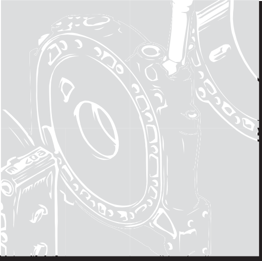
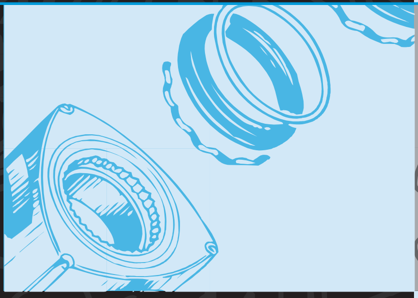
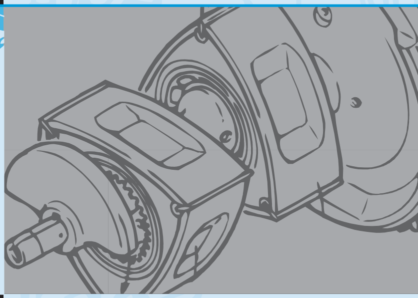


RENESIS ROTARY ENGINE FUNDAMENTALS





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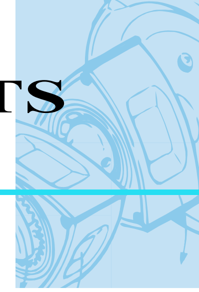

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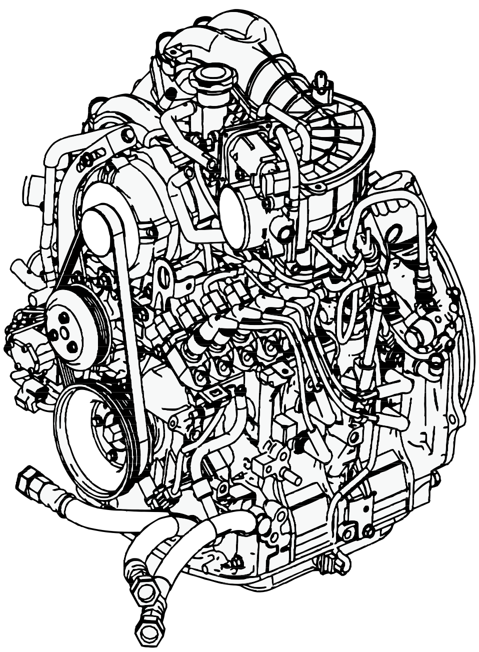


COURSE OVERVIEW

Welcome to the Mazda self-study guide, *RENESIS Rotary Engine Fundamentals*. Before you begin, please read the following information.

Audience and Purpose

This guide is designed for entry-level automotive technicians. It describes major rotary engine components and introduces the basic principles of rotary engine operation, including Mazda's RENESIS rotary engine.

This guide assumes that you have little or no knowledge about rotary engine operation. The information covered in this guide is required for Mazda's Engine Course.

1 - INTRODUCTION

Course Content and Objectives

In addition to this Introduction (Section 1), this guide includes five major sections and a Glossary. The objectives for each section follow:

Section 2 - Rotary Engine Components

- Describe how a rotary engine generates power
- Identify the major parts of a rotary engine

Section 3 - Basic Operation

- Describe the benefits of rotary engines
- Define rotary engine design characteristics: process time, displacement, and compression ratio

Section 4 - Rotary Engine Controls

- Describe major rotary engine control systems, including:

  -Intake

  -Ignition

  -Cooling

  -Secondary air

  -Lubrication

Section 5 - RENESIS Rotary Engine Features and Benefits

- Describe the major differences between standard rotary engines and RENESIS rotary engines
- Describe the features and benefits of the RENESIS rotary engine in terms of:

  - Fuel economy
  - Emissions
  - Weight and mounting
  - Eccentric shaft
  - Oil consumption

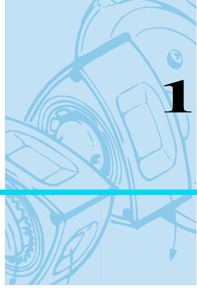
Section 6 - RENESIS Rotary Engine Systems

- Describe major RENESIS rotary engine systems, including:

  - Air intake
  - Jet air-fuel mixing
  - Exhaust ports
  - Metering oil pump
  - Wet sump oil system
  - Secondary air injection system
  - Catalytic converter
  - Electronic throttle control

Section 7 - Glossary

- Define terms used throughout this guide



1 – INTRODUCTION

HOW TO USE THIS GUIDE

To get the most benefit from this guide, complete the sections in order, from 1 through 6. Allow enough time to complete each section, and don't try to finish the whole book in one sitting. **You will retain more of what you learn if you split up the reading and review exercises over several days.**

Section Objectives

Each section begins with a list of learning objectives. These objectives tell you exactly what you will learn in the section. Read these objectives before you begin a section. When you have completed the section, go back and review the objectives to make sure you have learned the material.

Text and Illustrations

Each section includes text and illustrations that explain important concepts and terms. Read the text carefully and study the illustrations. You may also want to take notes as you go along.

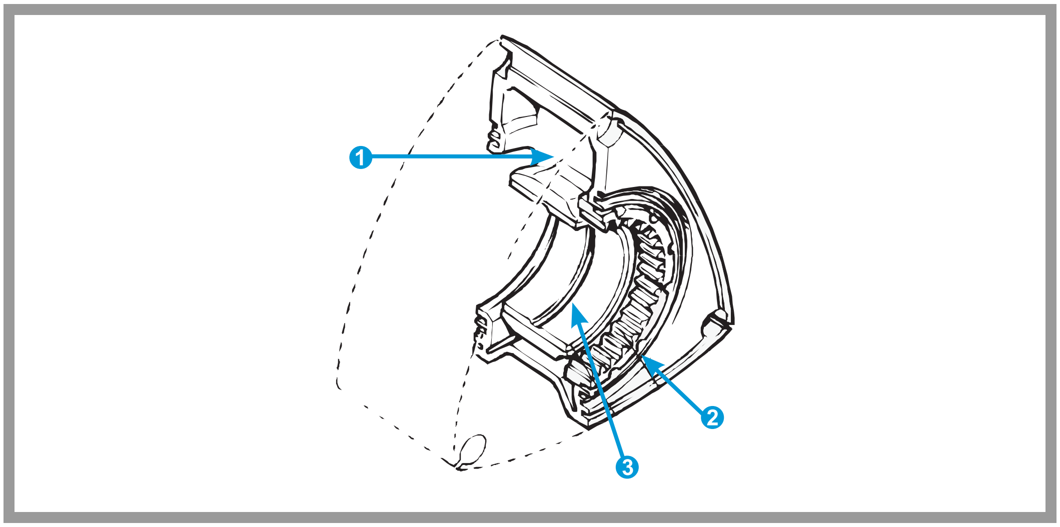
Each illustration includes numbered “callouts” that identify engine parts or processes described in the text. The numbered terms beside the illustration identify the parts that are called out, as shown in the following example from Section 2.

FIGURE 2-4.
An oil jet plug in the eccentric shaft injects oil into the rotor’s hollow interior.

1 Oil

2 Internal gear

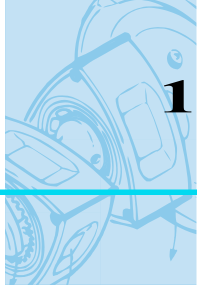
3 Rotor bearing



Review Exercises

This guide includes six sets of Review Exercises, which appear at various points throughout the guide. The exercises are designed to check your understanding of the material. Make sure you answer the questions in each Review Exercise. Then check your answers with the answer key.

If you’re not sure about one or more of your answers, go back and read the material again. Make sure you understand the previous material before moving on to new material.



1 - INTRODUCTION

2 – ROTARY ENGINE COMPONENTS

In a car or truck, the engine provides rotating power to drive the vehicle's wheels. This power is transferred to the wheels through the transmission and driving axle. In a rotary engine, this rotating power comes from the energy released when fuel burns in the engine's *working chambers*, similar to fuel burning inside the cylinders of a piston engine.

This section describes the major parts of a rotary engine, and explains how a rotary engine converts energy from burning fuel into power that drives the vehicle's wheels.

OBJECTIVES

After completing this section, you will be able to:

- Describe how a rotary engine generates power
- Identify the major parts of a rotary engine, including:
  - Rotor
  - Rotor housing
  - Front, side, and intermediate housings
  - Gas seals (apex, side, and corner seals)
  - Oil seals
  - Stationary gear
  - Eccentric shaft

HOW A ROTARY ENGINE DEVELOPS POWER

A rotary engine develops power in much the same way as a conventional piston engine. However, in a rotary engine, the *rotor* does the job of the pistons, connecting rods, and valves. The *rotor housing* and *side housings* enclose the rotor and function like the cylinders in a piston engine.

The process of burning the air-fuel mixture in the engine is called *combustion*. As the rotor turns inside the rotor housing, it forms working chambers in which the *combustion cycle* takes place.

The combustion cycle requires four steps, or strokes:

1. Intake — Admits the proper mixture of air and fuel into the working chamber.

2. Compression — Squeezes the air-fuel mixture so it will burn better and deliver more power.

3. Power (also called the expansion or combustion stroke) — Burns the air-fuel mixture.

4. Exhaust — Removes the burned gasses from the engine so the intake, compression, and combustion strokes can repeat.

Figure 2-1 shows the rotor turning inside the rotor housing during the four steps of the combustion cycle. A blue dot has been added to show the rotor's motion.

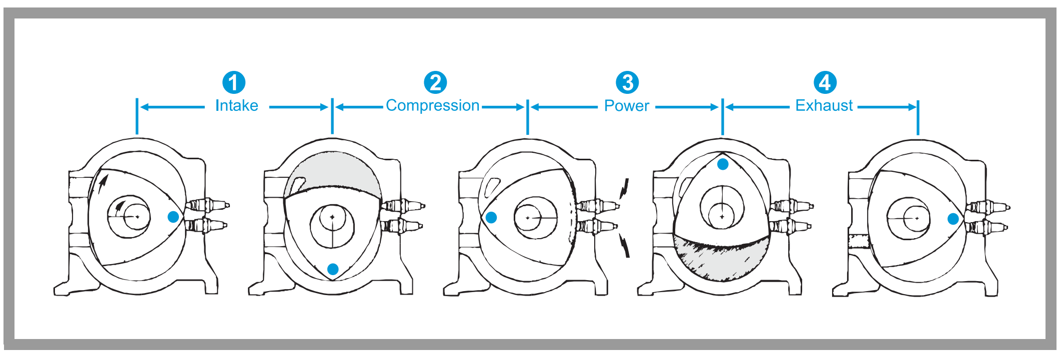


FIGURE 2-1. These are the four steps of the combustion cycle.

1 Intake

2 Compression

3 Power (Combustion)

4 Exhaust

Intake Stroke

When the working chamber is at (1), its volume is at minimum, corresponding to top dead center in a piston engine. The *intake stroke* begins here.

As the rotor continues to turn, the rotor uncovers the *intake ports* on the side housings, and the ports draw in the air-fuel mixture. At the same time, the intake working chamber grows larger, reaching maximum capacity at (2).

At this point, the rotor position corresponds to bottom dead center in a piston engine. In a rotary engine, this position is called *intake bottom dead center*.

Compression Stroke

At the end of the intake stroke, the rotor covers the intake ports. The working chamber's capacity gradually becomes smaller, and the air-fuel mixture is compressed. This is the *compression stroke*.

As the rotor turns, the working chamber continues to become smaller. When compression is almost complete, sparks from the spark plugs ignite the air-fuel mixture. At position (3), the working chamber is at its minimum capacity. This is called compression top dead center.

Power Stroke

When the air-fuel mixture ignites in the rotor's *combustion recess*, pressure and volume increase, and expansion continues. This is called the *power stroke*.

During this time, the combustion energy of the air-fuel mixture presses against the rotor's surface, forcing the rotor to turn on the *eccentric shaft*, which converts the combustion energy into rotational energy. This energy passes from the eccentric shaft through the clutch to the transmission and drive train, eventually powering the wheels. At this point, the working chamber's capacity again grows to its maximum. This is called power (combustion) bottom dead center.

Exhaust Stroke

When the power stroke is completed, the rotor expels burned gases from the *exhaust ports* in the rotor housing, and the capacity of the working chamber decreases. This is the *exhaust stroke*. When this stroke ends, the rotor returns to (1), where the cycle starts again.

The cycle shown in Figure 2-1 focuses on only one of the working chambers. The other two chambers operate in exactly the same way. Because there are three working chambers, one rotation of the rotor produces three power strokes. In addition, the rotor's internal gear ratio yields three rotations of the eccentric shaft for each complete rotation of the rotor.

In other words, there is one power stroke for each rotation of the eccentric shaft. And remember, the same cycle is being repeated in both rotors.

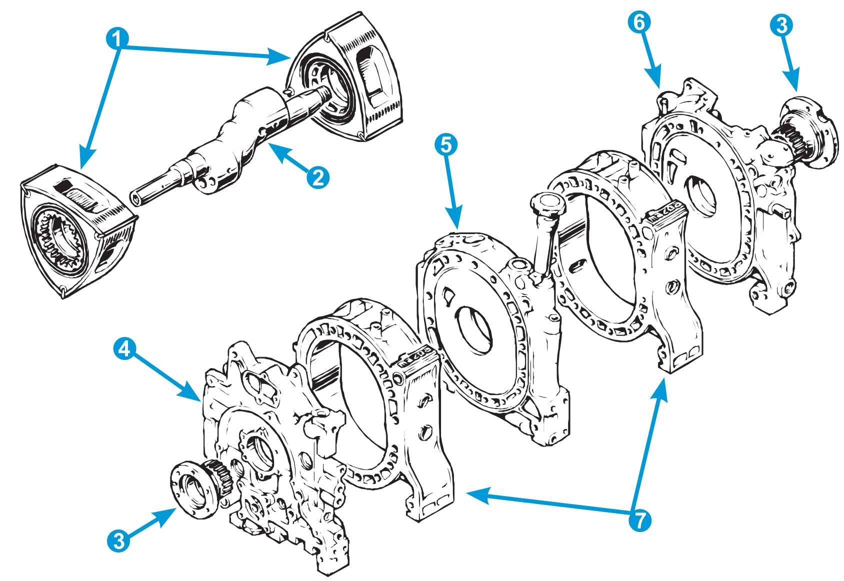
2 - ROTARY ENGINE COMPONENTS

ROTARY ENGINE COMPONENTS

Most rotary engines have two *rotors*. A two-rotor engine consists of the major parts shown in Figure 2-2.

FIGURE 2-2.
A rotary engine consists of these major parts.

1. Front and rear rotors
2. Eccentric shaft
3. Stationary gear
4. Front side housing
5. Intermediate housing
6. Rear side housing
7. Front and rear rotor housings



The two rotors (front and rear) are connected by an *eccentric shaft,* similar to a crankshaft in a piston engine. The eccentric shaft spins the rotors inside the rotor housing, which is enclosed between an intermediate housing and a side housing.

These housings are sandwiched tightly together to form a sealed chamber, similar to a cylinder in a piston engine.

Rotor

The rotor has three sides, like a triangle, and it is made of special cast iron. As the rotor turns inside the rotor housing, it functions like the pistons, connecting rods, and valves in a piston engine. Figure 2-3 shows the major parts of the rotor.

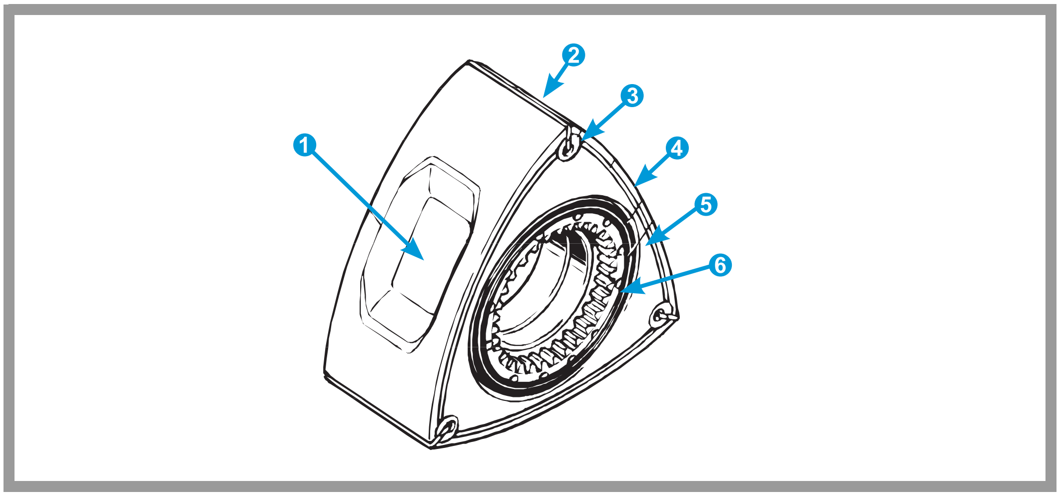


FIGURE 2-3.
The rotor does the jobs of the pistons, connecting rods, and valves in a piston engine.

1. Combustion recess
2. Apex seal
3. Corner seal
4. Side seal
5. Outer oil seal
6. Inner oil seal

The rotor converts the pressure of combustion gases into energy to drive the rotating eccentric shaft. The turning rotor causes the engine's intake and exhaust ports to open and close, allowing the proper air-fuel mixture into the engine and exhausting burned gasses after combustion.

Each of the rotor's three sides contains a combustion recess, sometimes called a bathtub. *Spark plugs* ignite the compressed air-fuel mixture in these recesses, generating power, which passes through the rotor bearing to the eccentric shaft, sometimes called the output shaft.

One side of the rotor contains an *internal gear*, as shown in Figure 2-4. This internal gear meshes with the *stationary gear* on the rotor housing and guides the rotor in its motion inside the housing. A *rotor bearing* at the rotor's center supports the eccentric shaft, which holds the rotor in place.

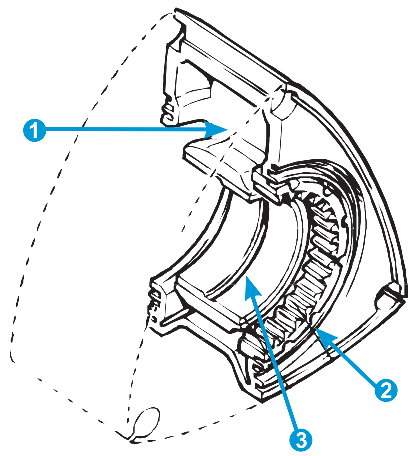


FIGURE 2-4.
An oil jet plug in the eccentric shaft injects oil into the rotor's hollow interior.

1 Oil

2 Internal gear

3 Rotor bearing

The interior of the rotor is hollow for easier cooling and reduced weight. An *oil jet plug* in the eccentric shaft lubricates the interior of the rotor.

As the rotor rotates inside its housing, it creates three working chambers in the space between the inner walls of the rotor housing and the three points of the rotor.

The rotor, like a piston in a piston engine, has *gas seals* that keep the working chambers airtight. The rotor also has *oil seals* that prevent lubricant from entering the working chambers.

Gas Seals

The gas seals in a rotary engine serve the same purpose as the piston rings in a piston engine. These seals maintain the airtightness of the three working chambers created by the rotor as it turns inside the rotor housing. The working chambers must be airtight so the combustion cycle can take place efficiently, without loss of power. Figure 2-5 shows the position of the gas seals fitted into the rotor.

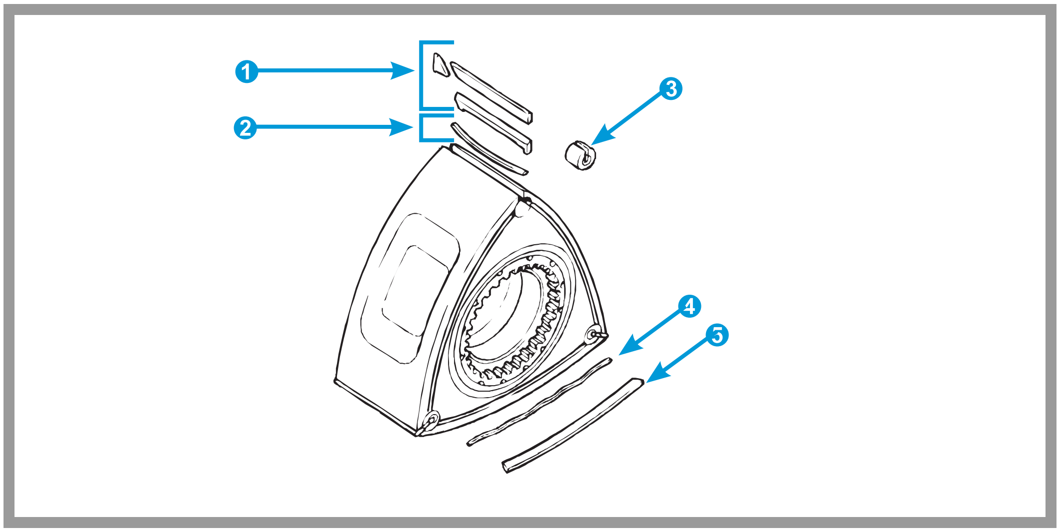


FIGURE 2-5.
Gas seals maintain the airtightness of the working chambers.

1. Apex seal
2. Apex seal spring
3. Corner seal and spring
4. Side seal spring
5. Side seal

There are three sets of gas seals: *apex seals*, *side seals*, and *corner seals*. The seals fit into grooves in the rotor, and each seal is attached with a spring.

The cast iron apex seal maintains the airtightness between the rotor housing's inner surface and the rotor. Depending on engine type, the apex seal may consist of two or three pieces, held in place by a two-piece spring. The apex seal is held in place by a combination of the apex seal springs and the centrifugal force of the rotor's rotation.

The side seal performs the same sealing function between the intermediate housing and the side housing of the rotor. The corner seal closes up any remaining space between the ends of the apex seal and the ends of the side seal.

During engine operation, gas pressure generated by the turning rotor presses against the lower portion of the apex seals, further improving the airtightness of the working chambers, as shown in Figure 2-6.

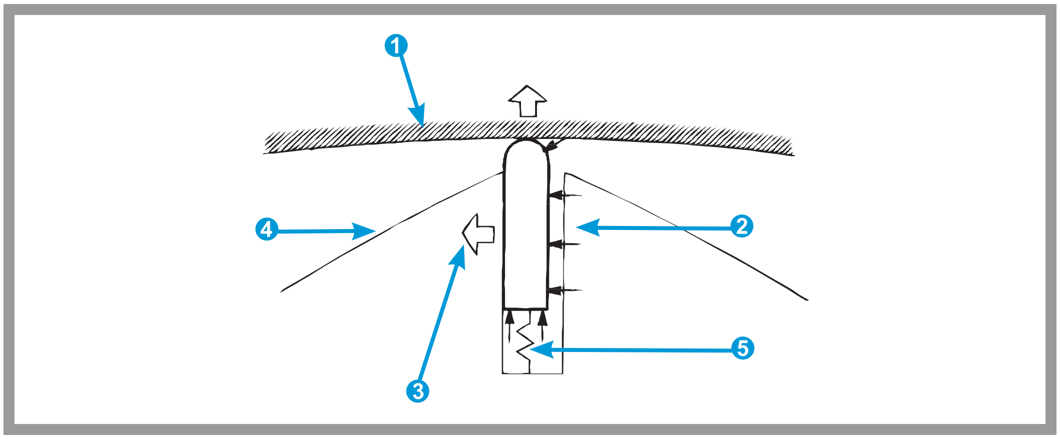


FIGURE 2-6.
Gas pressure further improves the sealing ability of the apex seals.

1. Rotor housing
2. Gas pressure
3. Pushing pressure
4. Rotor
5. Spring pressure

Oil Seals

Engine oil lubricates the rotor bearing and cools the rotor. The oil seals in the rotor prevent engine oil from passing through the clearance between the rotor wall and the side housing. The oil seals also keep oil from leaking into the working chambers. Figure 2-7 shows the rotor's inner and outer oil seals.

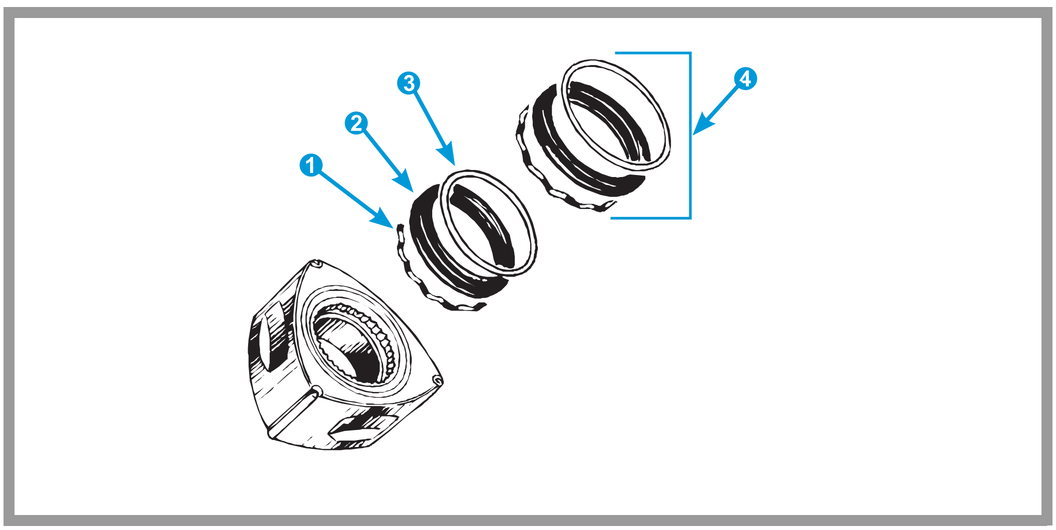


FIGURE 2-7.
Oil seals prevent oil from leaking into the working chambers.

1. Spring
2. Inner oil seal
3. O-ring
4. Outer oil seal, with O-ring and spring

The oil seals fit into grooves in the sides of each rotor. Both the inner and outer oil seal have a spring and an O-ring to improve sealing ability.

As the rotor spins, the oil seals form two overlapping ranges inside the rotor housing: a *scrape-away range* and a *cross-over range*.

As Figure 2-8 shows, when the oil seals slide against the surface of the side housing, they remove carbon within the scrape-away range. In the cross-over range, an oil film forms on the contact surfaces, indirectly lubricating the side seal and corner seal.

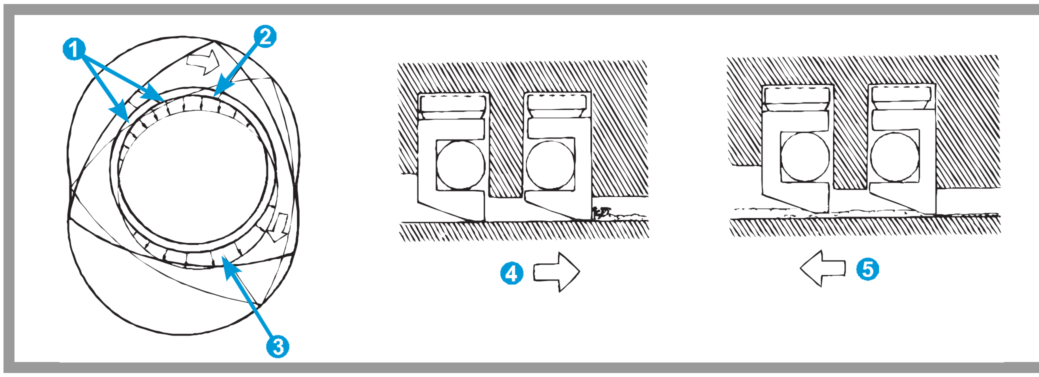


FIGURE 2-8.
The oil seals remove carbon buildup.

1. Oil seals
2. Scrape-away range
3. Cross-over range
4. During scrape away
5. During cross over

Rotor Housing

The rotor housing is made from aluminum alloy cast around a chrome-plated steel insert. The inner surface of the rotor housing is sometimes called the “trochoid” surface because of the curved shape it has.

The apex seals in the rotor slide against the inner surface of the rotor housing as the rotor turns. The rotor's rotation creates three working chambers (shaded in gray), as shown in Figure 2-9.

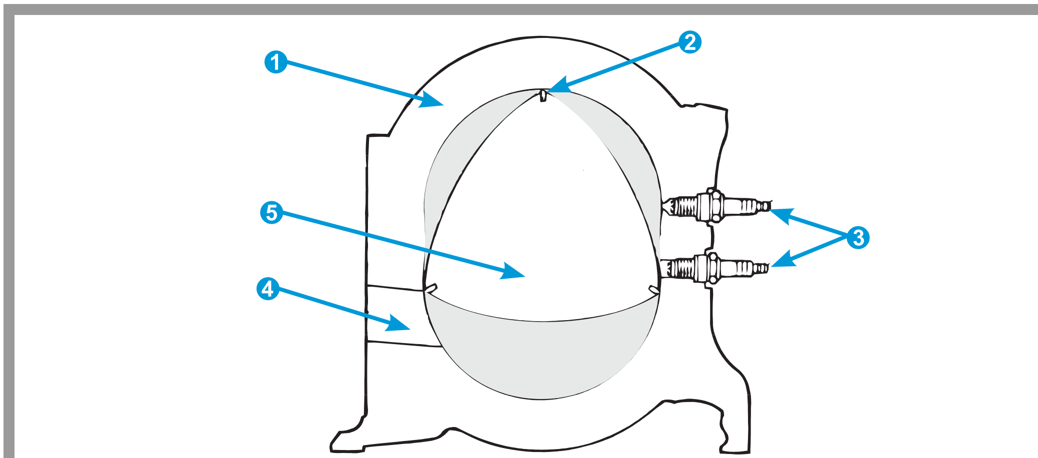


FIGURE 2-9.
The turning rotor creates three working chambers.

1. Rotor housing
2. Apex seal
3. Spark plugs
4. Exhaust port
5. Rotor

The *trochoid surface* of the rotor housing also contains the exhaust port, the oil nozzle installation hole, and the *spark plug installation holes*, as shown in Figure 2-10.

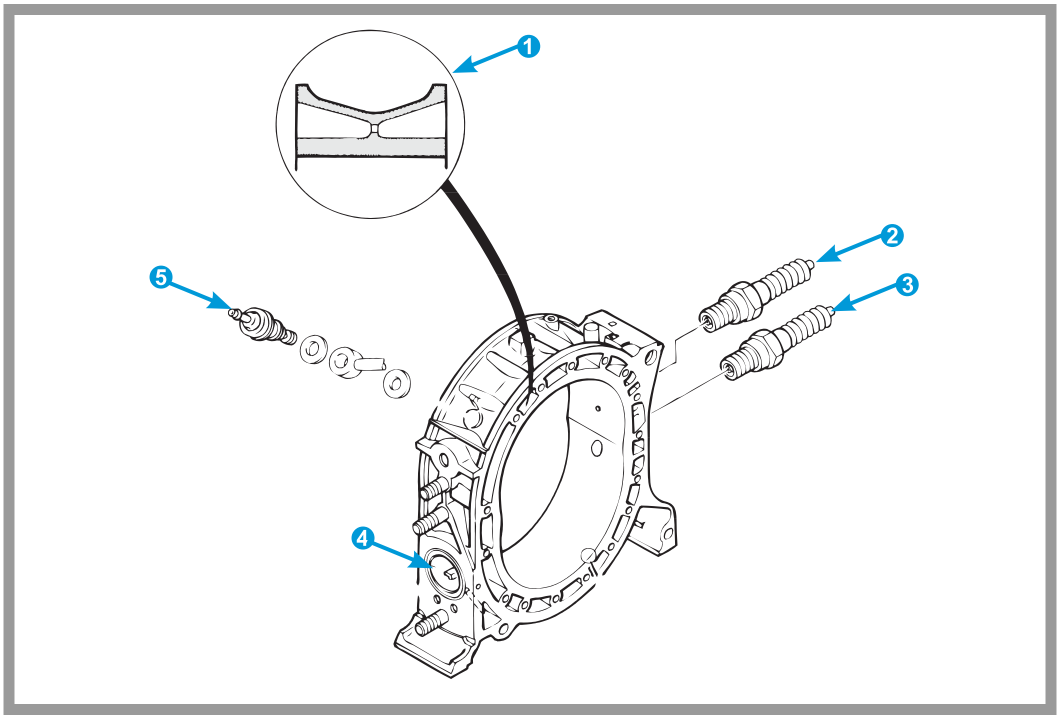


FIGURE 2-10.
The rotor housing is the installation point for many components.

1. Coolant passage
2. Trailing spark plug
3. Leading spark plug
4. Exhaust port
5. Housing oil nozzle

The rotor housing also has *coolant passages* around the outside of the trochoid surface to provide engine cooling.

Side Housings

The side housings form walls at the front and rear of the rotor housing. These walls define the airtight working chambers. The side housings also provide the contact surfaces for the side seals and the intake ports for the working chambers. The front and rear side housing may have one or more intake ports, depending on engine type. The intermediate housing usually has one intake port.

The side housings function like the cylinder and cylinder head in a piston engine. Figure 2-11 shows the front, intermediate, and rear side housings with typical intake port location.

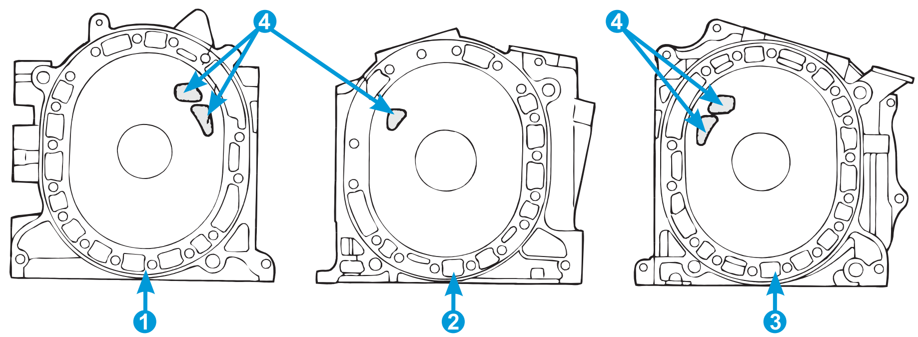


FIGURE 2-11.
The side housings form the side surfaces of the working chambers.

1. Front side housing
2. Intermediate housing
3. Rear side housing
4. Intake ports

Sealing rubber gaskets installed around the coolant passages of the side housings prevent coolant or gases from leaking, much like the head gasket works in a piston engine. Figure 2-12 shows the rubber sealing gasket's position in the side housing.

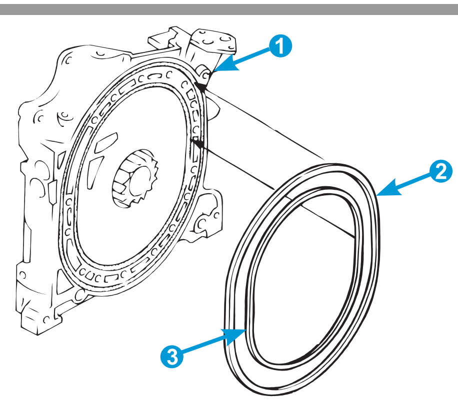


FIGURE 2-12.
Sealing rubber parts keep gas or coolant from leaking from the rotor housing.

1. Side housing
2. Outer sealing rubber
3. Inner sealing rubber

Side housings are usually made of cast iron, but may also be made of aluminum alloy. The interiors of the side housings are hollow, providing a coolant passage. The housings have a ribbed structure to increase rigidity and improve cooling.

The intermediate housing has a lubricating oil passage at its center so that the oil used to cool the rotor's interior can be returned to the oil pan. There may also be a passage for EGR (exhaust gas return) gases and secondary air that is used to burn the exhaust gas for cleaner emissions.

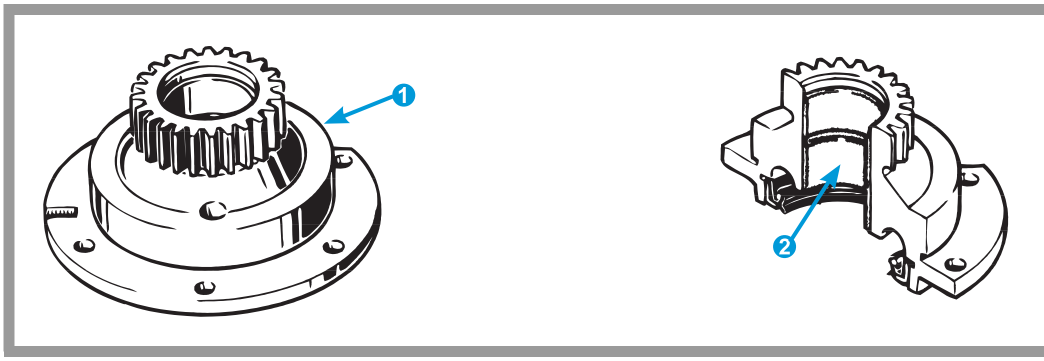
Stationary Gear

Two stationary gears, front and rear, are secured to the front and rear side housings. The stationary gears, along with the main bearings inside the gears, support the eccentric shaft as it turns. Figure 2-13 shows the stationary gear and main bearing.

FIGURE 2-13.
The stationary gear supports the eccentric shaft.

❶ Stationary gear

❷ Main bearing



The stationary gears mesh with the rotor's internal gear, guiding the rotor through its rotation inside the rotor housing. The stationary gear is made of special alloy steel for durability. It is unified with the main bearing and then pressed and bolted into the front and rear side housing.

Eccentric Shaft

The eccentric shaft is the output shaft of the rotary engine, similar to the crankshaft in a piston engine. The eccentric shaft, shown in Figure 2-14, is made of highly durable, forged carbon steel.

FIGURE 2-14.
The eccentric shaft is the engine's output shaft.

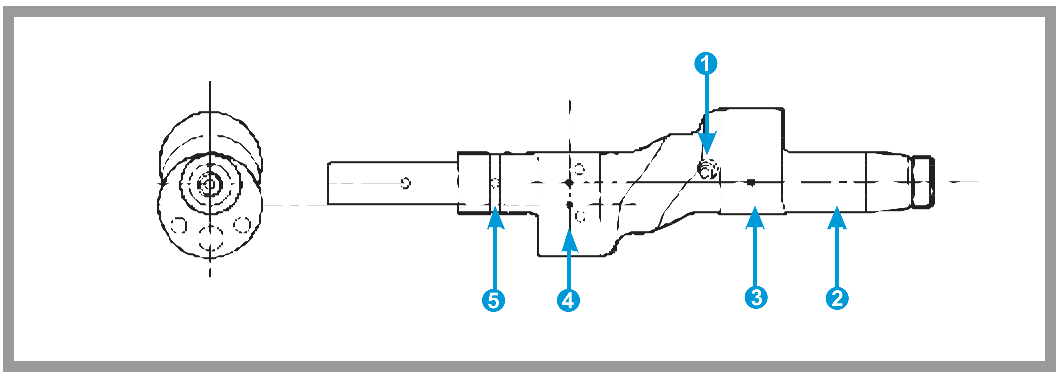
❶ Oil discharge port

❷ Rear main journal

❸ Rear rotor journal

❹ Front rotor journal

❺ Front main journal



The *rotor journal* (corresponding to a crankshaft pin) supports the rotor. At both ends of the shaft are front and rear *main rotor journals* that support the main bearings.

The center of the eccentric shaft is hollow and contains an oil passage to lubricate the rotor bearing and cool the rotor. The oil passage runs from the front end of the eccentric shaft to the rear main journal. Oil jets spray oil directly into the rotor's hollow inner chamber. Figure 2-15 shows the oil passage and oil jet nozzle.

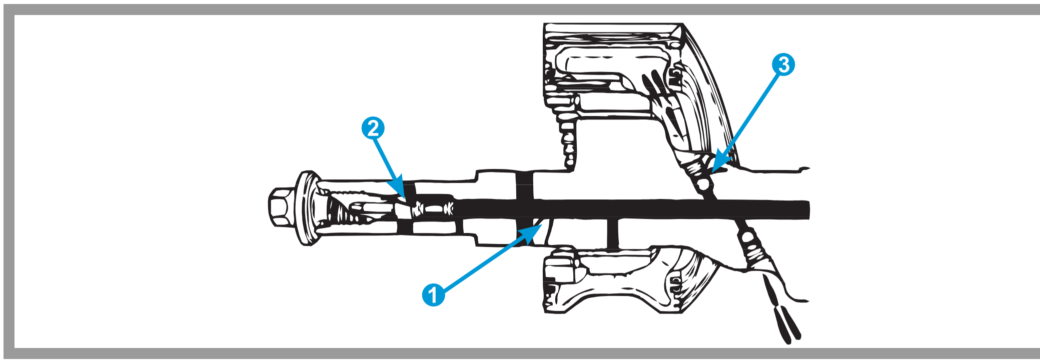


FIGURE 2-15.
An oil passage runs the length of the eccentric shaft.

1 Oil passage

2 Eccentric shaft bypass valve

3 Oil jet plug

The front end of the eccentric shaft has components such as a *balance weight*, a gear for an auxiliary drive, an oil pump, and a V-belt pulley (used to power the oil pump, generator, and A/C). These components vary, depending on engine type.

At the rear of the eccentric shaft is a *flywheel*, a heavy round plate that turns with the shaft. The weight of the flywheel keeps the eccentric shaft turning smoothly even though power is supplied only during the engine's power (combustion) stroke. Figure 2-16 shows the position of the flywheel and *balance weight* on the eccentric shaft.

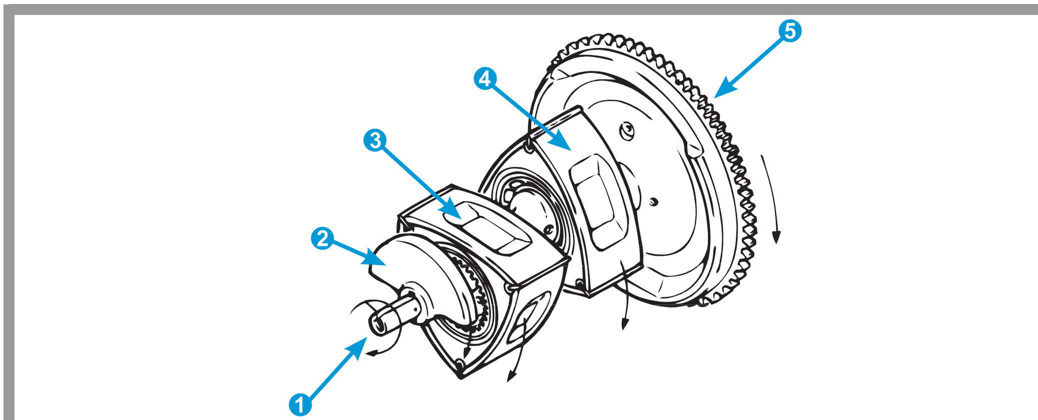


FIGURE 2-16.
The flywheel keeps the eccentric shaft turning smoothly.

1 Eccentric shaft

2 Balance weight

3 Front rotor

4 Rear rotor

5 Flywheel

The flywheel stores energy generated by the engine for a smooth transfer of power. The balance weight helps counterbalance the weight of the flywheel for smoother operation.

REVIEW EXERCISE 1

Fill in the words that correctly complete these sentences. Check your answers with the answer key on page 22.

1. In a rotary engine, the __________ performs the functions of the pistons, connecting rods, and valves in a piston engine.

2. The front and rear rotors are connected by a/an ________________ ____________.

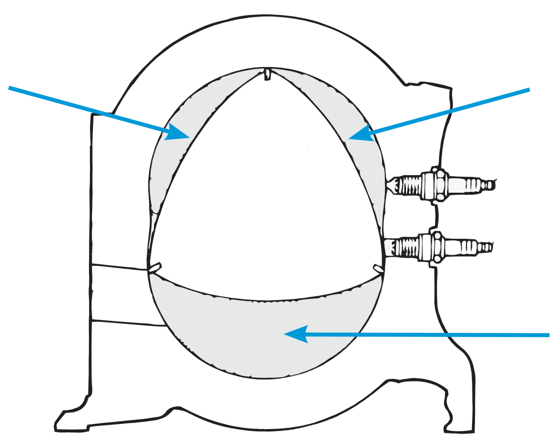
3. The rotor's internal gear meshes with the ______________ ________, guiding the rotor through its rotation inside the rotor housing.

4. To maintain the airtightness of the engine's working chambers, three sets of ________ _________ are installed in the rotor.

5. The eccentric shaft contains a/an ________ _______ _______, used to lubricate the interior of the rotor.

Refer to the following illustration to answer question 6.

6. The spaces marked by arrows around this rotor are called ________________ ________________.



While rotary engines develop power much like piston engines, they use different components to produce energy from burning fuel. This section describes the rotary engine's main advantages, explains more about their operation, and discusses some of the rotary engine's basic design characteristics.

OBJECTIVES

After completing this section, you will be able to:

- Describe the benefits of rotary engines
- Define rotary engine design characteristics: process time, displacement, and compression ratio

BENEFITS OF ROTARY ENGINES

Compact and High Output

Compared to piston engines, rotary engines are usually smaller, and produce more power for their size. A two-rotor rotary engine is only about two-thirds the size of a six-cylinder piston engine. Figure 3-1 shows the relative sizes of a six-cylinder piston engine, a four-cylinder piston engine, and a two-rotor rotary engine.

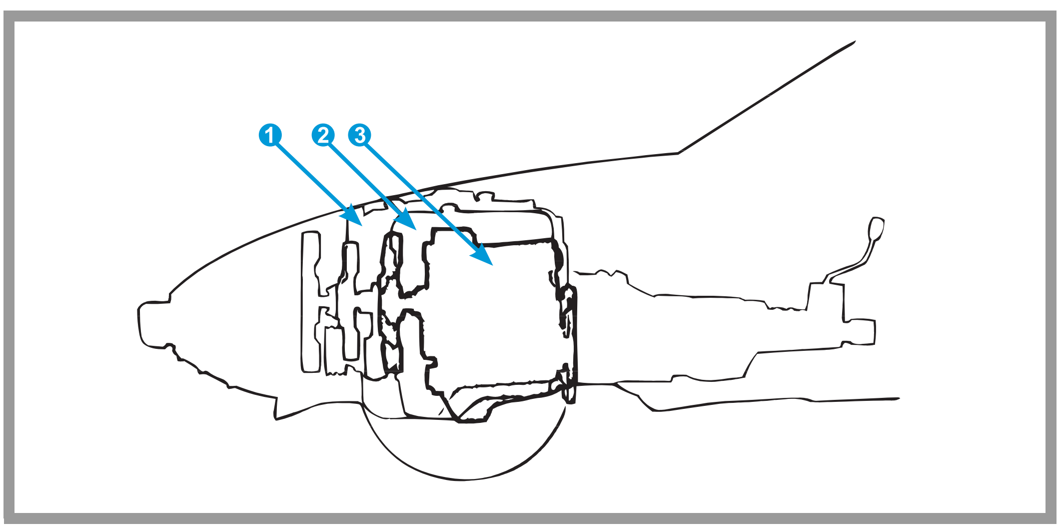
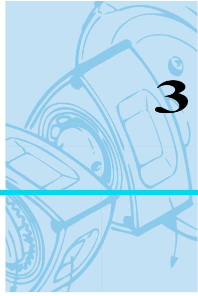


FIGURE 3-1.
The rotary engine is compact compared to a piston engine, but produces high power output for its size.

1. Six-cylinder piston engine
2. Four-cylinder piston engine
3. Two-rotor rotary engine



Answers to
Review Exercise 1

1. rotor
2. eccentric shaft
3. stationary gear
4. gas seals
5. oil jet plug
6. working chambers

Low Vibration and Noise Levels

In any engine, the forces generated by moving parts must be balanced so the engine can run smoothly at high rpm (revolutions per minute). In a piston engine, the alternating up-and-down motion of the pistons, valves, and connecting rods is difficult to balance.

In a rotary engine however, the rotor, eccentric shaft, flywheel, and other parts always rotate in the same direction (Figure 3-2), making perfect dynamic balance possible. This balance creates less noise and vibration. Also, in a rotary engine there is no opportunity for metal surfaces to strike each other, as they can during the up-and-down motion of the valves and pistons in a piston engine.

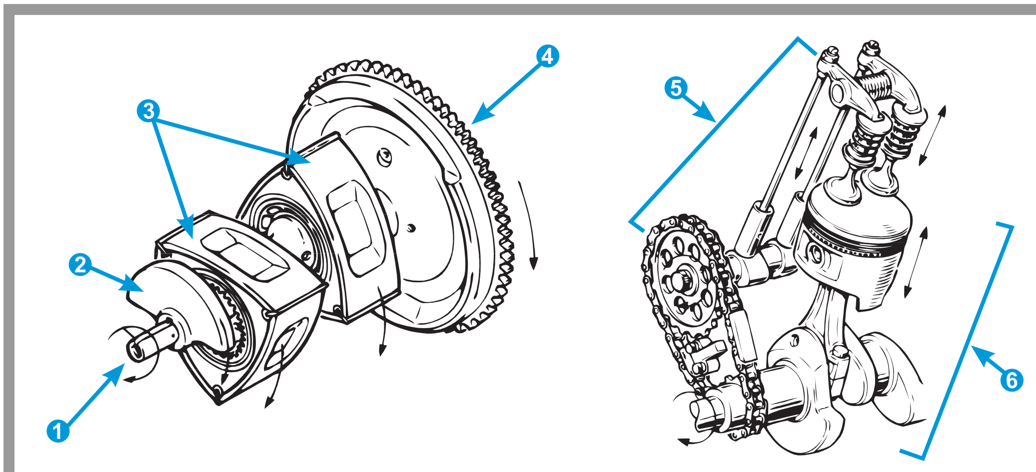


FIGURE 3-2.
All rotary engine parts rotate in the same direction, unlike piston engines.

1. Eccentric shaft
2. Balance weight
3. Rotors
4. Flywheel
5. Valve mechanism
6. Crank mechanism

Flat Torque Characteristics

A piston engine produces power only during the power stroke of the four-stroke cycle. The other three strokes — intake, compression, and exhaust — generate no power. In the interval between the end of one power stroke and the beginning of the next, the rotation of the crankshaft is momentarily interrupted, causing a change in force. This is called *torque fluctuation*. If torque fluctuation is great enough, it can cause engine vibration.

Because a rotary engine has three power strokes for each rotation of the rotor, the interval between power strokes is shorter. This reduces torque fluctuation and engine vibration.

Fewer Component Parts

The rotor in a rotary engine performs all the functions of the pistons, connecting rods, and valves in a piston engine. A rotary engine has no valves or valve-related components, so it has many fewer parts than a piston engine. In fact, a typical two-rotor rotary engine contains fewer than half the parts of a six-cylinder piston engine.

DESIGN CHARACTERISTICS

Process Time

Process time is the time it takes an engine to complete one of the four strokes of the combustion cycle: intake, compression, power, or exhaust. Process time is measured by the number of degrees that the crankshaft or eccentric shaft rotates during the stroke.

In a piston engine, the crankshaft must rotate twice to produce one power stroke. Remember, the intake, compression, and exhaust strokes do not produce any power; in fact, they use energy.

In a rotary engine, the four strokes are repeated in each of the three working chambers, so there are actually three power strokes during each complete rotation of the rotor. This means the eccentric shaft rotates three times for each complete rotation of the rotor.

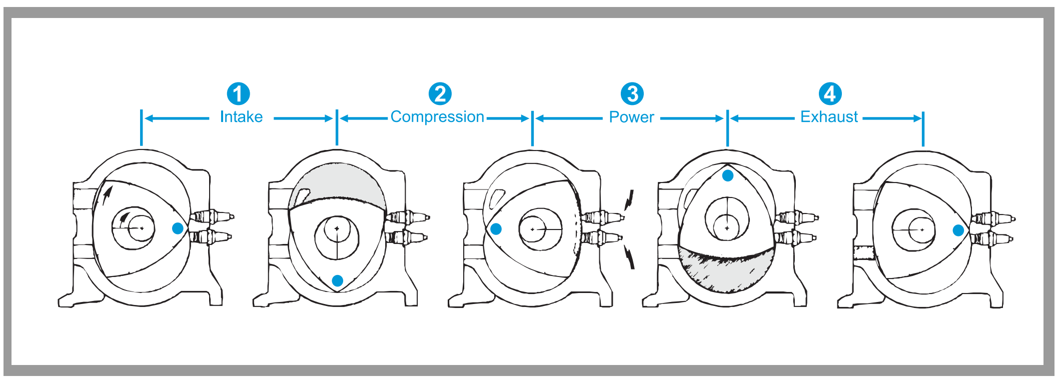


FIGURE 3-3.
A rotary engine produces three power strokes for each full rotation of the rotor.

1 Intake

2 Compression

3 Power (combustion)

4 Exhaust

In a rotary engine, the eccentric shaft rotates three times for each full rotation of the rotor (3 x 360° = 1080°). Because four strokes occur during the rotor's rotation, the process time for each stroke is 270° (1080° ÷ 4 = 270°).

In a piston engine, the crankshaft turns one half of a rotation during each stroke, so the process time of a piston engine is 180°. The rotary engine's longer 270° process time allows more time for gas exchange (intake and exhaust), producing more torque at high RPM, while reducing overall torque fluctuation, as Figure 3-4 shows.

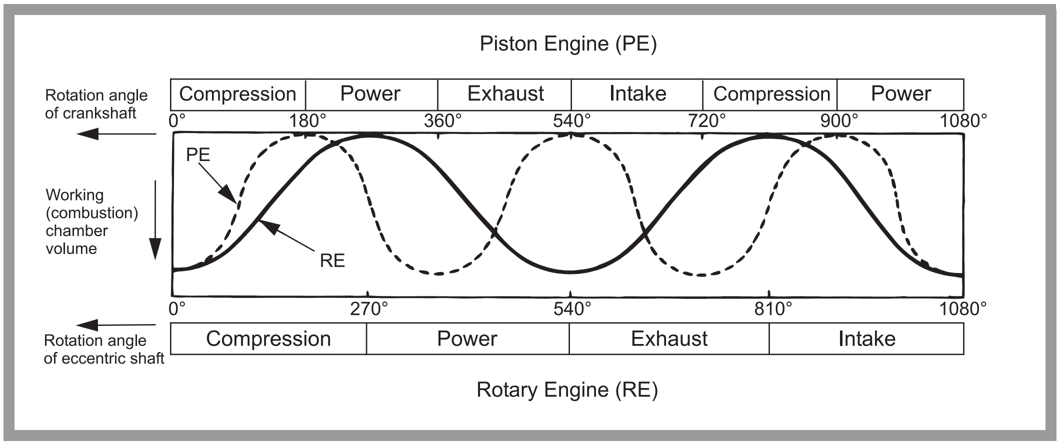


FIGURE 3-4. The rotary engine's 270° process time produces more power at high RPM and reduces torque fluctuation.

Displacement

In a piston engine, the *displacement* of a cylinder is the volume of the cylinder between its top dead center (TDC) and bottom dead center (BDC) positions. Engine displacement is the total displacement of all the cylinders in the engine. Displacement is usually measured in cubic centimeters (cc) or liters (L).

Generally speaking, engine displacement is a rough indicator of power output. For example, a 2000 cc (2.0 L) engine is usually more powerful than a 1500 cc (1.5 L) engine.

Rotary engines measure displacement differently. In a rotary engine, each rotor has three working chambers. To calculate displacement, you must first know the volume of a single working chamber.

To calculate single chamber volume, measure the maximum volume (intake BDC) of one working chamber and then subtract the chamber's minimum volume (power TDC), as shown in Figure 3-5. This gives you the volume of a single working chamber.

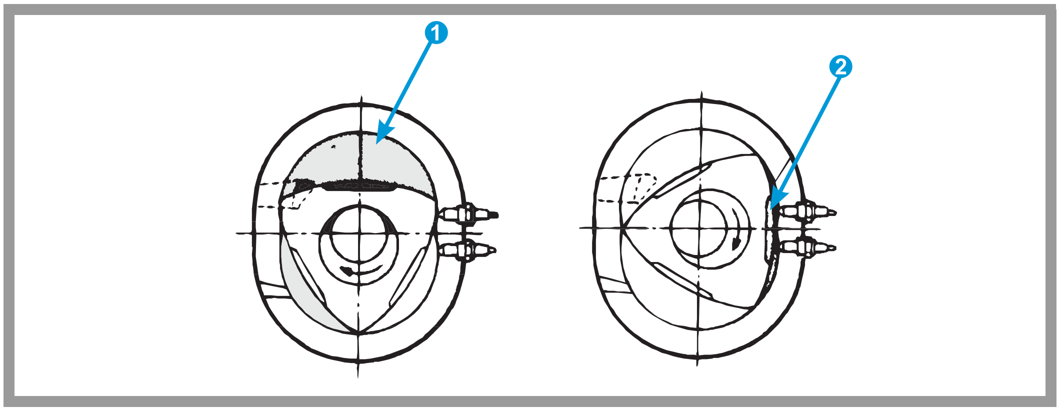


FIGURE 3-5.
To calculate engine displacement, first determine the volume of a single working chamber.

1. Maximum volume (Vmax / intake BDC)
2. Minimum volume (Vmin / power TDC)

The working chamber's maximum volume is called *Vmax*. Its minimum volume is called *Vmin*. To calculate the single chamber volume, subtract Vmin from Vmax. To calculate total engine displacement, multiply the single chamber volume by the number of rotors in the engine (usually two).

Single chamber volume = Vmax – Vmin
Total engine displacement = Single chamber volume x number or rotors

For example, Mazda's 13B rotary engine has a single chamber volume (Vmax) of 654 cc. Multiply the single chamber volume times the number of rotors and you get a total displacement of 1308 cc (1.3 L). This makes the 13B a 1300 cc, or 1.3 L engine, as shown below.

654 cc x 2 = 1308 cc (1.3 L)

Compression Ratio

Once you know the engine's displacement, you can calculate its *compression ratio*. Compression ratio measures how much the air-fuel mixture is squeezed during the compression stroke.

Usually, a higher compression ratio means greater power output. For example, a compression ratio of 10 to 1 will probably produce more power than a ratio of 9 to 1. However, higher-compression engines may require premium fuel. Most engines have compression ratios of 9.5 to 1 or less so they can run on regular unleaded fuel.

In a rotary engine, the compression ratio is the ratio of Vmax to Vmin. To calculate compression ratio, divide the single chamber Vmax by its Vmin.

For example, if an engine's single chamber Vmax is 575 cc and the Vmin is 62 cc, the compression ratio would be 9.27 to 1, as the following example shows.

575 cc ÷ 62 cc = 9.27:1

REVIEW EXERCISE 2

Fill in the words that correctly complete these sentences. Check your answers with the answer key on page 28.

1. One reason rotary engines produce more power for their size is that the eccentric shaft rotates __________ times for each complete rotation of the rotor.

2. If the time from the end of one power stroke to the beginning of the next is too long, the rotation applied to the shaft will be interrupted, causing ________________ ___________________.

3. The time it takes an engine to complete one of the four strokes of the combustion cycle is called the engine's ______________ __________ cycle.

4. In a rotary engine, the single chamber volume times the number of rotors is called the engine's ___________________.

5. The ____________________ ____________ of an engine measures how much the air-fuel mixture is squeezed before being ignited.

4 - ROTARY ENGINE CONTROLS

Sections 2 and 3 introduced the basic components of a rotary engine and described how they produce power from burning fuel. A rotary engine also uses several other systems to control engine performance and ensure peak efficiency. This section describes the major control systems of a rotary engine.

OBJECTIVES

After completing this section, you will be able to describe major rotary engine control systems, including:

- Ignition
- Intake
- Fuel Injection
- Cooling
- Secondary air
- Lubrication

ROTARY ENGINE CONTROL SYSTEMS

Ignition System

Each side of a three-sided rotor has a combustion recess (sometimes called a *bathtub*) where the spark plugs ignite the air-fuel mixture during the engine's power stroke. This combustion recess is longer and narrower than the combustion chamber in the cylinder of a piston engine.

Because this recess is so long, a rotary engine uses two spark plugs for each rotor to make sure the air-fuel mixture ignites efficiently and burns completely. This dual-plug system provides excellent combustion under a wide range of driving conditions.

4 - ROTARY ENGINE CONTROLS

Answers to Review Exercise 2

1. three
2. torque fluctuation
3. process time
4. displacement
5. compression ratio

In a rotary engine, the working chambers constantly move in the direction of rotor rotation. The side of the combustion recess that reaches the plugs first is called the *leading side*. The side that reaches the plugs last is called the *trailing side*.

Because of their position in the rotor housing, the spark plugs are also called leading and trailing. In a dual-plug system, the trailing spark plug fires first, followed closely by the leading plug.

To avoid contact with the rotor and its apex seal, the tips of the spark plugs are recessed into the rotor housing, as Figure 4-1 shows.

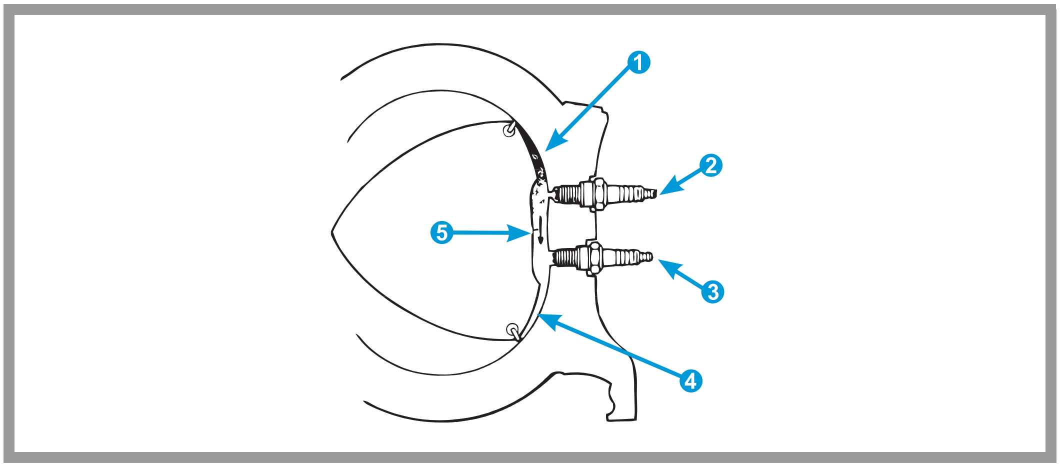


FIGURE 4-1. A rotary engine uses two spark plugs per rotor to improve combustion.

1. Trailing side
2. Trailing spark plug
3. Leading spark plug
4. Leading side
5. Gas flow

When the rotor reaches compression top dead center, the pressure at the trailing side of the recess is higher than the leading side. This forces the compressed air-fuel mixture into the leading side of the recess, and the trailing plug fires. This process enhances combustion efficiency.

When the rotor's apex seal passes by the trailing spark plug hole immediately after ignition, the combustion pressure on the leading side of the recess is much greater than the trailing side. This pressure difference could force exhaust gas to leak past the trailing spark plug hole and flow in the direction of lower pressure, as Figure 4-2 shows. The leaking exhaust gas is called *blowby.*

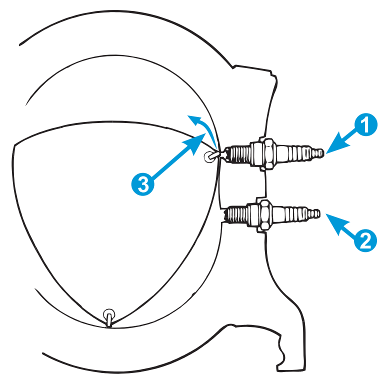


FIGURE 4-2.
The installation hole for the trailing side spark plug is smaller to reduce blowby.

1 Trailing spark plug

2 Leading spark plug

3 Combustion gas (blowby)

To prevent blowby, the trailing spark plug's hole is smaller than the hole for the leading plug. This smaller hole creates a tighter seal, but it can cause plug fouling at lower RPM. However, with modern spark plug technology, the trailing plug cleans itself when the engine runs at higher speeds.

Blowby normally does not occur past the leading spark plug because pressure is balanced in the current and the succeeding working chambers. Figure 4-3 shows the balanced pressure on either side of the leading plug. Since there is little risk of gas leaking past the leading plug, the hole for the leading plug can be larger, resulting in less plug fouling. This design improves engine performance at starting and at low speeds.

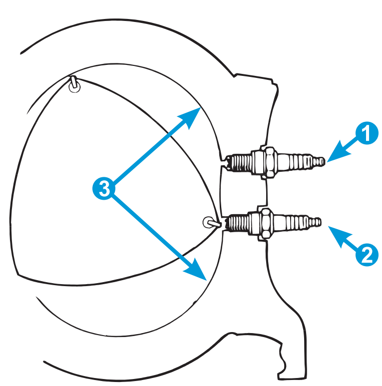


FIGURE 4-3.
Balanced pressure in the chambers on either side of the leading plug means its installation hole can be larger.

1 Trailing spark plug

2 Leading spark plug

3 Balanced pressure

Spark timing is critical to engine performance, so each spark plug (leading and trailing) has its own ignition coil to ensure proper timing. The *PCM* (*Power Train Control Module*) controls each ignition coil separately.

Spark plugs may be either side-electrode type, or ring-electrode type. Trailing and leading spark plugs may be marked *T* or *L* (you can think of T as standing for "top" and L for "lower"). Spark plugs may also be color-coded to mark their proper installation position in the rotor housing.

Intake (Induction) System

Modern piston engines use *fuel injectors* and valves to control the supply of air-fuel mixture to the cylinders. In a rotary engine, fuel injectors supply fuel through a *six-port induction system* to provide the proper air-fuel mixture to the working chambers at any given speed. See "Fuel Injection System" on page 33 for more information about fuel injectors.

Figure 4-4 shows the position of major engine components related to the intake system. In the Figure, "P" indicates primary intake ports, and "S" indicates secondary intake ports.

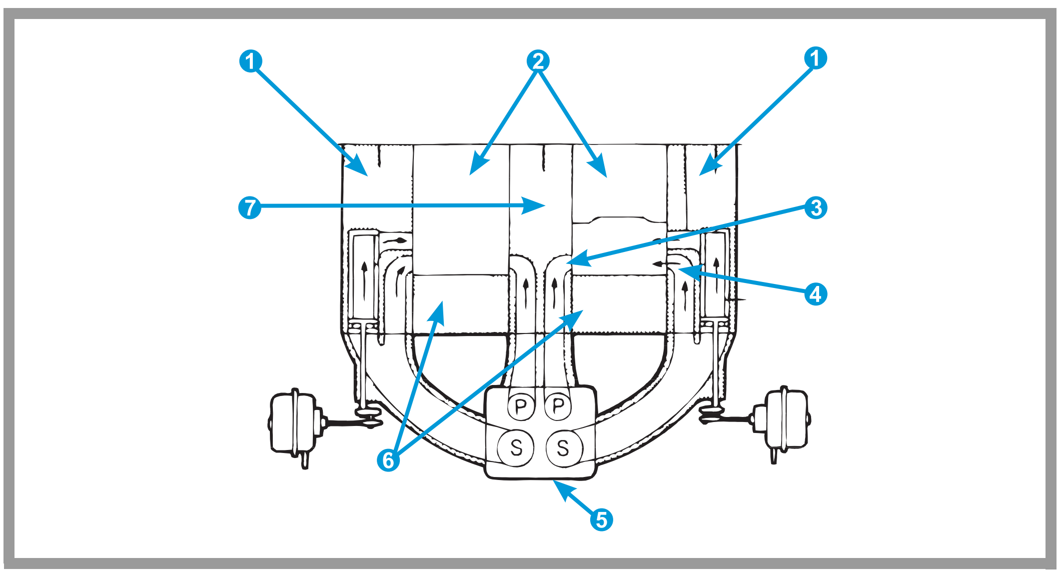


FIGURE 4-4. Primary, secondary, and auxiliary ports provide intake air to the engine.

1. Side housing
2. Rotors
3. Primary port
4. Secondary port
5. Intake manifold
6. Rotor housings
7. Intermediate housing

Under low-speed, low-load conditions, the intermediate housing's primary port takes in the air-fuel mixture. During medium-speed, medium-load conditions, the secondary port on the side housing also provides air-fuel mixture. Figure 4-5 shows the location of the intake ports in the side and intermediate housings.

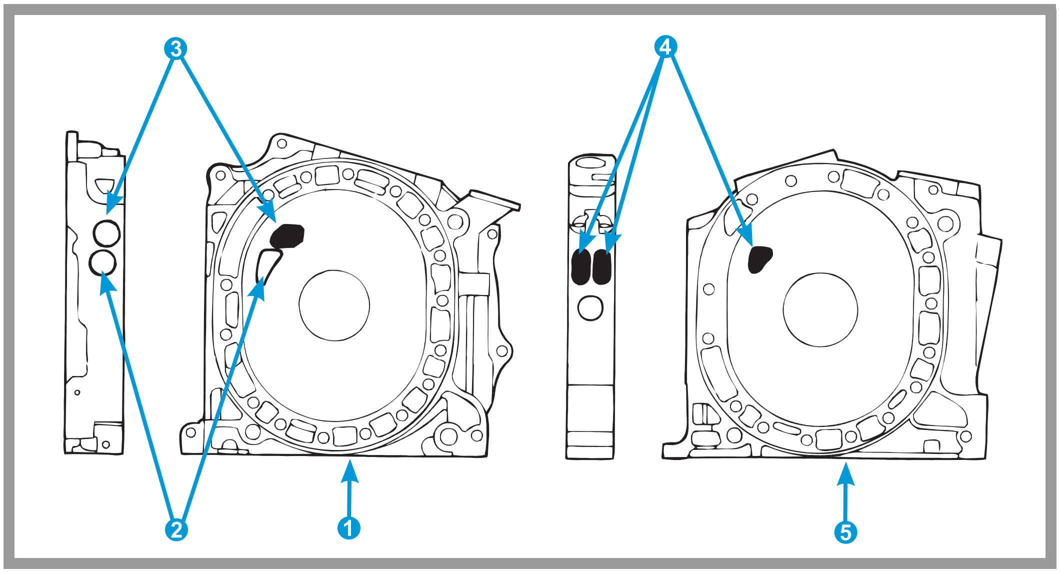


FIGURE 4-5.
Intake ports are located in the intermediate and side housings.

1. Side housing
2. Secondary port
3. Auxiliary port
4. Primary ports
5. Intermediate housing

During high-speed, high-load conditions, auxiliary ports in the side housing provide additional air-fuel intake. Valves controlled by *actuators* regulate the opening and closing of the auxiliary ports. Figure 4-6 shows the location of the auxiliary ports, valves, and actuators.

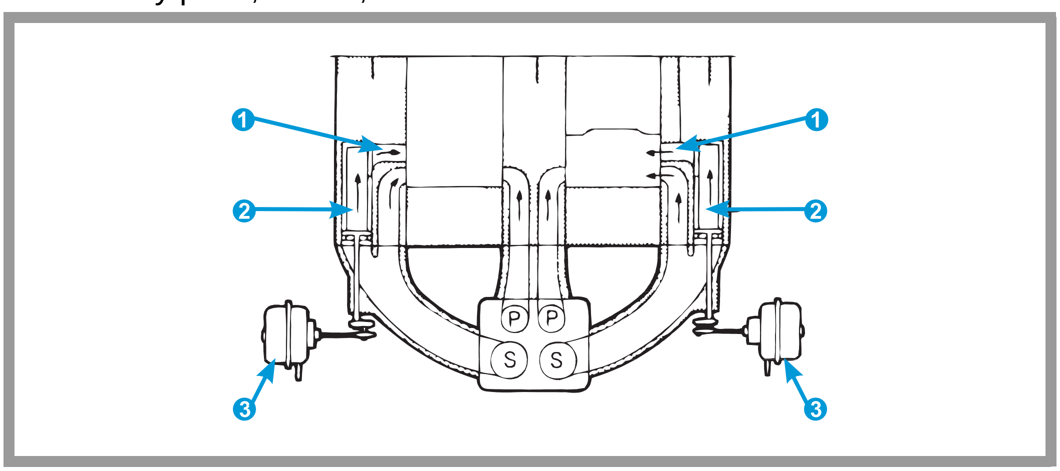


FIGURE 4-6.
Auxiliary intake ports activate under high-speed, high-load conditions.

1. Auxiliary ports
2. Auxiliary port valves
3. Actuators

Most normally aspirated (non-turbo charged) rotary engines use a six-port system, while all rotary turbo engines use a four-port induction system.

Variable Dynamic Effect Intake (VDI) System

To further improve engine performance, some rotary engines use an induction method known as a *Variable Dynamic Effect Intake (VDI) system*. The VDI system includes the VDI valve, a solenoid valve, and an actuator.

The VDI valve is built into the extension manifold. Figure 4-7 shows how the VDI system operates.

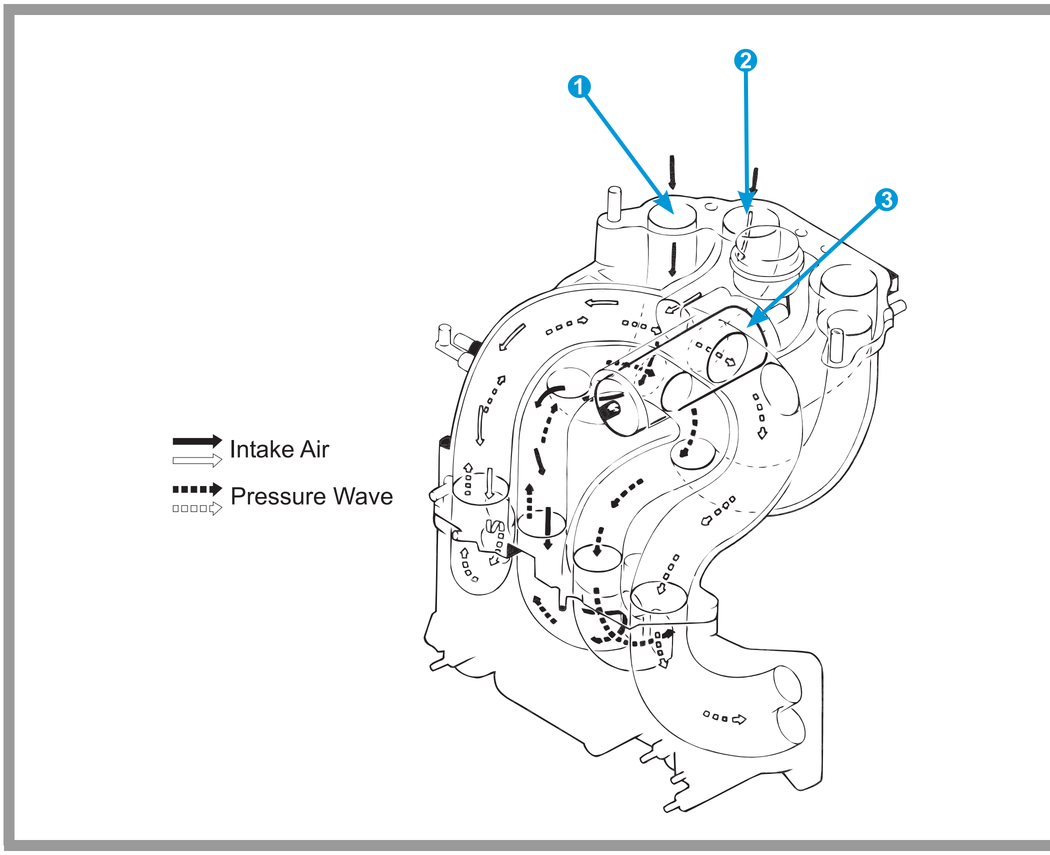


FIGURE 4-7.
At the low-speed range, the secondary and auxiliary ports close, and high-velocity intake air flows only from the primary port. This improves fuel atomization and combustion efficiency, increasing torque.

1. Intake air
2. Pressure wave
3. VDI valve

When the engine operates, intake air initially flows to a port that is closed by the rotor. This creates a pressure wave that sends the air to the open intake port, compressing it along the way.

At low engine speed, the VDI valve remains closed (Figure 4-8), effectively lengthening the pressure wave path. At high engine speed, the VDI valve opens, and the wave quickly pressurizes the intake air through the shortened path. This forces the precise amount of air into the working (combustion) chamber at all engine speeds.

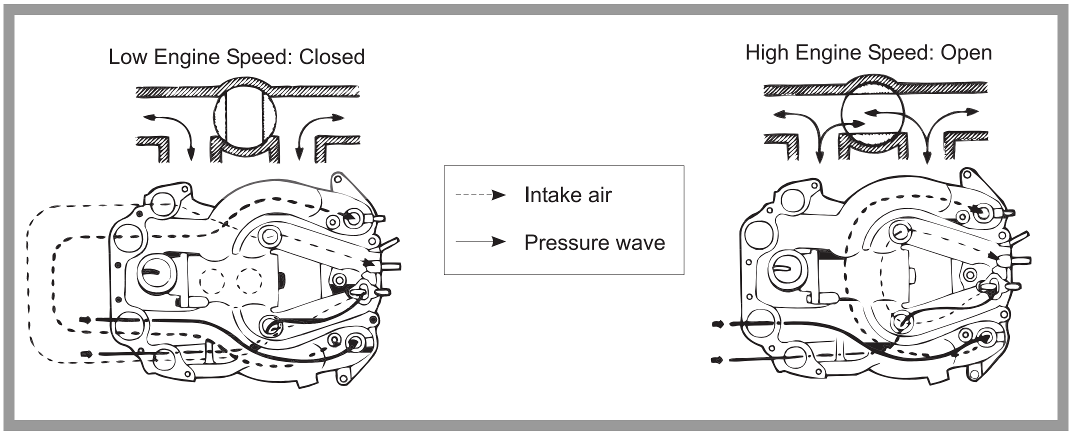


FIGURE 4-8.
At high engine speeds, the VDI valve opens, increasing the intake air amount. This provides added torque at the high-speed range.

Fuel Injection System

Fuel injectors supply fuel to the rotary engine in a precise ratio (about 14 parts air to 1 part fuel). Electronic fuel injection systems monitor a variety of environmental and engine conditions to precisely control the air-fuel mixture over a wide range of driving conditions.

A fuel injector (shown in Figure 4-9) is composed of a coil, spring, and needle valve. When the injector receives a signal from the PCM, current passes through the coil, pulling in the needle valve and injecting fuel.

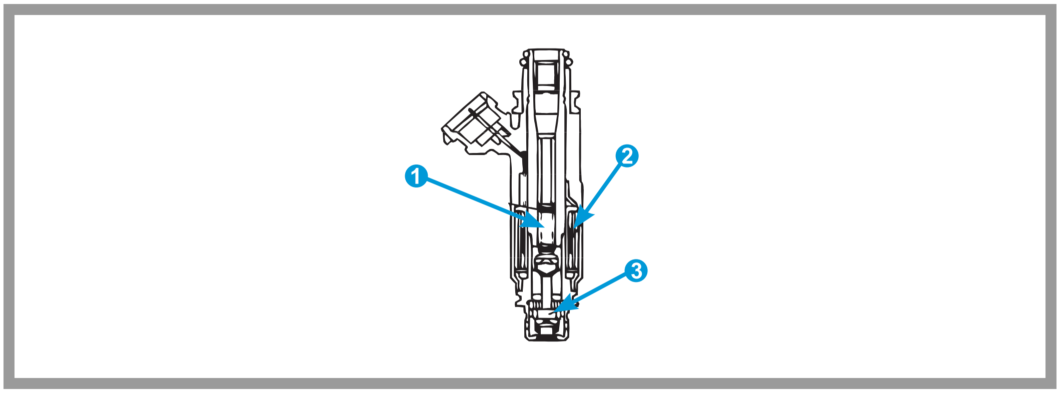


FIGURE 4-9.
Fuel injectors, provide the precise amount of fuel to match driving conditions.

1 Spring

2 Coil

3 Needle valve

Many rotary engines use a four-injector system with four nozzles that spray fuel into the engine's intake ports. Two primary injectors, one for each rotor, deliver fuel to the primary intake ports. A pair of secondary injectors, one per rotor, supply fuel to the intake system's secondary and auxiliary ports.

The number of injectors used depends on the engine's operating needs. Under low-speed, low-load conditions, only the two primary injectors operate. As power needs increase, the secondary injectors begin to deliver additional fuel. Figure 4-10 shows a four-injector system with primary and secondary injectors operating (shows injectors for one rotor only).

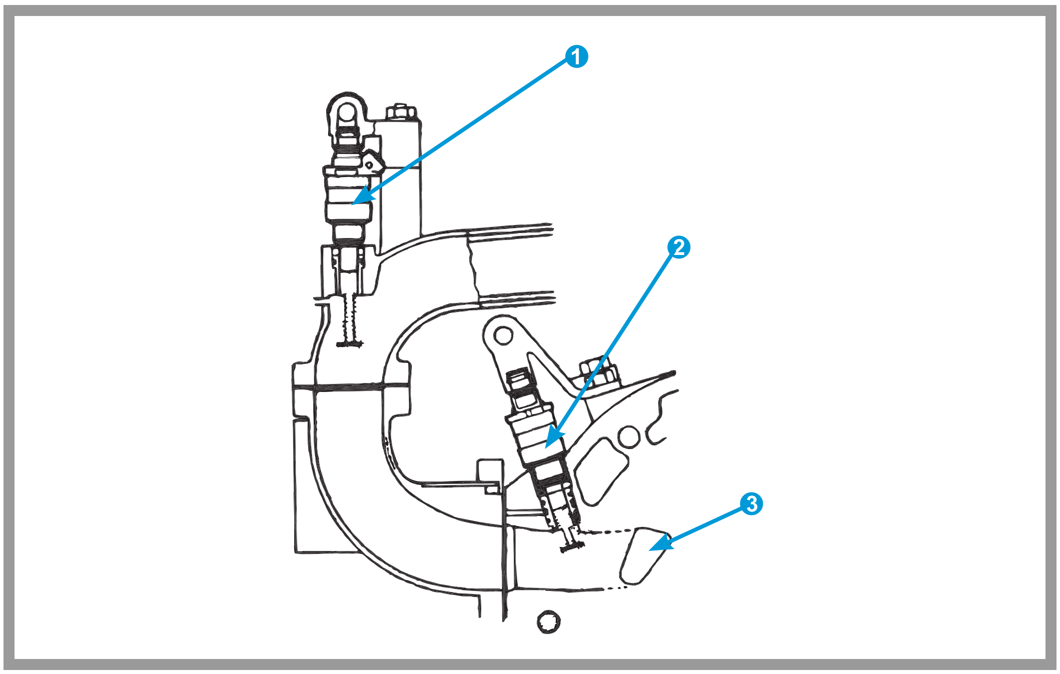


FIGURE 4-10.
A four-injector system uses primary and secondary injectors to match fuel flow to driving conditions.

1 Secondary injector

2 Primary injector

3 Primary intake port

Some advanced engine designs (such as RENESIS) have three injectors per rotor, one for each intake port.

Engine Cooling System

When a rotary engine operates, the parts of the rotor housing used for intake and compression remain relatively cool. However, with three power strokes during every rotation of the rotor, the rotor housing near the spark plugs becomes very hot. The area near the exhaust port also becomes heated because hot combustion gases pass through the port. These two areas form a "hot zone" in the rotor housing.

Coolant runs through passages in the sides of the rotor housings and side housings, absorbing heat from the hot zone. The coolant then circulates through the “cold zone” to balance internal engine temperatures and lower the coolant temperature. Figure 4-11 shows the coolant flow path through a rotary engine.

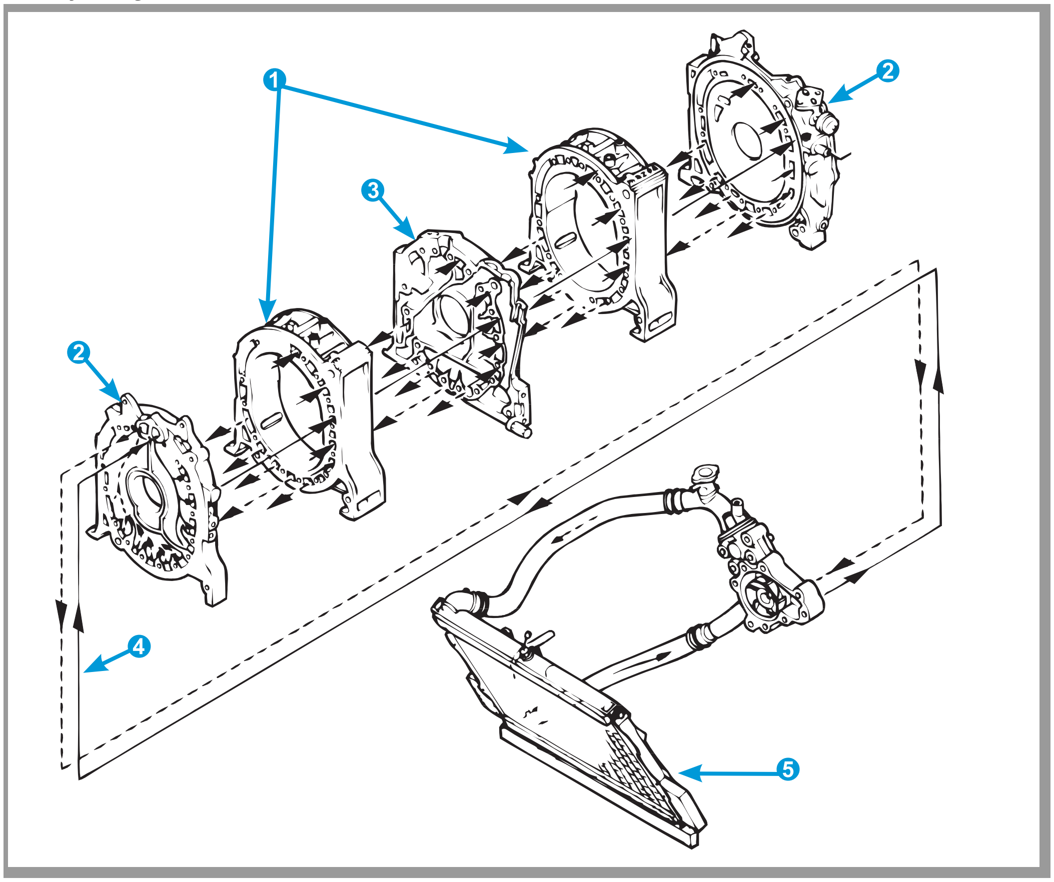


FIGURE 4-11. Coolant flow balances temperatures around the outside of the engine housings.

1. Front and rear rotor housings
2. Side housings
3. Intermediate housing
4. Coolant flow path
5. Radiator

Secondary Air System

The *secondary air injection control system* helps clean the exhaust gas by introducing fresh air into the exhaust port or *catalytic converter*. The *ECU (Emissions Control Unit)* regulates secondary air flow by activating solenoid valves and the air pump relay. The secondary air system consists of an air pump, an air pump relay, and several solenoid valves, as Figure 4-12 shows.

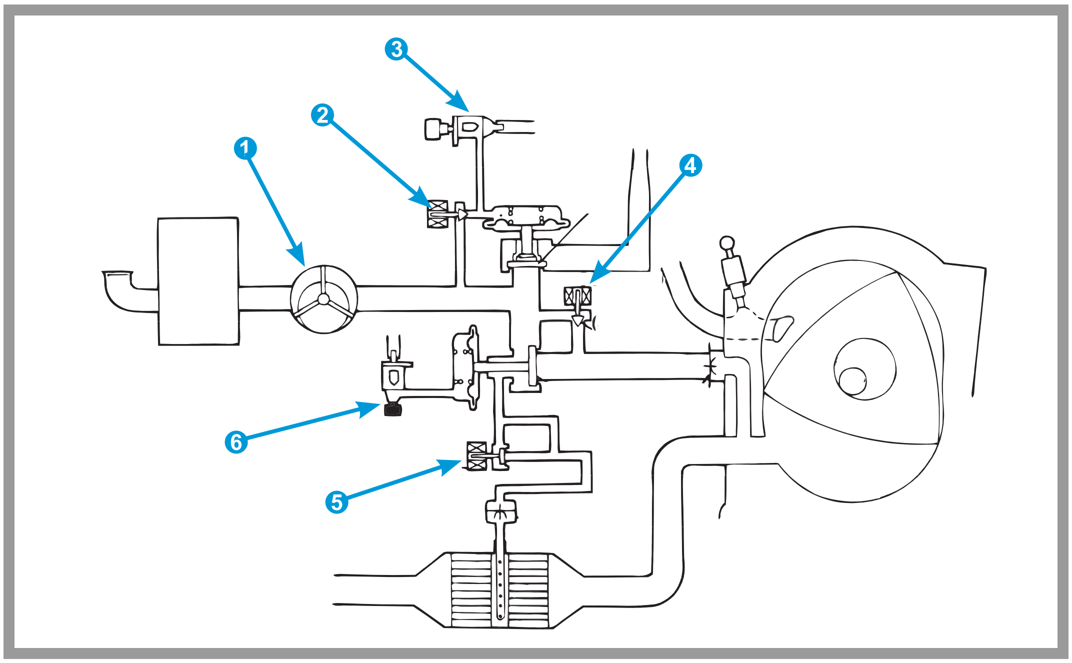


FIGURE 4-12. The secondary air system reduces emissions by causing the catalytic converter to activate more rapidly.

1. Air pump
2. Relief 2 solenoid valve
3. Relief 1 solenoid valve
4. Port air bypass solenoid valve
5. Split air bypass solenoid valve
6. Switching solenoid valve

The vane-type air pump provides secondary air to the air control valve. An electromagnetic clutch stops secondary air discharge during high-speed or heavy-load operation.

The air pump relay is controlled by the ECU and turns the air pump electromagnetic clutch ON and OFF.

The switching solenoid valve switches air flow between the secondary injection air port and the split air port. This valve is controlled by the ECU.

The ECU also controls the relief 1 solenoid valve which controls the air pump release pressure. This improves fuel economy.

When the engine is cold, the relief 2 solenoid valve controls the relief valve opening pressure to further reduce exhaust emissions.

Lubrication System (Metering Oil Pump)

A rotary engine uses engine oil for many purposes. Oil lubricates the main rotor bearings and helps prevent wear of the gas seals in the working chambers. Oil also improves airtightness in the working chambers.

Engine oil also cools the rotors. Oil jets in the eccentric shaft inject oil into the inner part of the rotor. Each time the rotor turns one full turn, rotational forces cause two discharges and drainages of the oil within the rotor. Figure 4-13 shows the oil flow path through a rotary engine lubrication system.

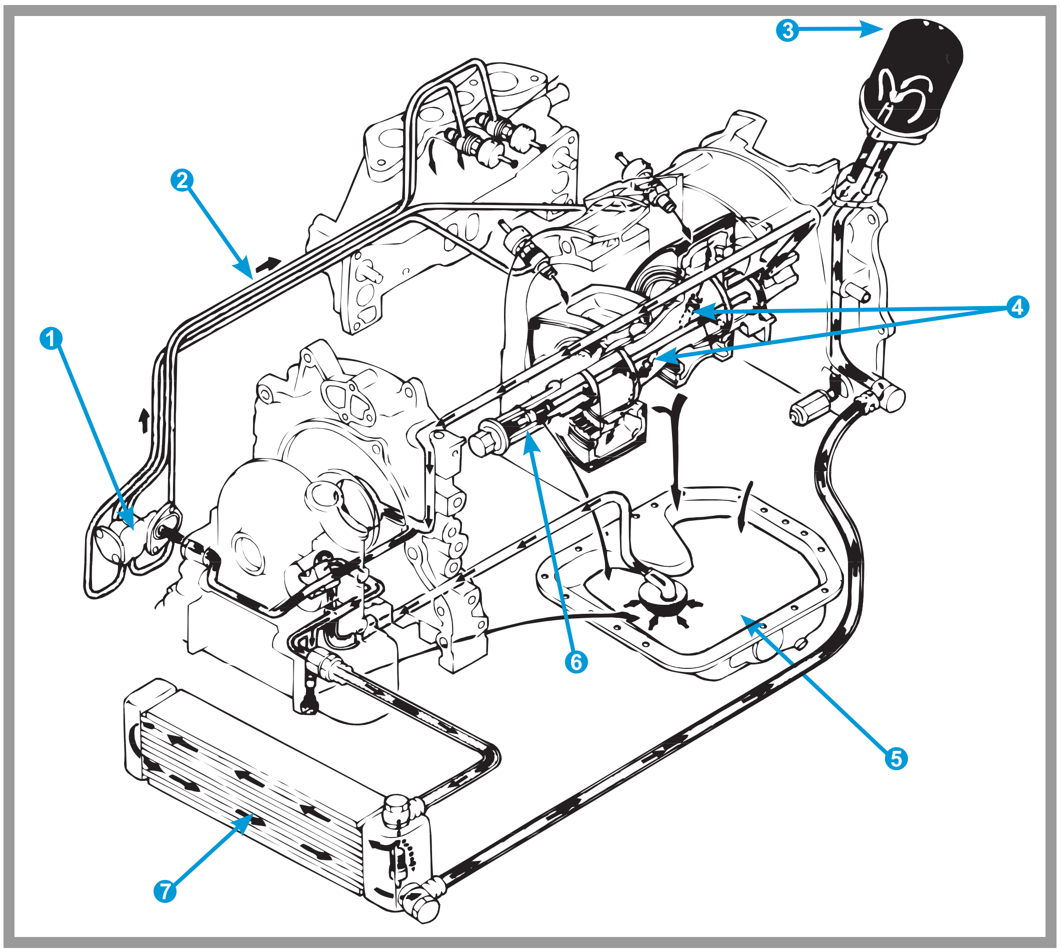


FIGURE 4-13. Rotary engines use oil for lubrication, cooling, and to improve sealing in the engine's working chambers.

1. Metering oil pump
2. Oil flow path
3. Oil filter
4. Eccentric shaft oil jet plugs
5. Oil pan
6. Eccentric shaft bypass valve
7. Oil cooler

The eccentric shaft contains a bypass valve to shorten engine warmup time. The bypass valve (shown in Figure 4-14) allows engine oil in the oil passage to escape at cold-engine start, maintaining pressure in the eccentric shaft. This pressure prevents the oil jets from injecting oil into the rotors until the engine is fully warm.

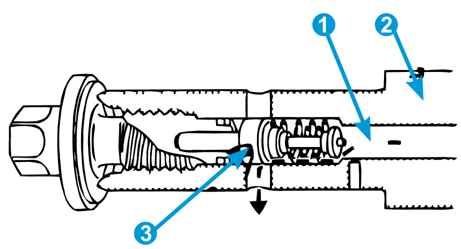


FIGURE 4-14.
The eccentric shaft bypass valve improves engine performance at start-up.

1 Oil passage

2 Eccentric shaft

3 Eccentric shaft bypass valve

The engine lubrication system is controlled by a *metering oil pump* which discharges oil through the oil nozzle to lubricate the gas seals — apex, side, and corner — and improve airtightness in the working chambers. The metering oil pump (shown in Figure 4-15) controls the flow of oil throughout the lubrication system.

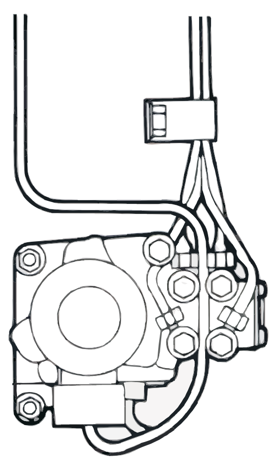


FIGURE 4-15.
The metering oil pump controls oil flow to all parts of the lubrication system.

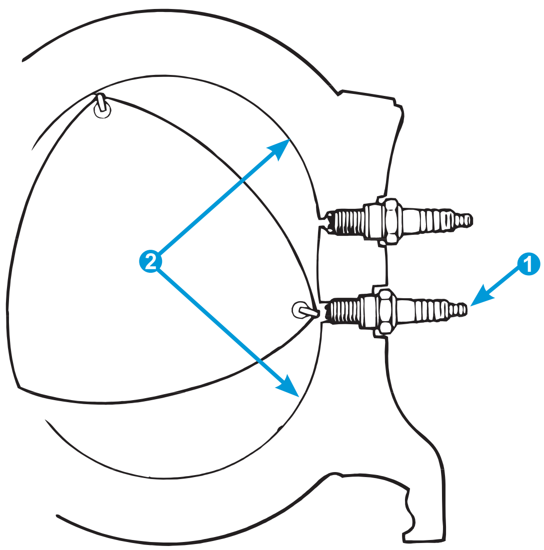
REVIEW EXERCISE 3

Fill in the words that correctly complete these sentences. Check your answers with the answer key on page 42.

1. Because of their installation position in the rotor housing, the spark plugs are designated _______________ and ________________.

2. To prevent pressure loss (blowby) around the trailing side spark plug, this plug's hole is _____________ than the leading side plug's hole.

Refer to the graphic below to answer questions 3 and 4.

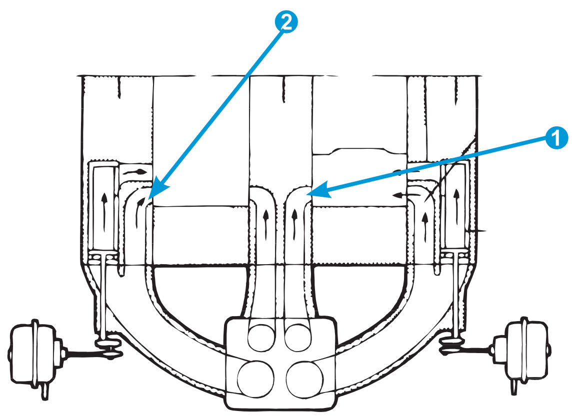


3. Number 1 in this graphic identifies the _______________ spark plug.

4. Number 2 identifies an area of _______________ pressure between the compression and combustion force.

5. A six-port induction system uses ______________, ________________, and ________________ ports to provide the proper air-fuel mixture to the working chambers.

Refer to the illustration below to answer questions 6 and 7.



6. Number 1 in this graphic identifies the intake system's ___________________ intake port.

7. Number 2 in this graphic identifies the intake system's __________________ intake port.

8. The portion of the rotor housing used for intake and compression tends to be relatively ________, whereas the portions used for combustion and exhaust tend to be ________.

9. The secondary air injection control system helps to ___________ the exhaust gas by introducing fresh air into the exhaust port or catalytic converter in response to driving conditions.

10. Oil lubricates the main rotor bearings, helps prevent wear of the gas seals, and also improves ____________________ in the working chambers.

5 - RENESIS ROTARY ENGINE FEATURES & BENEFITS

Previous sections of this guide described basic components and systems found on most rotary engines. This section introduces a specific engine, Mazda's RENESIS rotary engine.

This section describes some differences between the RENESIS and other rotary engines and highlights some of the RENESIS engine's major advantages.

OBJECTIVES

After completing this section, you will be able to:

- Describe the differences between standard rotary and RENESIS rotary engines
- Describe the features and benefits of the RENESIS rotary engine, in terms of:

  - Fuel economy
  - Emissions
  - Weight and mounting
  - Eccentric shaft
  - Oil consumption

RENESIS ROTARY VS. STANDARD ROTARY ENGINES

The RENESIS rotary engine is the most advanced rotary engine ever developed by Mazda. The name RENESIS comes from RE (Rotary Engine) and GENESIS, meaning a new generation of rotary engine performance.

Answers to Review Exercise 3

1. leading, trailing
2. smaller
3. leading
4. balanced
5. primary, secondary, auxiliary
6. primary
7. secondary
8. cool, hot
9. clean
10. airtightness

Differences Between Conventional and RENESIS Rotary Engines

RENESIS features many improvements over earlier rotary engine designs, including:

- Improved power performance

  - Side intake and exhaust ports
  - Dual two-piece apex seals
  - Keystone-shaped side seals
  - Cut-off seals
  - Lightweight flywheel

- Reduced engine weight

  - Thin walls on the side housings
  - Lightweight rotors
  - Aluminum rotor housings
  - Aluminum engine mount brackets

- Reduced engine noise and vibration through oil-filled engine mount gaskets

Side Intake and Exhaust Ports

A major innovation in the RENESIS design is its *side-exhaust*, side-intake configuration. The exhaust ports, normally located on the rotor housing of conventional rotary engines, are on the RENESIS engine's side housing. Figure 5-1 shows the side intake and exhaust ports.

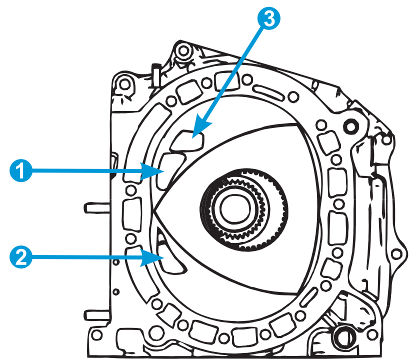


FIGURE 5-1. Intake and exhaust ports on the side housings give RENESIS more power, better mileage, and lower emissions.

1. Side intake port
2. Side exhaust port
3. Side intake port (high-power version only)

This design eliminates any undesirable overlap between the opening of the exhaust and intake ports. This makes the intake and exhaust strokes more efficient because combustion gas does not flow into the intake stroke.

Most rotary engines feature a single exhaust port for each rotor, while the RENESIS has two exhaust ports per rotor, giving RENESIS an exhaust port area twice that of conventional designs.

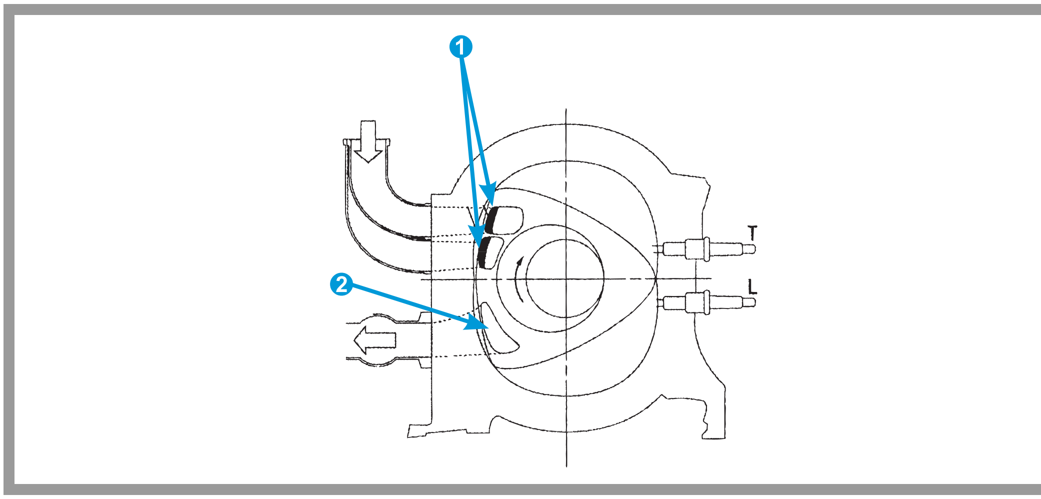
In addition to improving exhaust flow, this dual-exhaust design allows exhaust port timing to be delayed. This provides more time for the power stroke, increasing power output and fuel efficiency.

Compared to conventional rotary engines, the RENESIS intake port area is 30 percent larger, greatly improving intake flow. Figure 5-2 shows the larger side intake ports.

FIGURE 5-2.
Larger side intake ports allow more air into the working chambers for better combustion.

❶ 30% larger intake port area

❷ Side exhaust flow



In addition, the RENESIS' unique gas- and oil-sealing system is specifically designed to match the side exhaust configuration. *Cut-off seals* in the rotor sides make the working chambers even more airtight. Tighter sealing greatly improves power output and fuel efficiency, while lowering emissions.

Intake (Induction) and Fuel Injection Systems

RENESIS has a six-port-induction (6PI) variable induction system, featuring three intake ports for each rotor. The system uses DC (direct current) motors to open and close shutter valves at each rotor's intake port, using the incoming air's dynamic force to improve intake efficiency.

RENESIS also features ultra-fine fuel injectors for improved fuel atomization. *Atomizing* fuel breaks it into small particles so it burns more completely. Small, high-power ignition coils provide a more powerful spark for better ignition.

The combination of ultra-fine injectors and powerful ignition causes virtually complete combustion, producing better mileage and lower emissions.

Standard and High-Power RENESIS Engines

The RENESIS engine comes in two versions: standard power and high power. The standard-power version has an automatic transmission, generates 207 horsepower, and has two exhaust ports.

The high-power version has a manual six-speed transmission, generates 247 horsepower, and features four exhaust ports and an additional side intake port.

The high-power version also has two advanced systems, the *Variable Fresh Air Duct (VFAD) valve* and the *Auxiliary Port Valve (APV)* position sensor and APV motor. These systems improve engine torque and output at the high-speed range. They will be discussed more fully in Section 6.

RENESIS ROTARY ENGINE FEATURES & BENEFITS

Fuel Economy

The RENESIS engine's unique intake, exhaust, and fuel injection systems all help to produce excellent fuel economy. These systems provide an overall leaner air-fuel ratio and can improve fuel economy at idle by up to 40 percent.

The RENESIS engine runs with an overall leaner air-fuel mixture because unlike piston engines, rotary engines do not need richer air-fuel mixtures to prevent knock under heavy load.

Another RENESIS innovation, the *anti-wet port*, also helps fuel economy. This system flows *jet air* (air moving at high velocity) into the primary intake port. A sharp-tipped nozzle installed in the intake manifold injects the jet air to blow off any fuel adhering to the intake port's surface. Figure 5-3 shows the anti-wet port action.

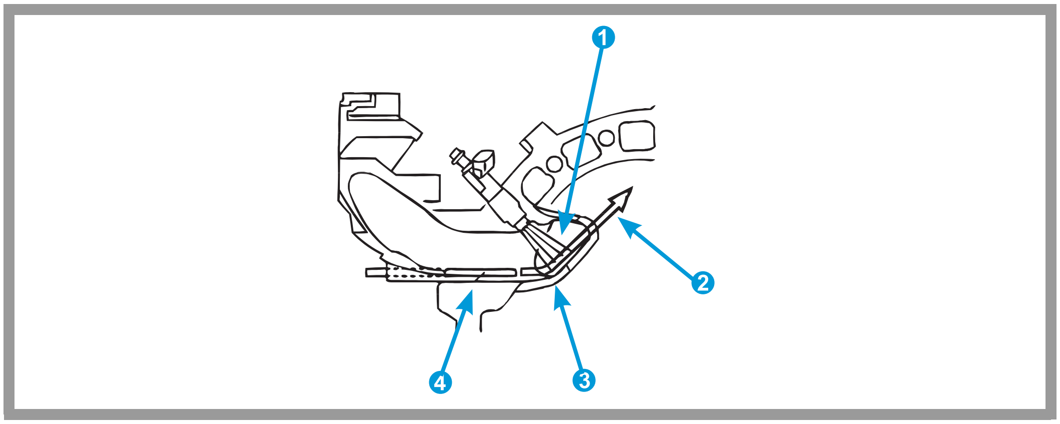


FIGURE 5-3. The anti-wet port projection on the intake port helps provide the ideal air-fuel mixture.

1. Primary intake port
2. Jet air
3. Anti-wet port
4. Jet air-fuel mixing nozzle

Located on the bottom edge of the intake port, the anti-wet port forms an air current so the air-fuel mixture blown off by the jet air flows to the spark plugs more efficiently. This produces an ideal air-fuel mixture.

Emissions

Vehicle emission standards are strict, and Mazda expects them to be even tighter in the future. Therefore, the RENESIS engine uses Mazda's unique and advanced catalytic technologies.

Another RENESIS feature that lowers emissions is its side exhaust design. With side exhaust ports, unburned gas that used to blow by the apex seals is sent to the next power stroke to be reburned.

This side-exhaust design reduces hydrocarbon (HC) emissions from unburned fuel. Figure 5-4 shows a traditional rotor housing exhaust port (on the left) and the RENESIS side exhaust design (on the right).

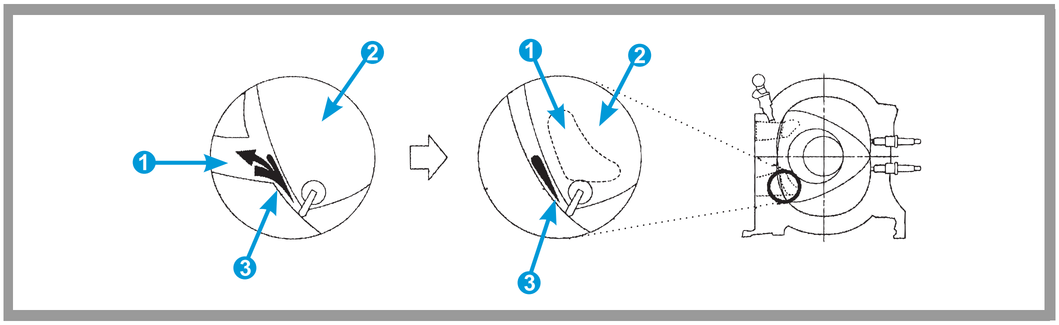


FIGURE 5-4.
Side exhaust ports let hydrocarbons sweep past the port to be reburned on the next power stroke.

1 Exhaust port

2 Rotor

3 Unburned fuel

Weight and Mounting

The compact RENESIS design allows center-midship mounting and a 50/50 front-to-rear weight distribution, producing excellent balance and handling.

Although powerful, the RENESIS engine is extremely light. It features lightweight rotors for improved engine response. These special cast-iron rotors have a hollow interior. By reducing the thickness of the ribs in the rotor interior, Mazda reduced rotor weight by 14 percent.

For improved engine response, the flywheel is approximately 20 percent lighter than traditional designs.

Several other RENESIS features help reduce its weight, including:

- Aluminum engine mount brackets
- Thin walls on the side housings
- Aluminum rotor housings
- Compact oil filter (outer diameter of 65 mm [2.56 in.])
- Steel oil pan with thin design
- Plastic oil strainer
- Down-flow type radiator with aluminum core and plastic tank

Eccentric Shaft

RENESIS features an eccentric shaft made of highly durable, forged carbon steel. The shaft is processed with induction hardening for improved wear resistance.

An oil passage runs from the front end of the eccentric shaft to the rear main journal. This passage supplies lubrication for each rotor journal and the oil jet plugs. The oil jet plugs inject oil into the rotor interior to help cool the rotor. Figure 5-5 shows the eccentric shaft and oil jet plugs.

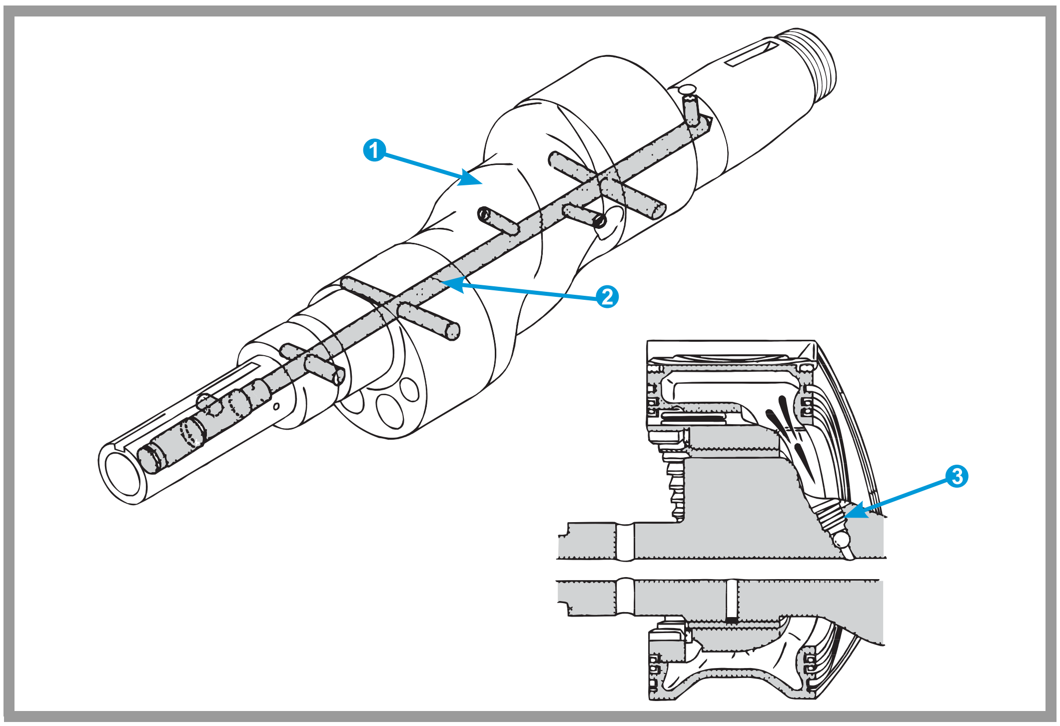


FIGURE 5-5.
Oil jet plugs inject oil into the rotors to help cool them.

1. Eccentric shaft
2. Oil passage
3. Oil jet plugs

The eccentric shaft also contains a bypass valve to shorten the engine warm-up period. The eccentric shaft bypass valve allows engine oil in the oil passage to escape at cold-engine start, maintaining pressure in the eccentric shaft. This pressure keeps the oil jet plugs from injecting oil until the engine warms up.

Oil Consumption

The RENESIS engine uses an electric-type *metering oil pump* to reduce oil consumption. The metering oil pump precisely controls the amount of the oil discharged to the various engine parts. The RENESIS engine lubrication system can reduce oil consumption by up to 50 percent over traditional designs. Figure 5-6 shows the RENESIS lubrication system.

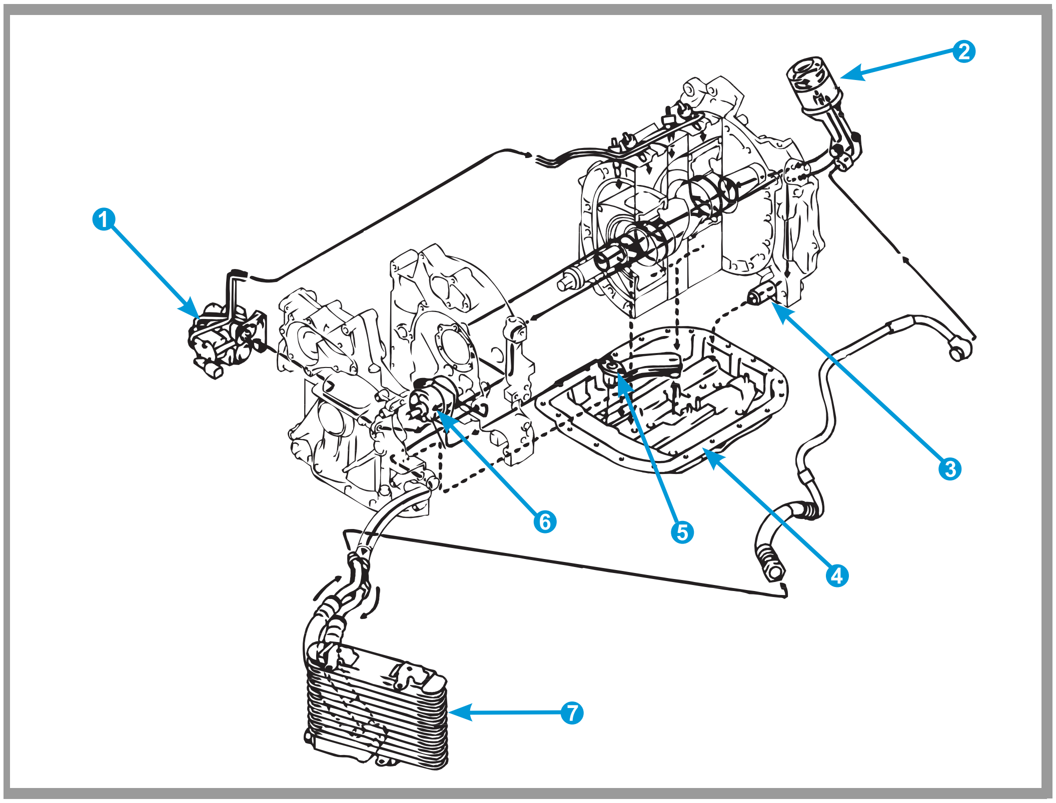


FIGURE 5-6.
The metering oil pump is the heart of a lubrication system that can reduce oil use by up to 50%.

1. Metering oil pump
2. Oil filter
3. Oil pressure regulator valve
4. Oil pan
5. Oil strainer
6. Oil pump
7. Oil cooler

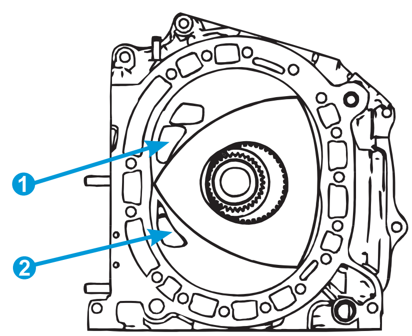
The metering oil pump is controlled by the PCM, which sends a pulse signal controlling the amount of oil discharged to the metering oil pump. The PCM adjusts the oil discharge according to the engine rotation, engine coolant temperature, and amount of intake air.

For more information on how the metering oil pump works, refer to Section 6.

REVIEW EXERCISE 4

Fill in the words that correctly complete these sentences. Check your answers with the answer key on page 53.

Refer to the graphic below to answer questions 1 and 2.



1. Number 1 in this graphic identifies the RENESIS engine's ___________ ________.

2. Number 2 in this graphic identifies the RENESIS engine's ______________ ________.

3. Compared to conventional rotary engines, the RENESIS _________ _________ area is 30 percent larger, greatly improving intake ability.

4. The projection on the bottom edge of the intake port that flows jet air into the primary intake port is called the ________-_________ _________.

5. __________ ______________ ports let hydrocarbons be swept past the port to be reburned on the next power stroke.

6. The RENESIS engine uses an electric-type _______________ oil pump to reduce oil consumption.

6 - RENESIS ROTARY ENGINE SYSTEMS

Mazda's advanced RENESIS rotary engine has the highest power-to-weight ratio ever achieved by a naturally aspirated (non-turbocharged) rotary engine. To realize this outstanding performance, RENESIS uses many advanced systems to increase intake and exhaust efficiency, provide the ideal air-fuel mixture, and produce the mozst efficient combustion possible.

This section discusses some of the RENESIS rotary engine's advanced systems in greater detail.

OBJECTIVES

After completing this section, you will be able to describe major RENESIS rotary engine systems, including:

- Air intake
  - Secondary shutter valve (SSV)
  - Variable dynamic effect intake (VDI) valve
  - Variable fresh air duct (VFAD) shutter valve
  - Auxiliary port valve (APV)
- Jet air-fuel mixing
- Exhaust ports
- Metering oil pump
- Wet sump oil system
- Secondary air injection system
- Catalytic converter
- Electronic throttle control

RENESIS ROTARY ENGINE SYSTEMS

Air Intake System

The RENESIS rotary engine features a *Sequential Dynamic Air Intake System (S-DAIS)* for improved engine output. The S-DAIS increases the amount of intake air to enhance combustion efficiency. The system controls the size of the intake ports and the air length in the intake pipes according to engine needs. Figure 6-1 shows the components of the S-DAIS.

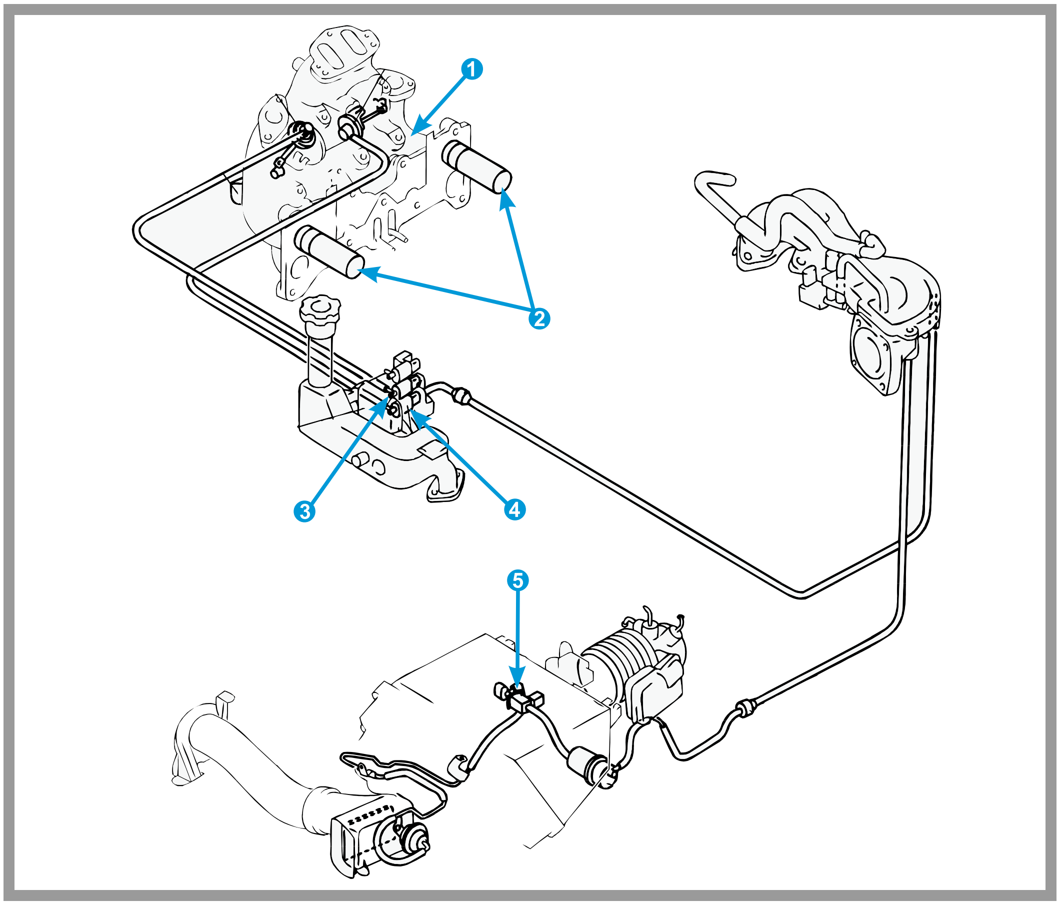


FIGURE 6-1.
The air intake system uses a combination of valves and ducts to provide the precise amount of air needed for all driving conditions.

1. Intake manifold
2. Auxiliary port valve (high-power engine only)
3. Secondary shutter valve
4. Variable Dynamic Effect Intake valve
5. Variable Fresh Air Duct valve (high-power engine only)

By combining S-DAIS with side intake and exhaust ports, RENESIS generates high torque and high power output at all engine speeds. The S-DAIS consists of several valves and ducts, including:

- *Secondary Shutter Valve (SSV)* — In response to signals from the PCM, this valve opens and closes to allow more or less air into the intake system.

Answers to Review Exercise 4

1. intake port
2. exhaust port
3. intake port
4. anti-wet port
5. side exhaust
6. metering

- *Variable Dynamic Effect Intake (VDI) valve* — Described in Section 4 of this Guide, the VDI valve ensures that the combustion chamber receives the precise amount of air at all engine speeds.
- *Variable Fresh Air Duct (VFAD) valve* — Available only on the high-power RENESIS engine, this valve controls the flow of intake air into the S-DAIS.
- *Auxiliary Port Valve (APV)* — Also available only on the high-power RENESIS, the PCM opens and closes this motorized valve to regulate air flow.

To enhance intake air flow and combustion efficiency, the S-DAIS controls the size of the intake ports and the air length in the intake pipes by opening or closing the valves according to engine speed and load conditions.

Low-Speed Range

In the low-speed range, the secondary and auxiliary ports close, and high-velocity air flows only from the primary port. This improves fuel atomization at low speeds, producing better combustion efficiency and higher torque.

Medium-Speed Range

When engine speed reaches the medium range, the VFAD valve and APV open (high-power version only). With the VFAD valve open, the shorter length of the fresh-air duct reduces intake air resistance. In addition, the SSV opens, and intake air from the secondary port begins flowing.

High-Speed Range

At high speeds, the APV opens (high-power version only), allowing airflow from all intake ports, and further improving torque. The VDI valve also opens at high speed, and the length of the intake air in the pipe is shortened, providing efficient dynamic air pressurizing.

When the intake ports shut abruptly, the intake air is compressed. This pressurizes the intake air in the rotor chambers, increasing the intake air amount and improving torque at high-speed. Figure 6-2 shows the operation of the VFAD, APV, VDI, and SSV valves at various engine rpm.

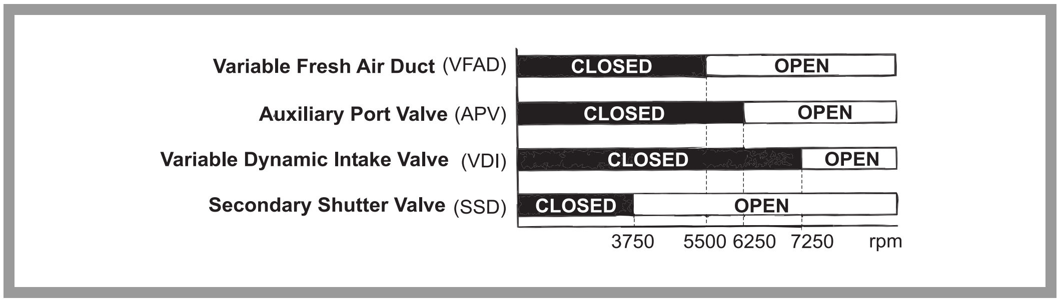


FIGURE 6-2.
The air intake control provided by the S-DAIS system makes the RENESIS rotary engine highly responsive under all driving conditions.

Jet Air-Fuel Mixing System

RENESIS uses a *jet air-fuel mixing system* to improve fuel economy, especially at engine idle. The jet air-fuel mixing nozzle is located at the primary port outlet of the intake manifold, as shown in Figure 6-3. Atmospheric pressure is applied from upstream of the throttle valve, through the hose to the nozzle.

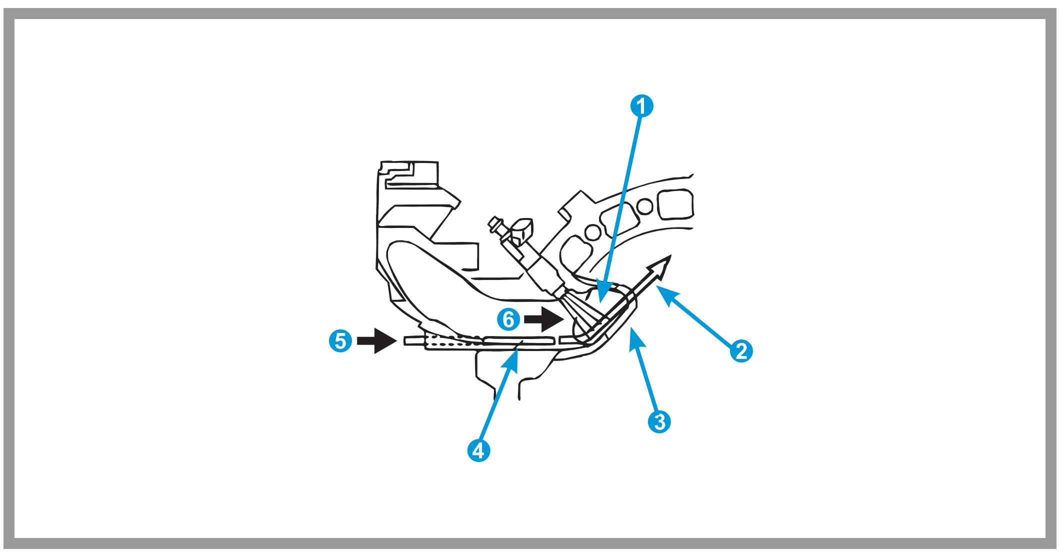


FIGURE 6-3.
The jet air-fuel mixing system improves fuel economy, especially at low speeds.

1. Primary port
2. Jet air
3. Anti-wet port
4. Mixing nozzle
5. Atmospheric pressure
6. Intake manifold vacuum

Under low load, jet air (high speed air) blows through the air pipe, along the surface of the intake port. The air blows off any fuel that might stick to the surface of the intake port. The anti-wet port at the bottom of the primary intake port helps atomize the fuel so the air-fuel mixture flows to the spark plugs more efficiently. This system produces stable combustion and improves fuel economy.

Exhaust Ports

The exhaust ports on the RENESIS rotary engine are located on the side housings, rather than on the rotor housings as in previous rotary engines. Figure 6-4 shows the RENESIS engine's side intake and exhaust port locations.

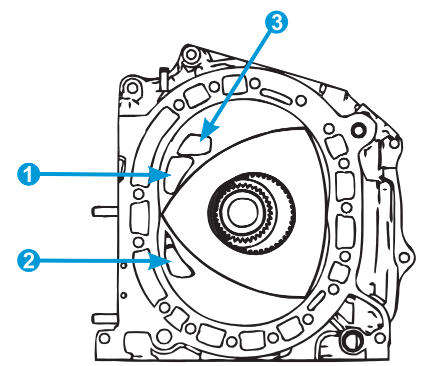


FIGURE 6-4. RENESIS exhaust ports are located on the side housings.

1. Intake port
2. Exhaust port
3. Intake port (high-power version only)

The RENESIS side exhaust design prevents the intake and exhaust ports from overlapping, so no exhaust gases flow into the intake stroke, as Figure 6-5 shows. This creates more stable combustion and reduces emissions.

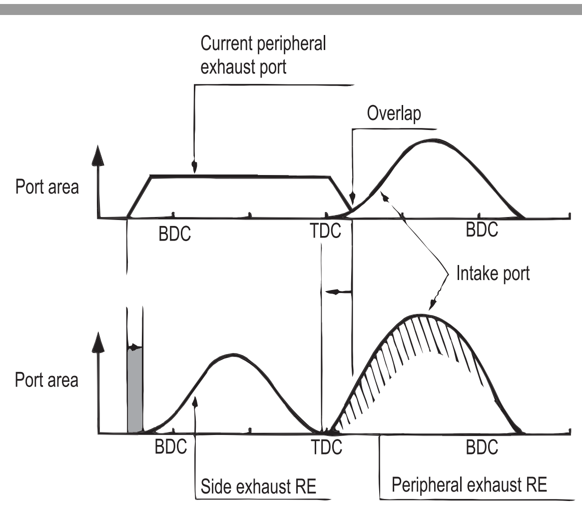


FIGURE 6-5. Most rotary engines (RE) have exhaust ports on their rotor housings (peripheral exhaust). RENESIS uses exhaust ports on its side housings, eliminating unwanted overlap between the exhaust and intake strokes.

The RENESIS engine also has two exhaust ports per rotor. This provides about twice the exhaust port surface area of previous rotary engine designs. This means each port can open for a shorter period, allowing more time for the power stroke. This results in more efficient combustion and reduced fuel consumption.

REVIEW EXERCISE 5

Fill in the words that correctly complete these sentences. Check your answers with the answer key on page 58.

1. The motorized valve in the S-DAIS system on the high-power RENESIS engine is called the ________________.
2. At high speeds, the _____________ valve in the S-DAIS opens, effectively shortening the length of the intake air pipe.
3. The jet air-fuel mixing nozzle is located at the ____________ __________ ____________ on the intake manifold.
4. The anti-wet port helps to ____________ the fuel.
5. Exhaust ports on the RENESIS engine are located on the ___________ housings.

Metering Oil Pump

RENESIS uses an electric metering oil pump to reduce oil consumption by precisely controlling the amount of oil supplied to the lubrication system. See Figure 6-6.

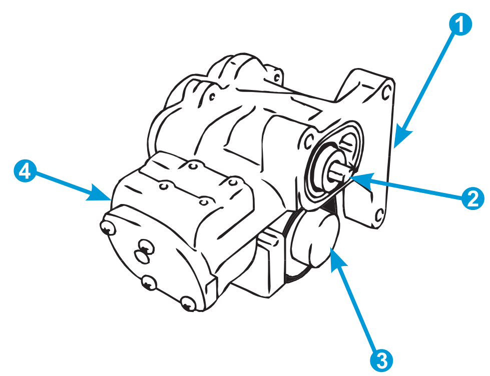


FIGURE 6-6. The electric-type metering oil pump delivers the precise amount of oil required, under the control of the PCM, based on driving conditions.

1 Engine attachment side

2 Oil inlet

3 Stepping motor

4 Oil outlet

The PCM controls the amount of oil supplied to the metering oil pump according to engine rotation, coolant temperature, and amount of intake air.

The eccentric shaft turns the driven gear in the oil pump, which pressurizes the oil. The PCM signals the stepping motor in the metering oil pump, which activates a plunger to inject oil into the lubrication system. This ensures that the pump supplies the correct amount of oil, based on driving conditions.

The metering oil pump also has a fail-safe function that operates when the engine senses a failure in the pump motor. During fail-safe operation, the PCM keeps the pump operating at minimum requirements, ensuring that it provides the minimum amount of oil necessary at each engine rotation rate.

Under fail-safe conditions, normal driving is possible when the amount of oil required by the engine is within the minimum oil needed. If the amount of oil required is more than the minimum oil supplied, the PCM restricts fuel injection and suppresses engine rotation. This prevents the seals inside the engine from seizing.

Wet-Sump Lubrication System

The RENESIS engine's low *wet-sump lubrication system* features an oil pan just 40 mm deep, about half the size of an oil pan in previous rotary engine designs. See Figure 6-7. This design allows the eccentric shaft to be installed higher than the crankshaft in a conventional piston engine, out of the sump.

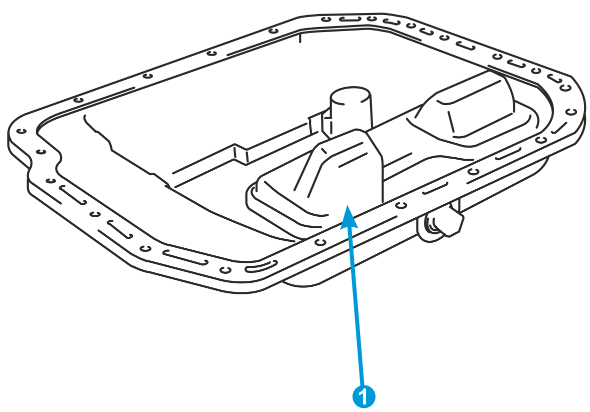


FIGURE 6-7.
The oil pan has a baffle chamber that keeps oil from moving around in the pan.

1. Baffle chamber
2. Oil level switch

In addition, RENESIS has a baffle chamber in the oil pan to keep oil from moving around, even under hard cornering. An oil level switch monitors the amount of oil in the pan. The RENESIS wet-sump system is about three percent lighter than the dry-sump system used in previous rotary engines.

Answers to
Review Exercise 5

1. auxiliary port valve (APV)
2. variable dynamic effect intake valve (VDI)
3. primary port outlet
4. atomize
5. side
6. metering

Secondary Air Injection (AIR) System

The *secondary air injection (AIR) system* helps clean the exhaust gas by introducing fresh air into the exhaust port during cold starts. The PCM regulates secondary air flow by activating solenoid valves and the air pump relay. The secondary air system consists of an air pump, an air pump relay, and several solenoid valves, as shown in Figure 6-8.

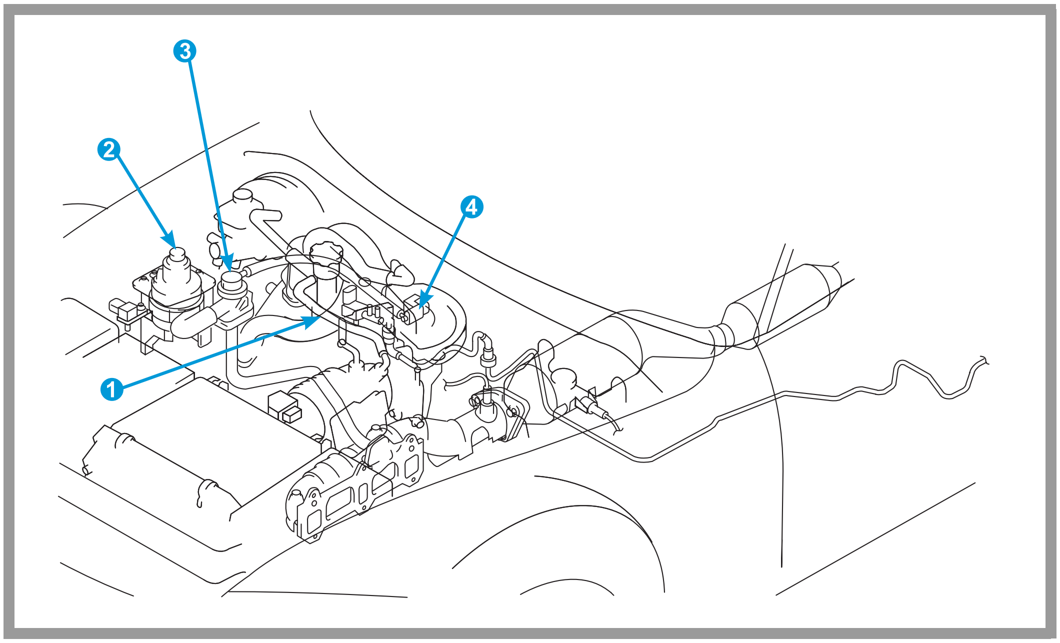


FIGURE 6-8.
The secondary air injection system helps clean the exhaust gas during cold starts.

1. Ventilation hose
2. Secondary air injection pump
3. Secondary air control valve
4. Secondary air injection solenoid valve

The secondary air injection system pumps air to the exhaust ports. The secondary air reacts with unburned gas to raise the exhaust gas temperature. This causes the catalytic converter to activate rapidly.

The AIR system is controlled by the PCM. When a cold engine starts, the AIR pump operates, and the PCM turns on the AIR solenoid valve. The AIR control valve opens and lets the air flow through the secondary air ports into the exhaust ports in the side housing. When the AIR pump stops, the AIR solenoid valve turns off, closing the AIR control valve and preventing the reverse flow of exhaust gas from the exhaust ports to the AIR pump.

Catalytic Converter

The RENESIS rotary engine uses a *catalytic converter* system to clean exhaust emissions. See Figure 6-9. Toxic substances such as hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_X) in the exhaust gas are purified by two processes, oxidation and reduction, while passing through the catalytic converter.

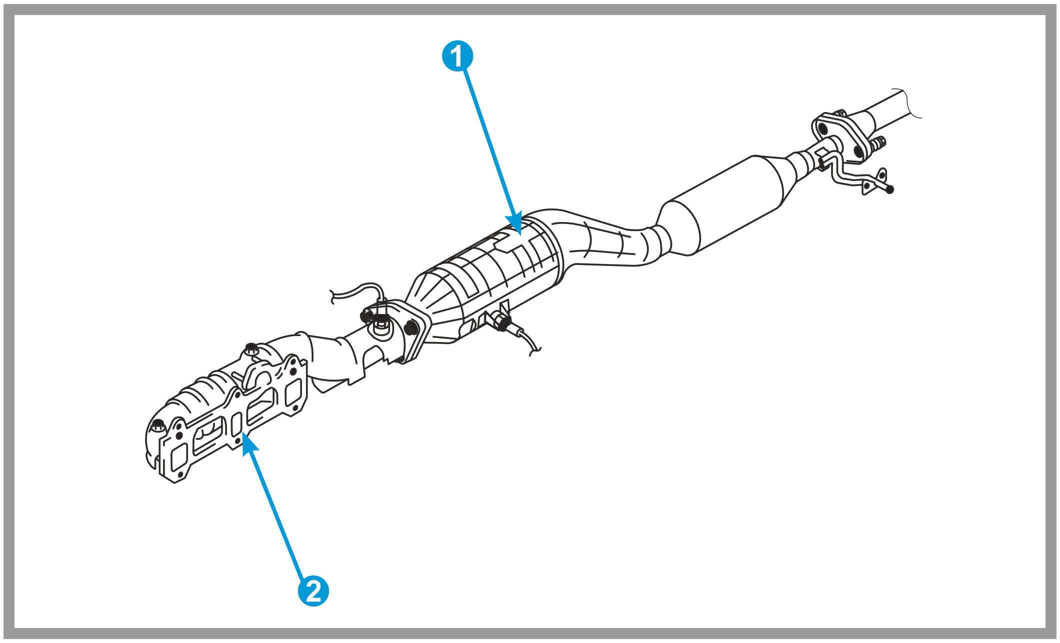


FIGURE 6-9. The catalytic converter system on the RENESIS reduces toxic emissions.

1 Catalytic converter

2 Exhaust manifold

During oxidation, the converter combines toxic hydrocarbons and carbon monoxide with oxygen (O_2) to produce non-toxic carbon dioxide (CO_2) and water (H_2O). During reduction, the converter turns toxic nitrogen oxides into non-toxic nitrogen and oxygen. The catalytic converter uses part of the oxygen produced during reduction for the oxidation process.

The RENESIS catalytic converter system uses a *high-performance three-way catalyst* to clean exhaust gases.

Electronic Throttle Control

RENESIS rotary engines feature an electronic throttle that converts throttle input into an electronic signal for more accurate and responsive valve control. Using signals from the PCM, an actuator opens and closes the electronic throttle valve, enabling precise intake air control. See Figure 6-11.

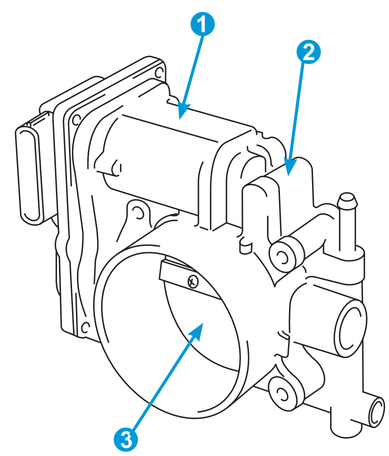


FIGURE 6-10.
The PCM controls the opening and closing of the electronic throttle valve.

1. Actuator
2. Throttle body
3. Throttle valve

REVIEW EXERCISE 6

Fill in the words that correctly complete these sentences. Check your answers with the answer key on page 64.

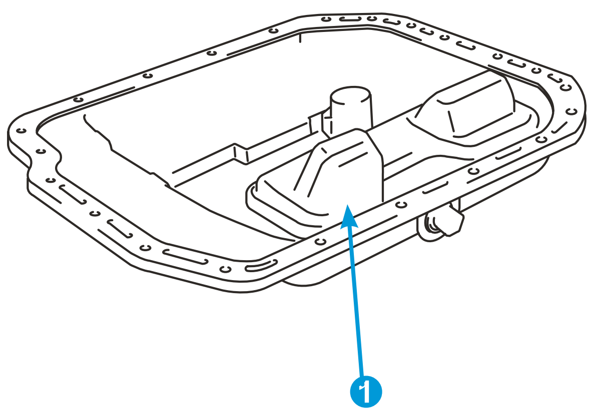
1. RENESIS uses an electric type ______________ _________ _________ to reduce oil consumption by controlling the amount of oil supplied to the lubrication system.

2. The RENESIS engine features a low ______-_______ lubrication system with an oil pan about half as deep as previous rotary engine designs.

3. RENESIS has electronic throttles that are controlled by the ________.

4. The secondary air injection (AIR) system helps clean exhaust gas by introducing air into the exhaust ports during __________ _________.

Refer to the diagram below to answer question 5.



5. Number 1 in the illustration is the ___________ __________ ___________ .

actuators — electronic switches that control the opening and closing of various engine components, such as auxiliary intake port valves.

anti-wet port — a projection on the bottom of the primary intake port. The anti-wet port helps atomize fuel so the air-fuel mixture flows to the spark plugs more efficiently.

apex seals — gas seals installed in the ends of the rotors to maintain the airtightness between the rotor housing's inner surface and the rotor.

atomizing — the process of breaking fuel into small particles for more complete combustion.

auxiliary port valve (APV) — a motorized valve that operates under the control of the PCM to regulate air flow in the S-DAIS system. Available only on the high-power RENESIS engine.

baffle chamber — an elaborately shaped chamber in the oil pan to keep oil from moving around, even during hard cornering.

balance weight — a weight on the eccentric shaft to counterbalance the weight of the flywheel for smoother operation.

bathtub — another name for the *combustion recess* on the sides of the rotor. This is where the spark plugs ignite the air-fuel mixture.

blowby — exhaust gas leaking past the rotor's apex seal through the trailing spark plug's installation hole. Blowby can reduce mileage and increase emissions.

catalytic converter — an exhaust system component that cleans toxic hydrocarbons, carbon monoxide, and nitrogen oxides from exhaust gases.

combustion — the controlled burning of the air-fuel mixture in the engine's working chambers.

combustion cycle — burning the air-fuel mixture in the engine to produce power. Consists of the intake, compression, power, and exhaust strokes.

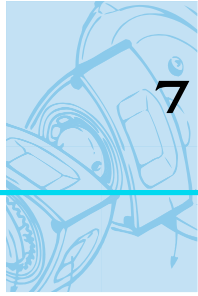
combustion recess — a chamber on the sides of the rotor in which the spark plugs ignite the air-fuel mixture during the engine's power stroke. Also called the "bathtub."

combustion stroke — another name for the *power stroke.*

compression ratio — a measure of how much the air-fuel mixture is squeezed during the compression stroke.

compression stroke — the step of the combustion cycle that compresses the air-fuel mixture so it will burn better and deliver more power.

compression top dead center — the rotor position at the completion of the compression stroke. The power (combustion) stroke begins here. The working chamber is at minimum volume (Vmin).



7 - GLOSSARY

Answers to Review Exercise 6

1. metering oil pump
2. wet-sump
3. PCM
4. cold starts
5. oil pan baffle chambers

coolant passages — passages in the outer surfaces of the side housings through which coolant flows to regulate engine temperature.

corner seals — gas seals installed in the corners of the rotor to seal any remaining space between the ends of the apex seal and the ends of the side seal.

cross-over range — a range of motion covered by the oil seals as they slide against the side housing. In the cross-over range, an oil film forms on the contact surfaces, indirectly lubricating the side seal and corner seal.

cut-off seals — a set of gas seals, similar to side seals, installed in the sides of the rotor to improve airtightness in the working chambers. Used on the RENESIS engine.

displacement — the ratio of a working chamber's maximum volume (Vmax) to its minimum volume (Vmin); a measure of engine power.

ECU (Emissions Control Unit) — the computer control module that controls engine emissions systems.

eccentric shaft — the rotary engine's output shaft, similar to the crankshaft in a piston engine. Connects the front and rear rotors and spins the rotors inside the rotor housing.

eccentric shaft bypass valve — a valve in the eccentric shaft oil passage that allows engine oil in the passage to escape at cold-engine start, maintaining pressure in the eccentric shaft and shortening engine warm-up.

electronic throttle control — a throttle control system that converts throttle input into an electronic signal for more accurate and responsive valve control. An electronic throttle valve opens and closes with an actuator, according to a signal from the PCM.

exhaust ports — openings through which exhaust gases flow during the exhaust stroke. Exhaust ports may be in the rotor housings or side housings.

exhaust stroke — the step of the combustion cycle that removes burned gases from the engine so the intake, compression, and power strokes can repeat.

expansion stroke — another name for the *power stroke.*

flywheel — a heavy metal plate attached to the eccentric shaft. The flywheel's weight helps maintain smooth engine rotation during non-power strokes.

fuel injector — a component made up mainly of a coil, spring, and needle valve. Used to inject fuel into the intake ports.

gas seals — three sets of seals (apex, side, and corner) that serve the same purpose as the piston rings in a piston engine. These seals maintain the airtightness of the three working chambers created by the rotor as it turns inside the rotor housing.

high-performance three-way catalyst — a type of catalytic converter that is most effective when exhaust gases are hot.

intake bottom dead center — the rotor position at the completion of the intake stroke. The compression stroke begins here. The working chamber is at maximum volume (Vmax).

intake (induction) system — a system of intake ports (openings) in the intermediate and side housings that provide the proper amount of intake air to the working chamber during the intake stroke. Most rotary engines use a six-port induction system.

intake ports — openings in the side and intermediate housings that let the engine draw in air during the intake stroke. An engine may have primary, secondary, and auxiliary intake ports.

intake stroke — the step of the combustion cycle that admits the proper mixture of air and fuel into the working chamber.

intermediate housing — the engine housing that lies between both rotor housings. The intermediate housing has a lubricating oil passage at its center so oil used to cool the interior of the rotor can be returned to the oil pan.

internal gear — a gear on the inside of the rotor that meshes with the stationary gear on the rotor housing and guides the rotor in its motion inside the housing.

jet air-fuel mixing system — an advanced intake method used on RENESIS engines that improves fuel economy by using jet (high speed) air. The jet air-fuel mixing nozzle is at the intake manifold's primary port outlet.

leading side — the side of the combustion recess that reaches the spark plugs first. Based of their installation position in the rotor housing, plugs are called "leading" or "trailing."

main rotor journals — smooth round surfaces on the eccentric shaft that allow the shaft to be supported by the main bearings.

metering oil pump — an electric-type oil pump that delivers precise oil discharge under the control of the PCM. The PCM controls the amount of oil discharge according to engine rotation, coolant temperature, and amount of intake air.

needle valve — a thin, needle-like valve controlled by an electric coil and spring. A basic component of a fuel injector.

oil jet plug — a component in the eccentric shaft that lubricates the interior of the rotor to keep it cool.

oil seals — seals installed in the sides of the rotors, consisting of a seal, spring, and O-ring. Oil seals prevent oil from passing through the space between the rotor wall and the side housing and entering the working chambers.

output shaft — another name for the *eccentric shaft*.

PCM (Power Train Control Module) — the computer control module that electronically controls many engine systems.

power (combustion) bottom dead center — the rotor position at the completion of the power stroke. The exhaust stroke begins here. The working chamber is at maximum volume (Vmax).

power stroke — (sometimes called the expansion or combustion stroke) the step of the combustion cycle that burns the air-fuel mixture.

process time — the time it takes an engine to complete one of the four strokes of the combustion cycle: intake, compression, power, or exhaust. Process time is measured by the number of degrees the eccentric shaft rotates during the stroke.

RENESIS rotary engine — an advanced rotary engine developed by Mazda. The name RENESIS comes from RE (Rotary Engine) and GENESIS, meaning a new generation of rotary engine performance.

rotor — an engine component with a combustion recess on each of its three sides. As the rotor turns inside the rotor housing, it functions like the pistons, connecting rods, and valves in a piston engine, converting the pressure of combustion gases into energy to drive the eccentric shaft.

rotor bearing — a bearing at the center of the rotor that supports the eccentric shaft, which holds the rotor in place.

rotor journal — part of the eccentric shaft (similar to a crankshaft pin) that supports the rotor.

rotor housing — engine housings that contain the rotor as it spins. Apex seals in the rotor slide against the inner surface of the rotor housing as the rotor turns, forming the three working chambers.

scrape-away range — a range of motion covered by the oil seals as they slide against the side housing. In the scrape-away range, the angled edge of the seal removes any carbon deposits from the side housings.

sealing rubber gaskets — rubber gaskets installed around the side housing's coolant passages to prevent coolant or gases from leaking. Similar to the head gasket in a piston engine.

secondary air injection (AIR) control system — engine components that help clean exhaust gas by introducing fresh air into the exhaust port or catalytic converter.

secondary shutter valve (SSV) — a component of the S-DAIS system that opens and closes in response to signals from the PCM to allow more or less air into the intake system.

sequential dynamic air intake system (S-DAIS) — an advanced induction (intake) system that improves engine output by increasing the amount of intake air. The S-DAIS controls the size of the intake ports and the air length in the intake pipes according to engine needs.

side exhaust — an exhaust configuration where exhaust ports, normally located on the rotor housing of conventional rotary engines, are on the side housing of the rotor chamber.

side housing — an engine housing that forms a wall at the front and rear of the rotor housing. These walls define the airtight working chambers. The side housings also provide contact surfaces for the side seals and intake ports for the working chambers.

side intake and exhaust ports — a design configuration on the RENESIS engine that places the intake and exhaust ports on the side housings. In traditional designs, exhaust ports are on the rotor housing.

side seals — gas seals installed in the sides of the rotor that seal the space between the intermediate housing and the rotor's side housing to maintain airtightness in the working chambers.

six-port induction system (6PI) — an induction (intake) system that uses three sets of ports (primary, secondary, and auxiliary) to provide the proper amount of intake air to the working chamber at any given engine speed.

spark plug — produces a spark to ignite the air-fuel mixture in the rotor's combustion recess.

stationary gears — front and rear gears secured to the side housings that mesh with the rotor's internal gear. These gears, along with the main bearings inside the gears, support the eccentric shaft as it turns.

torque fluctuation — an interruption of the crankshaft's (or eccentric shaft's) rotation in the interval between the end of one power stroke and the beginning of the next, causing a change in force. If torque fluctuation is great enough, it can cause engine vibration.

trailing side — the side of the combustion recess that reaches the spark plugs last. Based of their installation position in the rotor housing, plugs are called "leading" or "trailing."

trochoid surface — the interior surface of the rotor housing. So called because of its special curved shape.

variable dynamic effect intake (VDI) system — a component of the S-DAIS system. The VDI valve ensures that the combustion chamber receives the precise amount of air at all engine speeds.

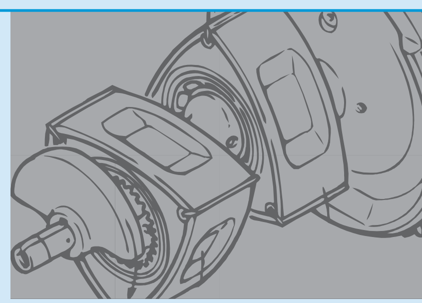
variable fresh air duct (VFAD) valve — a valve that controls the flow of intake air into the S-DAIS system. Available only on the high-power RENESIS engine.

Vmax — a working chamber's maximum volume (intake bottom dead center), used to calculate engine *displacement*.

Vmin — a working chamber's minimum volume (power top dead center), used to calculate engine *displacement*.

wet-sump lubrication system — a lubrication system that stores engine oil in the oil pan (the sump), below the eccentric shaft. In a dry-sump system, extra oil is stored in a tank outside the engine rather than in the oil pan.

working chambers — the three chambers formed around the rotor as it rotates inside the rotor housing. The intake, compression, power, and exhaust strokes all happen inside the working chambers.



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