iron. With the 8C, the iron was replaced by aluminum for the side housing to reduce engine weight, achieving a reduction of 15 kg or more (approximately 20%) just from the engine alone.

On the other hand, aluminum is not as strong as the conventional cast iron. So, we introduced a Mazda-proprietary casting method called Advanced Precision Mazda Casting (APMC). This method picks the best metal mold capable of cooling in a short period of time and sand suitable for forming complex shapes. The technology has been put to practical use in production of the SKYACTIV engine cylinder heads.

Utilizing the model-based technology, a method was developed for injecting aluminum, allowing for a light-weight shape with a thin-walled side housing for the 8C rotary engine. The complex thin-walled components achieve both a light weight and high-strength by having the aluminum reach every nook and cranny of the sand mold and applying a cooling plate (metal mold) having high thermal conductivity to the sliding surfaces that require strength to rapidly cool the area to form a precise metal structure.


Upper gray component is a metal cooling plate


Electromagnetic pump packs liquid aluminum

2. Machining process

■ **Rotor: Integrating steps to enhance machining precision**

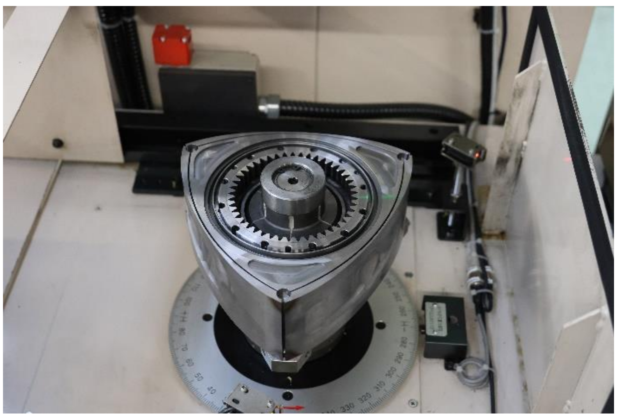
Components fabricated in the materials process are sent to the next step for machining. This step cuts the materials and machines grooves, holes, and performs other milling and grinding necessary for functionality as well as grinds and polishes machine surfaces in preparation. During this step, grooves are cut in which the apex, side and other seals as well as auxiliary components are inserted on the rotor.

Making sure the weight is precisely balanced is also an important step in rotor machining. During this step, the rotor is handed off from one robot to the next in a process that cuts and grinds during each step of the way. Small deviations develop each time a machine jig clamps onto the rotor. On account of this, the process designed for the 8C rotary engine significantly reduced the number of rotor cutting steps from 50 to 9. As the frequency at which the rotor is held by the different machines decreased, the degree of precision rose.

In addition, the work of adjusting the balance, which takes place after cutting and grinding, is done automatically by applying a processing technology that measures and corrects to process the combustion chamber of the SKYACTIV engine, thereby further improving the balance precision. Work that used to be done manually is now performed for the 8C by measuring the balance to calculate the amount for adjustment, which is sent to processing machinery where a decision is made using touch sensors regarding the amount to be corrected along with any variation, then employing end mills to perform the adjustment processing. The highly precise machining achieved during these steps is called Donpisha Processing internally at Mazda.

Also, machinery used on the machining line is the same as that for machining the reciprocating SKYACTIV engines. Currently, this takes place on a dedicated line for the rotary engine, but the potential is there, if the jigs are reset, for it to also be used for machining electric components someday, not just other engine parts. A production line has been designed that offers the flexibility to be able to accommodate changes in demand in the age of electrification.

Rotor machining line



Measuring machined rotors to calibrate the weight balance

■ **Rotor housing: Digitalizing predecessors' know-how through co-creation with local suppliers**

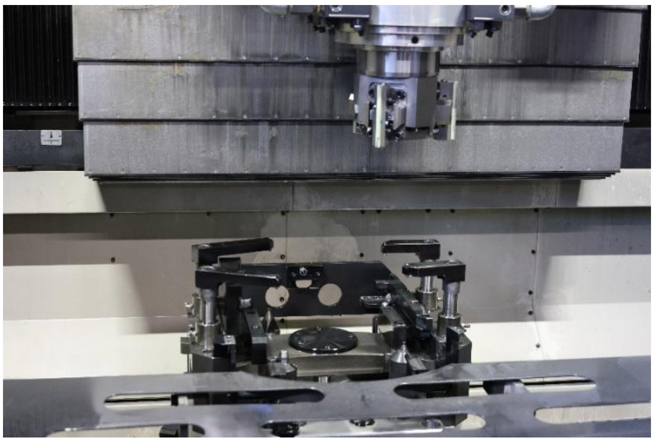
The rotor housing is a component that is specially formed into a cocoon shape. That is why the honing machine, which polishes the inner wall surface needs to be more specialized and complex than equipment used for polishing the cylinder blocks of a reciprocating engine. When adopting a honing machine for the 8C rotary engine, it was necessary to introduce a new honing machine with improved flexibility that made it possible to utilize such equipment as well as the equipment for the 13B, which was continuing to be shipped as a replacement parts.

The key was digitalizing the honing process, using a numerical control (NC) program. The conventional machine control equipment was only able to process the 13B, but adoption of the NC program made it possible to provide optimal honing while syncing the multiple axes driving grinders and the rotor housing in a manner adjusted to each specific rotor housing.

However, as there had been no previous attempts to digitally control the honing machine for specially-shaped components such as a rotor housing and no new equipment had been introduced in a long time, there was a dearth of relevant know-how even within Mazda itself. A very difficult issue was faced particularly in optimizing the program to accommodate variables with the 8C and 13B models, such as suppressing the machining vibration occurred due to switching the 8C and 13B as well as adjusting the surface pressure when the honing stones went over the exhaust port holes only on the 13B.

It was local companies in Hiroshima that extended their cooperation to find solutions to these challenges. Interviews were conducted in the search for experience and know-how possessed by individuals from local companies involved in designing machinery used when previously processing rotary engines. Fact-finding missions were conducted to research old prototype equipment as well as mass production facilities for the 13B introduced 40 years earlier and used until recently. Then, the NC program was repeatedly fine-tuned while referencing the knowledge and results of research gained through those activities.

Co-creation with local companies made it possible to work out adoption of new honing machines for both the 8C and 13B.

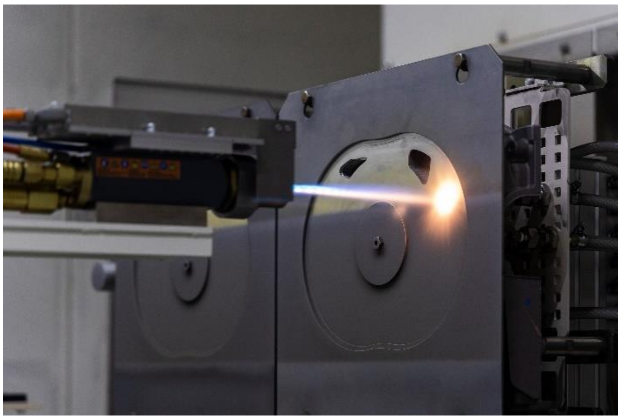


Honing machining capable of polishing both the 8C and 13B rotor housings

■ Side housing: New spraying technology to reduce abrasion

When creating an aluminum side housing for the 8C rotary engine, issues were faced with the deterioration of oil consumption due to a decline in performance with the oil seals, friction when sliding along the side housing, as well as between oil seals and side seals on the rotor side. So, an effort was made to reduce friction resistance and abrasion to ensure oil seal function. A cermet spray was applied to the side housing, using a high-speed flame method that afforded a good fit with the oil seal in addition to high abrasion resistance.

High-speed flame spraying is a coating technique where the coating material is heated with a high velocity flame so it melts and accelerates up to supersonic speed, then brushed on the surface of the material. The crushed particles solidify and accumulate evenly so that a fine film forms. Spraying the aluminum side housing went through a process of trial and error by cooling it using air on the reverse side and spraying over a wide area to achieve a practical method that would be able to form an even film without any deformation of the soft aluminum material. This technique was successful in improving the hardness of the surface of areas where the rotor moved along the smooth surface of the side housing inner walls regardless of the change of the material from cast iron to aluminum.



High-speed flame method of cermet spraying

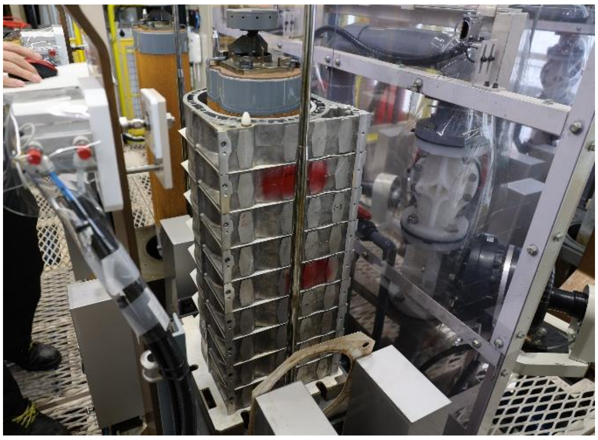
3. Plating process

■ **Rotor housing: Plating technology that supports lubrication and abrasion resistance**

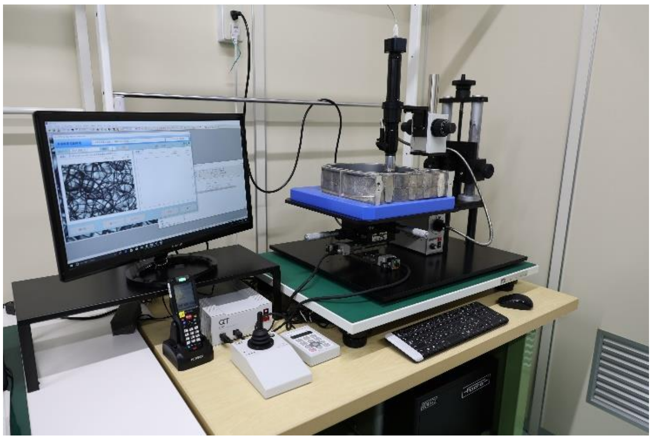
Once it has gone through the cutting process, balance inspection, and other steps, the rotor housing is then carried to the plating process where the interior wall surface is plated. Because this process ensures airtightness which affects performance of the rotary engine, it consequently reduces wear and tear. The rotor housing has always been plated to reduce abrasion, which was improved for the 8C with a plating process providing a very low frictional resistance, making it even easier to maintain an oily film of lubricant.

The goal in developing the new plating process, which began roughly 5 years ago, was to enable a plating layer of a quality significantly exceeds that of the 13B to be deposited quickly over a short period of time. The thickness of the deposited plating layer is 150 μm or 0.15 millimeters. To keep the oil which is necessary for lubrication evenly across the surface over which the rotor slides, very fine grooves for oil to collect are prepared and the width and number of grooves per unit of area need to be kept within standard. Also, the entire layer of plating must maintain the same level of quality no matter what depth up to a thickness of 150 μm. Satisfying all of these performance requirements makes it possible to realize engine performance that is stable and deteriorates little over years of use.

In addition, the amount of time required for depositing the layer of high-speed chrome molybdenum plating, developed for production of this 8C rotary engine, was successfully shortened from the previous 6.5 hours down to 3 hours. The plating process is also able to be performed at our own plants because Mazda had previously manufactured a rotary engine and possesses accumulated significant know-how from that experience.



Plating tank for 8C rotary engine



Microscope used to verify condition of oil grooves in the plating layer

4. Assembly process

■ **Intuition handed down over generations of craftsmen maintains the ultimate quality**

After passing through the materials and machining processes, each 8C rotary engine component is stamped with a two-dimensional code for production data control and traceability. These are then put together at the rotary engine assembly plant where a hoist, known as a J Bar, transports the parts in one corner of the west section of the headquarters plant where the engine assembly line is set up. There is a room partitioned off exclusively for assembling rotary engine internals. This room is called the RE Takumi Workshop. Craftsmen carefully assemble by hand each component, including seals, springs, and other parts for the rotor. There are only three individuals in the entire company who have passed the rigorous internal standard qualifying them to perform the assembly work. When production of the 8C rotary engine was launched, a technology was adopted that improved work precision using cutting-edge image processing for processes checked visually. However, the delicate manual work performed by these craftsmen is essential in this process where the rotor is assembled, while checking for reaction force of the springs and the fit of seals. The keen sense that these skilled craftsmen possess maintains the final quality when one rotary engine is finished being assembled with components for which a high degree of precision has been consistently pursued throughout the materials, machining and plating processes.

It feels as though perhaps this manual work is something that proficient senior workers are able to shoulder, but, in fact, there are many young employees engaged in the assembly process. In one corner of the plant, there is a room called the Engine Assembly Skill Training Site. It is there that skills are passed each and every day, allowing rotary engines to continuously be built over the years ahead. These techniques are passed to ensure they will be carried on in the future as well.

These assembled rotary engines are checked to ensure functionality at each of the quality assurance gates during the assembly process. Auxiliary parts are attached to complete the entire engine and motoring tests conducted to ensure all engine functions, including pressure in the combustion chamber as well as looking for any abnormal noises or vibrations. Finally the ignition test is conducted to inspected the actual state of the engine combustion and literally fire up the engine. This is how one 8C rotary engine is produced.


Gas seals are assembled by hand

Team members involved in rotary engine assembly

Interview with Engineers

■Hiroshi Yamamura, Production Engineering Development Promotion Department, Production Engineering Division

"The approach taken is to streamline production of the 8C beginning with the materials stage through machining and assembly. That is what we refer to as the pursuit of precision balance. Because the 8C only has one rotor in contrast to the previous model, we have gone all out from the time this rotary engine was on the drawing board through all production processes. All engineering divisions involved in production have done their utmost in the pursuit of precision. That translates into the proper fabrication of components beginning from the material stage in order to pursue precision in all processes based on the approach of Donpisha Processing to properly realize functions during assembly. In addition, during 8C production, we have been fully making use of knowledge developed in engineering the SKYACTIV engine. Design of a production line allowing flexibility with an eye toward multiple uses in the future, the integration of processes, the APMC method, traceability for quality assurance, and so on are all activities that have been streamlined first with the SKYACTIV technology."

■Hiroshi Yoshida, Production Engineering Development Promotion Department, Production Engineering Division

"All of the engineers engaged in each of the processes, not just the designers, have given a total effort to each aspect of the production process to mass-produce a rotary engine for the first time in roughly 11 years since 2012. We have used the latest machine tools and instruments in confronting the challenge of achieving high-precision manufacturing in all areas. Even so, the ultimate key in this process is people, that is the skills maintained by craftsmen. To deliver the best product to our customers, each and every engineer is wholeheartedly engaged in manufacturing these rotary engines."

Hiroshi Yamamura
Production Engineering Development Promotion Department

Hiroshi Yoshida
Production Engineering Development Promotion Department