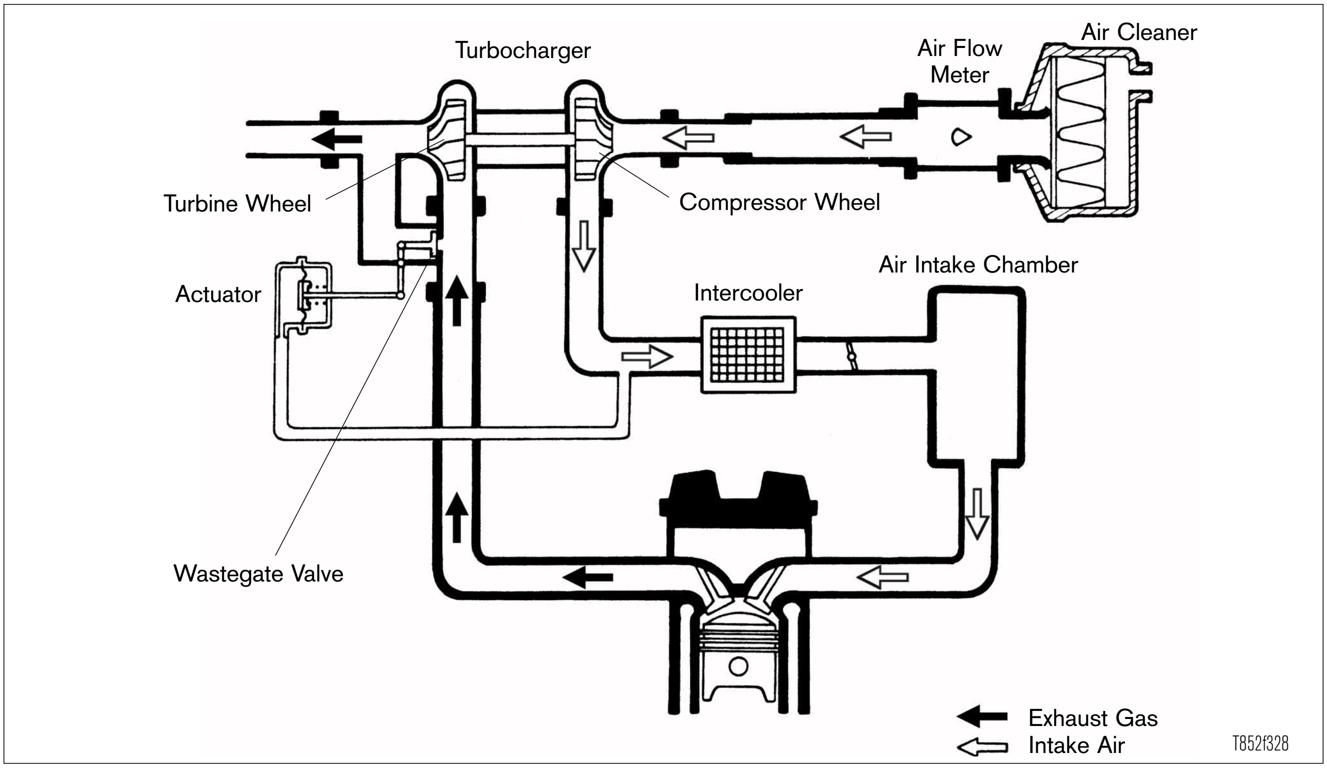
Section 9

Turbocharging & Supercharging Systems



Lesson Objectives 1. Familiarity with turbocharging systems and supercharging systems operations

Turbocharging & Supercharging Systems

Turbocharging System with Intercooler

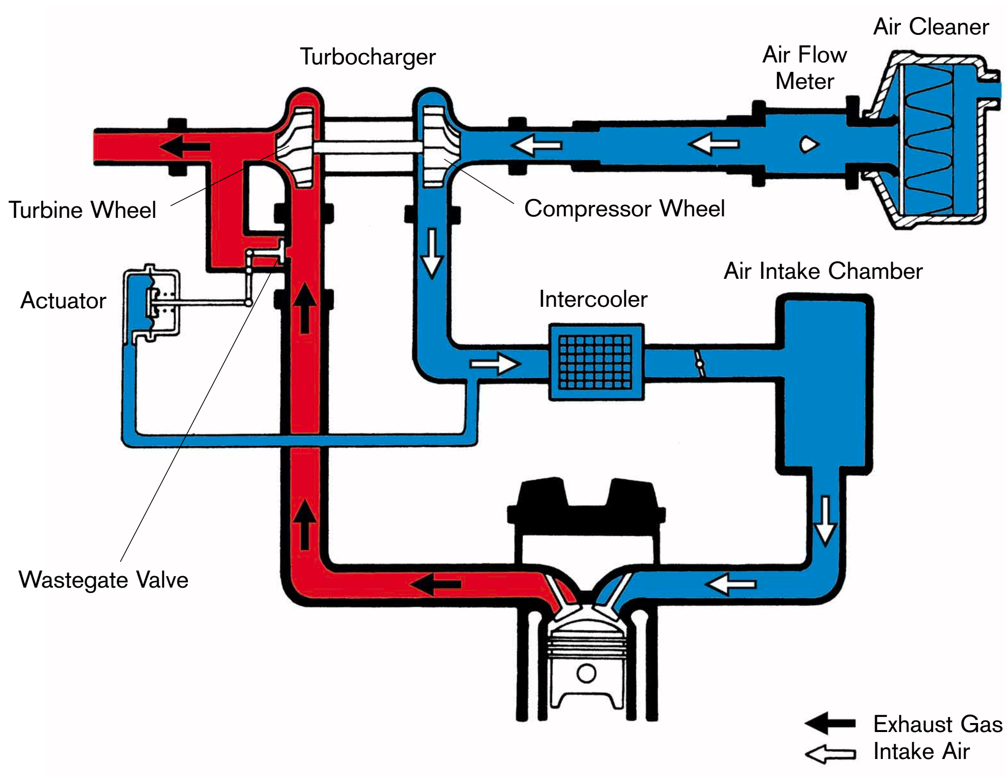


Fig. 9-01

T852f328

Turbocharging Systems

The turbocharger is basically an air pump that is designed to utilize some of the fuel's energy that would otherwise be wasted in the form of heat carried away by the exhaust gases. The exhaust gases drive the turbine wheel, that is coupled to the compressor wheel by means of a shaft. This compressor wheel is driven at high speeds, forcing more air into the cylinders. Since turbochargers use the wasted energy in the exhaust gases, the power output of the engine can be increased with less power loss. The turbocharger is provided with a waste gate valve to control the boost pressure on the intake air. Most turbocharged gasoline engines are also equipped with an intercooler to increase engine horsepower. The intercooler lowers the intake air temperature increasing air intake density.

Turbocharger Components

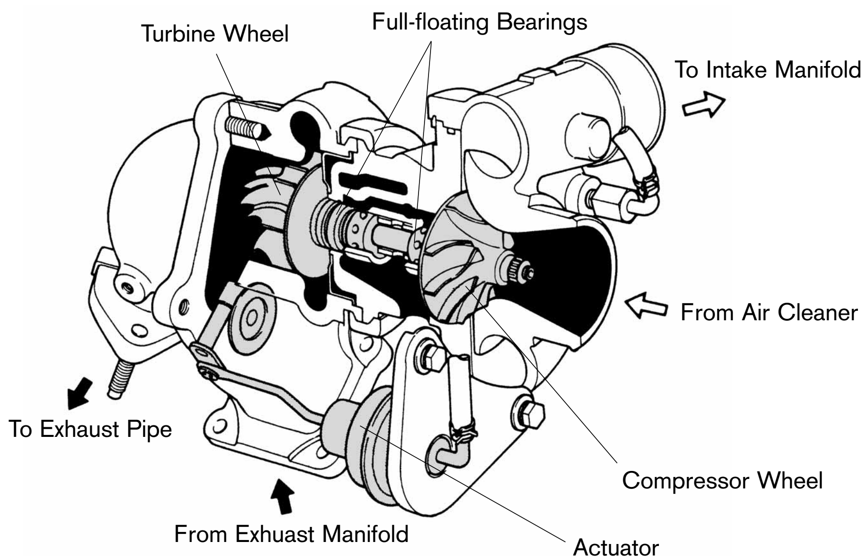


Fig. 9-02

T852f329

Components Turbine and Compressor

The turbine wheel and the compressor wheel are mounted on the same shaft. Exhaust gas flows from the exhaust manifold to the turbine wheel, and the pressure of the exhaust gas turns the turbine wheel. When the turbine wheel turns, the compressor wheel also turns, forcing the intake air into the cylinders. Since the turbine wheel is exposed directly to the exhaust gases, it becomes extremely hot; and, since it rotates at high speeds, and must be heat resistant and durable, it is made of an ultra-heat resistant alloy.

Center Housing Assembly Center Housing Assembly

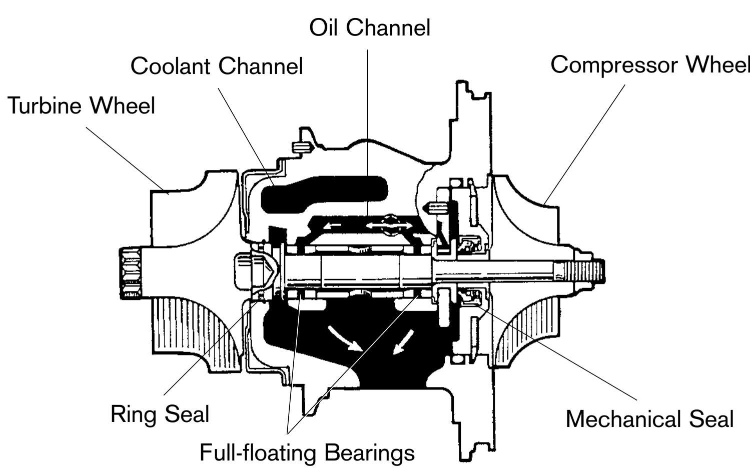


Fig. 9-03

T852f330

Center Housing The center housing supports the turbine and compressor wheels via the shaft. Inside the housing, engine oil is circulated through channels that are provided for this purpose. Also, engine coolant is circulated through coolant channels that are built into the housing.

Full Floating Bearings Since the turbine and compressor wheels turn at speeds of up to 100,000 rpm, full-floating bearings are used to ensure the absorption of vibrations from the shaft and to lubricate the shaft and bearings. These bearings are lubricated by the engine oil and rotate freely between the shaft and the housing to prevent seizing during high-speed operation. Engine oil is prevented from leaking by two ring seals or by a mechanical seal and a ring seal fitted to the shaft.

Wastegate Valve and Actuator The waste gate valve is built into the turbine housing. Its purpose is to reduce the boost pressure when this begins to rise too high. When this valves opens, part of the exhaust gas bypasses the turbine wheel and flows to the exhaust pipe. The opening and closing of the waste gate valve is controlled by the actuator.

Lubrication

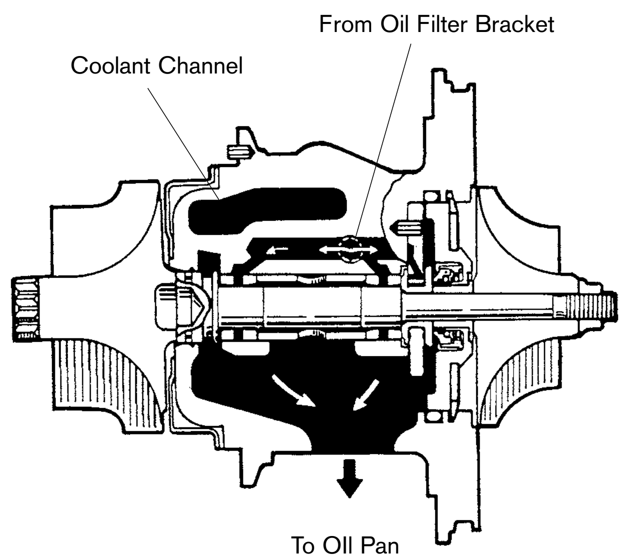


Fig. 9-04

T852f331

Lubrication In order to lubricate the full-floating bearings inside the center housing, engine oil is supplied from the oil inlet pipe and circulated among the bearings.

After lubricating the bearings, this oil passes through the oil outlet pipe and returns to the oil pan.

Cooling

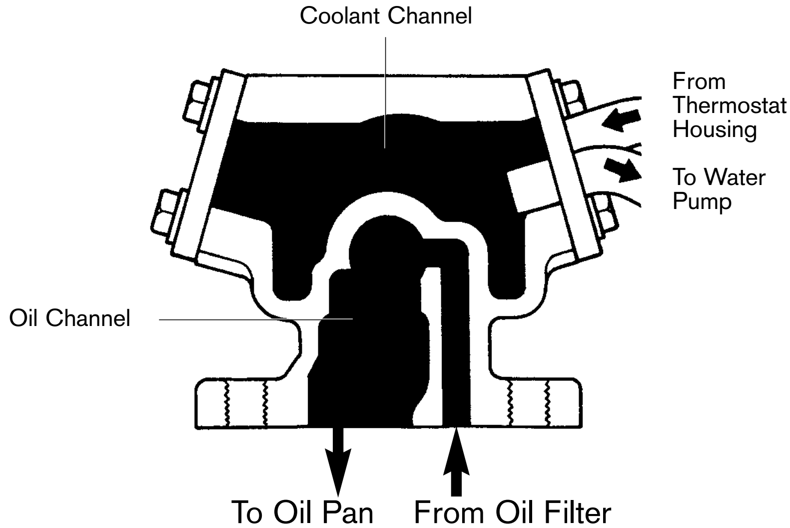


Fig. 9-05

T852f332

Cooling

The turbocharger is cooled by engine coolant. Engine coolant is sent from the thermostat housing and introduced into the coolant channel (provided in the center housing) via the coolant inlet pipe. After cooling the turbocharger, the coolant passes through the coolant outlet pipe and returns to the water pump.

Boost Pressure Control

A turbocharger attains a high output by boosting the pressure of the air fed into the cylinders, but if the boost pressure rises too high, the explosive force created by combustion of the air/fuel mixture will become too great and the engine will be unable to withstand the pressure. Therefore, boost pressure is controlled by the actuator and waste gate valve. With some gasoline engines, the boost pressure is also controlled in accordance with the octane rating of the fuel used (premium or regular gasoline).

Wastegate Closed

As long as the boost pressure inside the intake manifold cannot overcome the spring in the actuator, the actuator will not operate and the waste gate valve remains closed. All exhaust gas is therefore routed into the turbine housing.

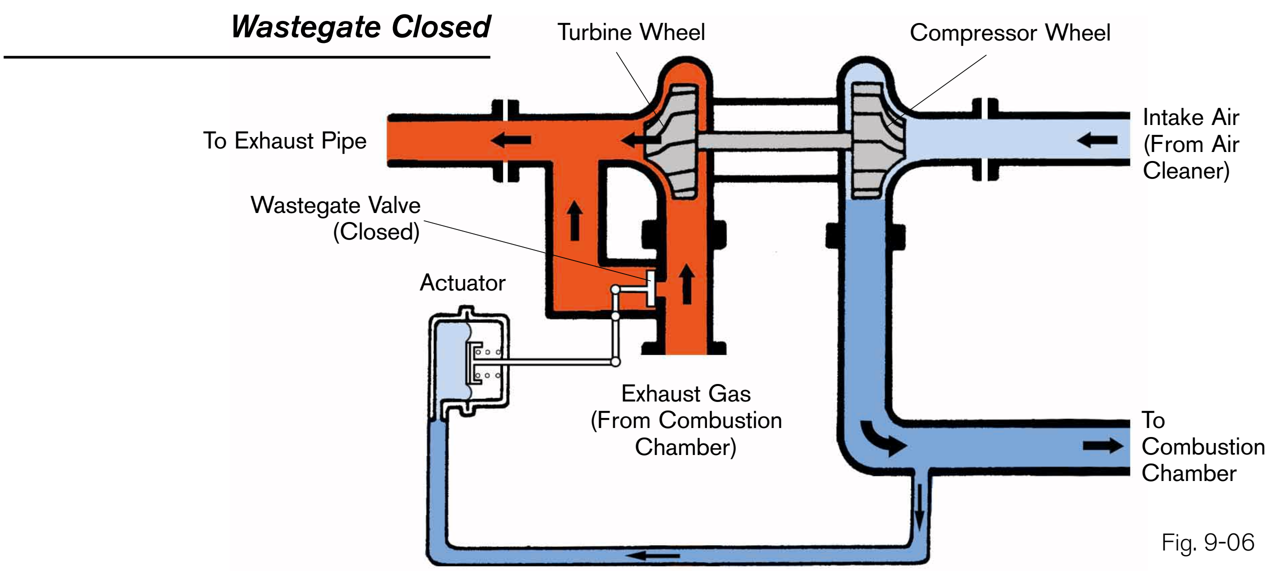


Fig. 9-06

T852f333A

Wastegate Opened As the accelerator pedal is depressed, fuel injection volume and exhaust gas pressure increase, thus increasing the boost pressure. When the boost pressure overcomes actuator spring pressure, that is, the intercept point, the waste gate valve is opened by the actuator (because of the combined forces of the exhaust gas pressure on the waste gate valve and the boost pressure on the actuator diaphragm) and part of the exhaust gas is diverted around the turbine wheel. As a result, the turbine speed is kept within the optimal range to prevent the boost pressure from rising excessively.

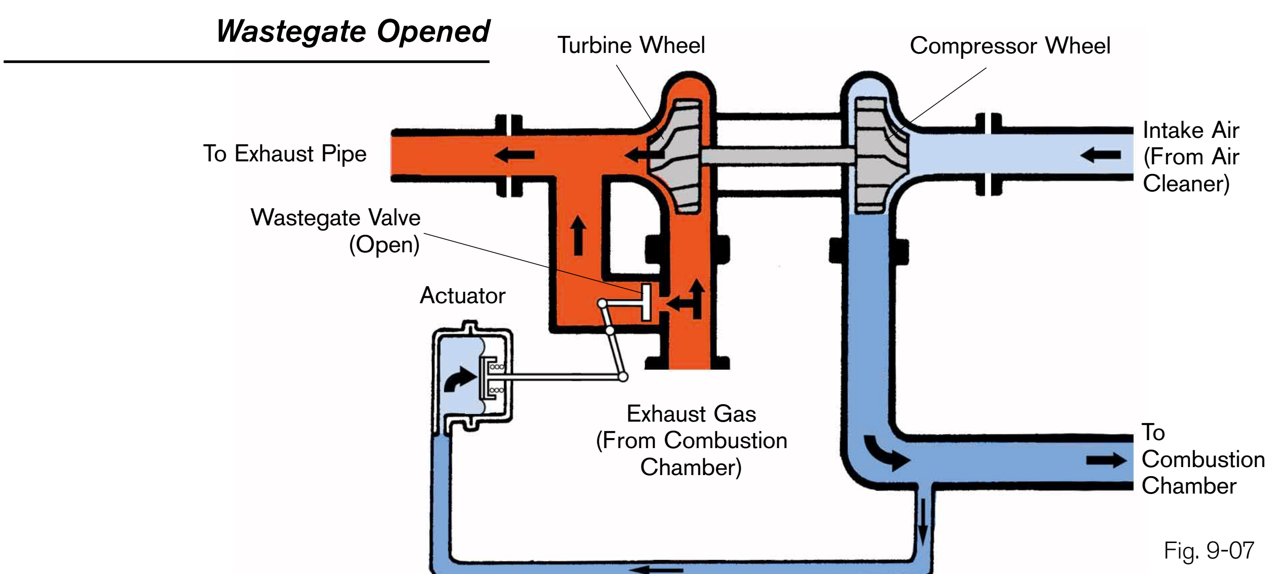


Fig. 9-07

T852f333B

ECM Boost Control

The boost pressure is basically controlled by the actuator and waste gate valve as mentioned previously. In some gasoline engines, the boost pressure also is controlled in two patterns in accordance with the type of fuel used (premium or regular gasoline). This maximizes engine performance and maintains engine durability, as well as suppressing knocking under all engine running conditions, including during warm-up, irrespective of the gasoline octane rating.

Pressure at the inlet side of the compressor housing is introduced into the actuator via the VSV (Vacuum Switching Valve) which is controlled by the ECM. The ECM turns the VSV ON or OFF depending on whether premium or regular gasoline is being used (as determined by the knock sensor signal) and engine conditions. The VSV stays OFF when regular gasoline is used.

Boost Pressure vs. Engine Speed

The relationship between the engine speed and boost pressure when the accelerator pedal is fully depressed is shown in the graph at the right. These characteristics will vary depending upon the load that is placed upon the engine.

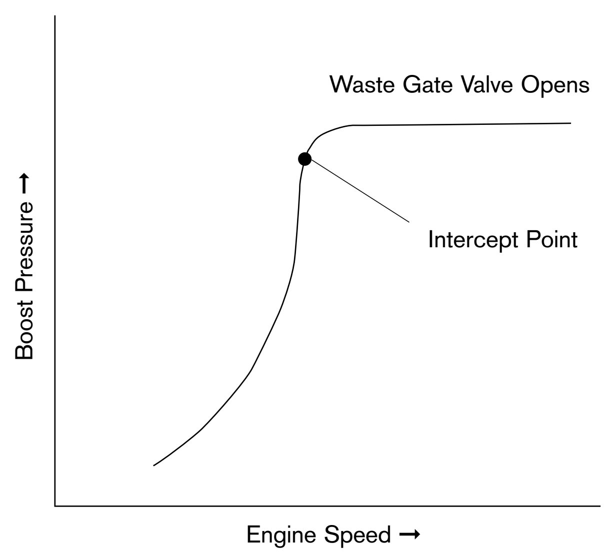


Fig. 9-08

T852f335

ECM Boost Control

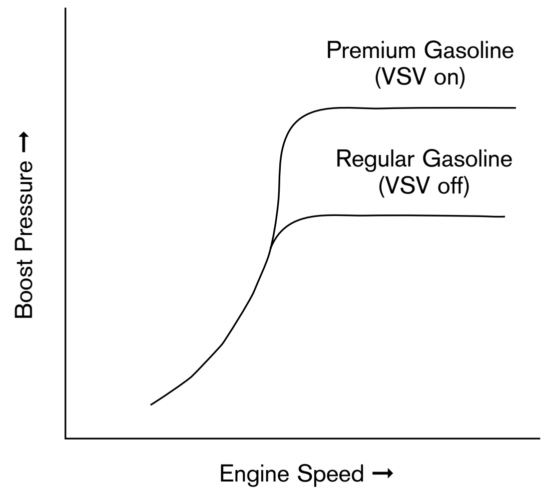


Fig. 9-09
T852f336

VSV ON

When the VSV goes ON, the pressure applied to the actuator escapes to the inlet side of the compressor housing. As a result, this pressure (Pa) becomes lower than the boost pressure (PB). The result is a higher boost needed to overcome spring pressure in the actuator and open the wastegate.

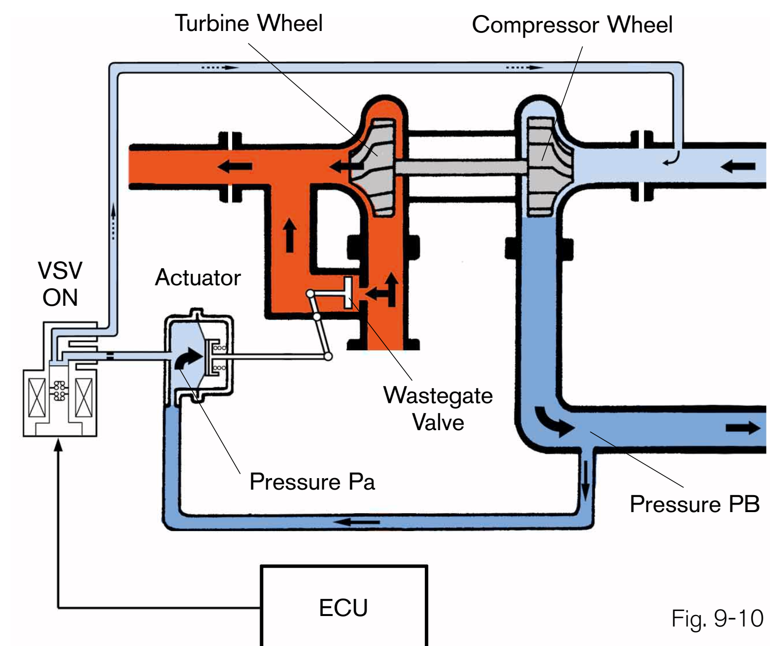


Fig. 9-10
T852f333C

VSV OFF

As long as the VSV is OFF, the boost pressure (PB) is applied directly to the actuator

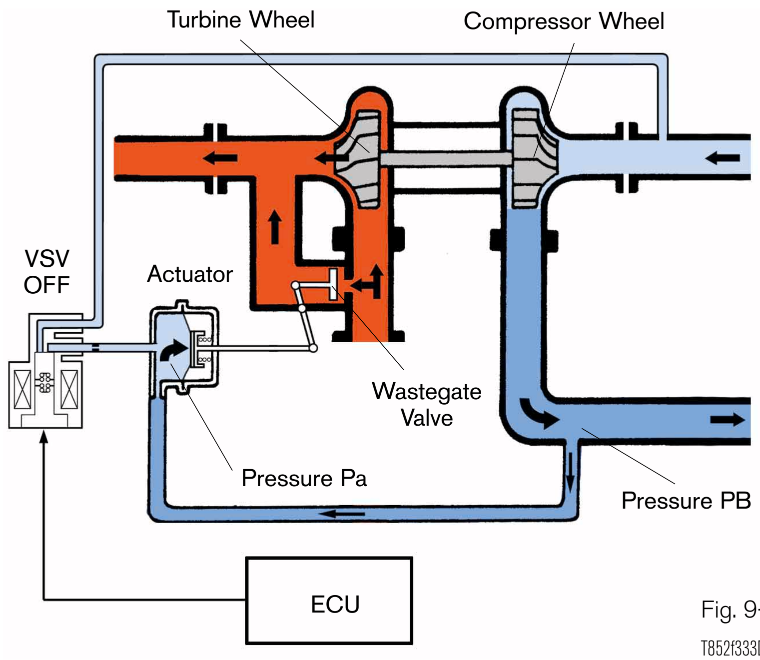


Fig. 9-11

Two-Way Twin-Turbocharger System

In place of the single turbocharger system used in the 7M-GTE engine, the 2JZ-GTE engine adopts the Two-Way Twin-Turbocharger System. Under this system, the two compact turbochargers provide separate functions according to the engine running condition. While one turbocharger gives boost at low rpm and low engine load conditions, the two turbochargers together give boost at high rpm and high engine load conditions for increased output.

Two-Way Twin-Turbocharger System

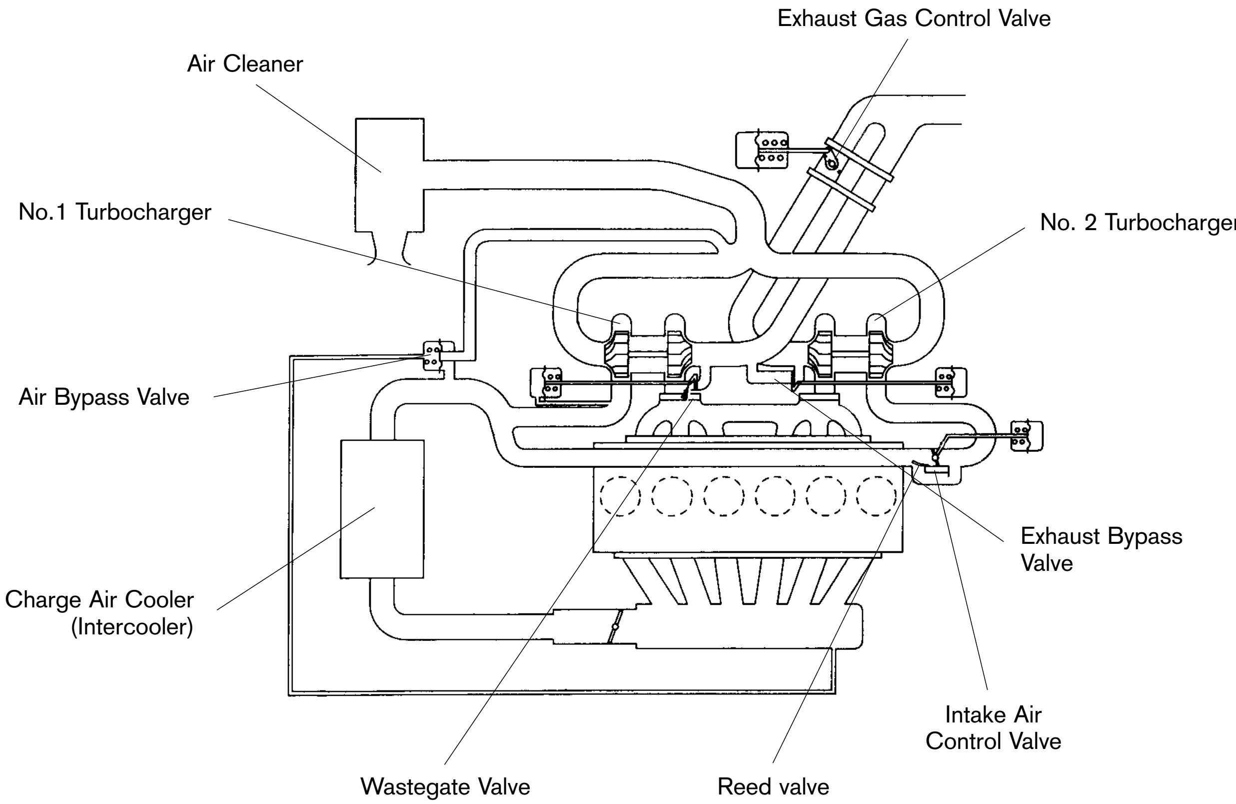


Fig. 9-12

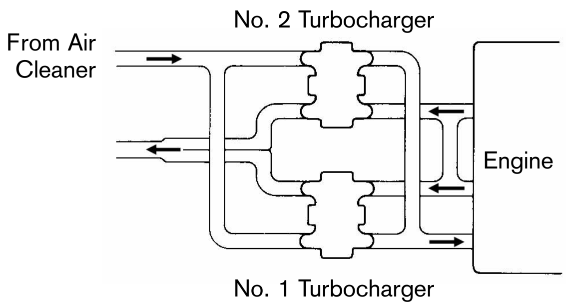
T852f339A

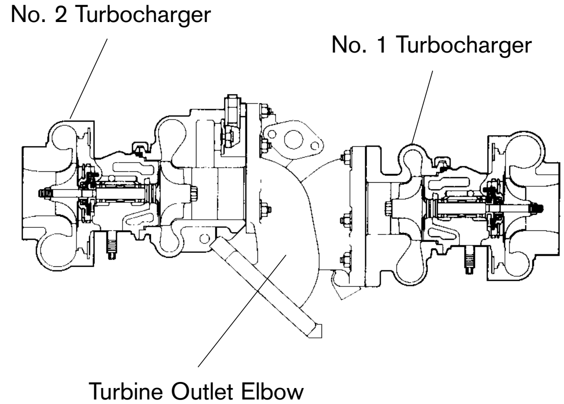
Components of Two-Way Twin-Turbocharger System

Twin-Turbochargers - By directly mounting the twin-turbocharger assembly onto the exhaust manifolds, the exhaust gas travel is made extremely short and direct. This results in an efficient transmission of power to the turbochargers with a minimal exhaust gas pressure loss.

Twin-Turbocharger Assembly

The twin-turbocharger assembly consists of the No. 1 turbocharger, No. 2 turbocharger, and turbine outlet elbow.





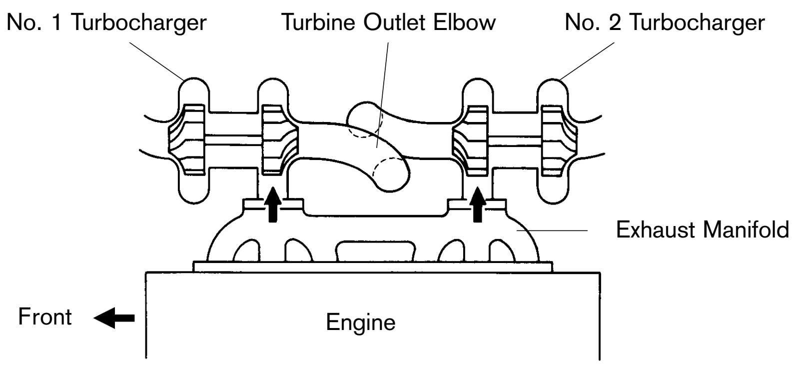


Fig. 9-13

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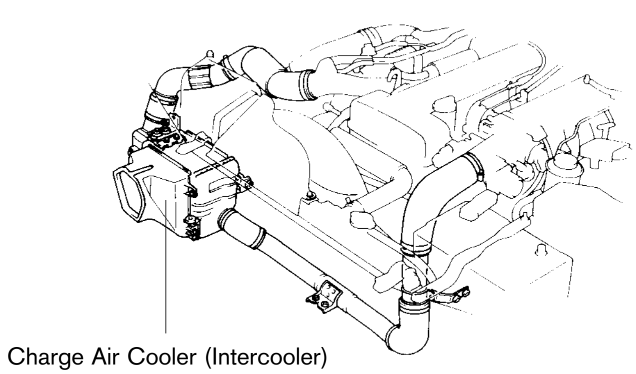
T852f342

Charge Air Cooler (Intercooler) - The intercooler, located between the turbocharger and intake manifold, cools the intake air increasing air density and therefore engine power.

Charge Air Cooler



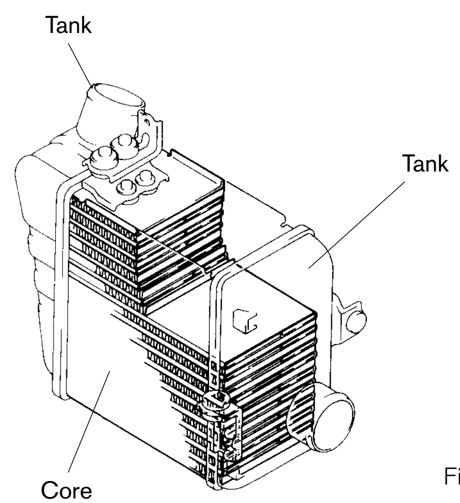


Fig. 9-14

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Control Valves

There are six control valves used in the Two-Way Twin-Turbo System.

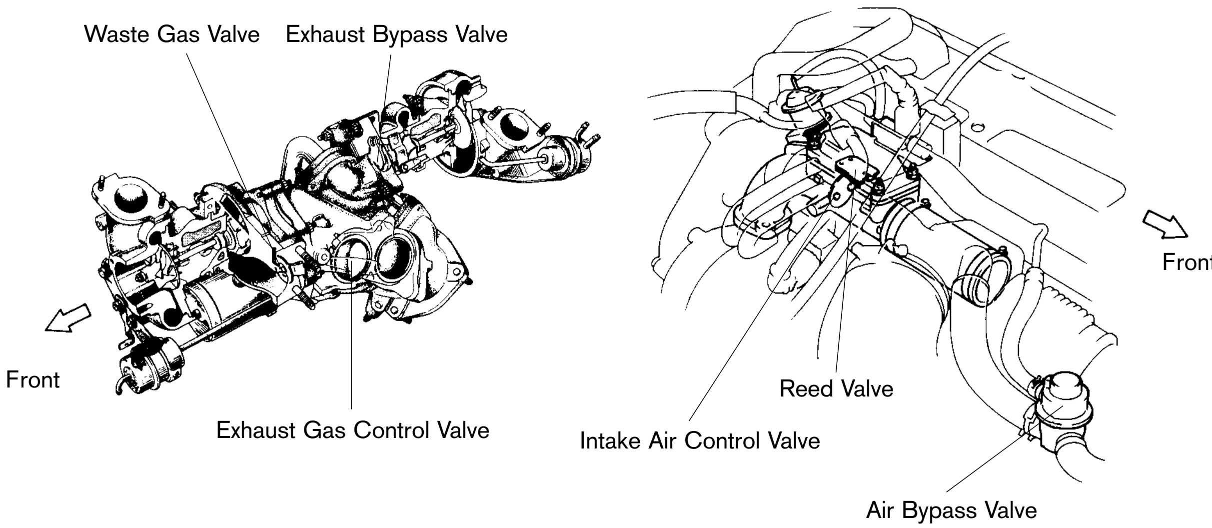


Fig. 9-15

T852f345/T852f346

Intake Air Control Valve - Located downstream of the No. 2 turbocharger intake airflow, during No. 2 turbocharger start/stop operation it permits or stops the flow of intake air through the No. 2 turbocharger.

Exhaust Gas Control Valve - Made of ceramic, and located downstream of the No. 2 turbocharger exhaust gas flow, during No. 2 turbocharger start/stop operation it permits or stops the flow of exhaust gas through the No. 2 turbocharger.

Waste Gate Valve - Integrated into the No. 1 turbocharger, this valve controls the boost pressure of the entire system by bypassing a portion of the exhaust gas flowing through the No. 1 turbocharger during a two-turbocharger boost operation.

Exhaust Bypass Valve - Integrated into the No. 2 turbocharger, this valve controls the boost pressure of the entire system by bypassing the exhaust gas from the No. 2 turbocharger during a single-turbocharger boost operation (when only the No. 1 turbocharger is boosting). At the same time, this bypass allows the turbine wheel of the No. 2 turbocharger to start spinning ahead of the starting of the No. 2 turbocharger operation.

Reed Valve - Immediately following the start of the No. 2 turbocharger operation, the intake air control valve is closed. This causes a quick rise in the intake air pressure between the No. 2 turbocharger and the intake air control valve. The reed valve controls the intake air pressure by bypassing a portion of this high-pressure intake air downstream of the reed valve.

Air Bypass Valve - When the throttle valve is quickly released during boosting, the intake air pressure between the turbocharger and the throttle valve increases rapidly. The air bypass valve diverts a portion of this high-pressure intake air upstream of the turbocharger, thereby controlling the boost pressure, and reducing the pulsing noise.

Twin-Turbocharger System

In this system, the separate functions of the two turbochargers are achieved by controlling the operation of the No. 2 turbocharger. This is accomplished by using control valves to allow or stop the intake air and exhaust gas flow. Although the No. 2 turbocharger's basic start/stop operation timing is determined by the engine speed, the timing is varied according to the engine load.

Twin Turbo Operation

Region A: low rpm, low engine load.

Region B: high rpm, high engine load.

TC1: Only the No. 1 turbocharger operating.

TC1 + TC2: Both the No. 1 and No. 2 turbochargers operating.

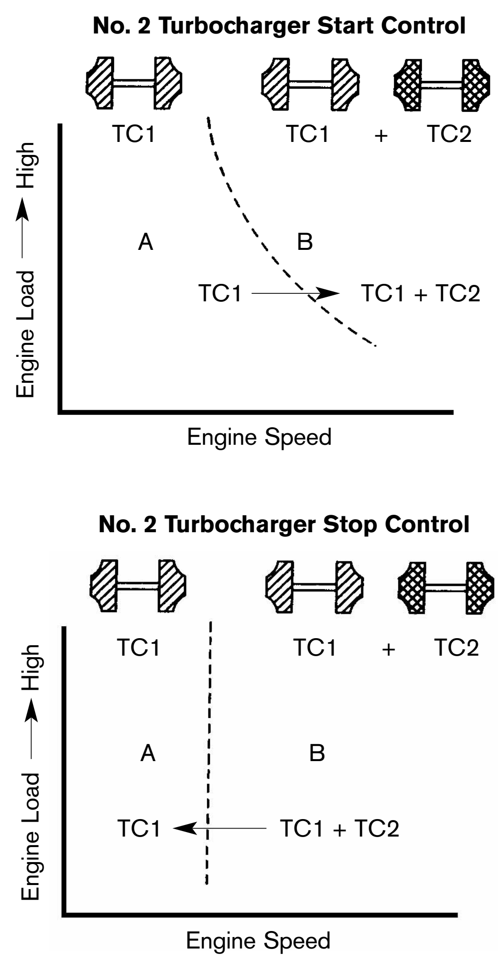


Fig. 9-16
T852f347/T852f348

Single-Turbocharging Phase

Since the actuators for the intake air control valve and exhaust gas control valve are inactive during low engine rpm operation, these valves remain closed. The waste gate valve is also closed, and only the No. 1 turbocharger will provide the boost pressure. When the intake air turbocharging pressure downstream from the No. 1 turbocharger reaches a predetermined level, the exhaust bypass valve executes a boost pressure control. At the same time, the exhaust bypass valve opens to supply the exhaust gas to the turbine side of the No. 2 turbocharger, causing the No. 2 turbocharger turbine wheel to start rotating. Accordingly, when the No. 2 turbocharger starts boosting, this process can smooth out the joining of the boost pressures.

Single-Turbocharging Phase

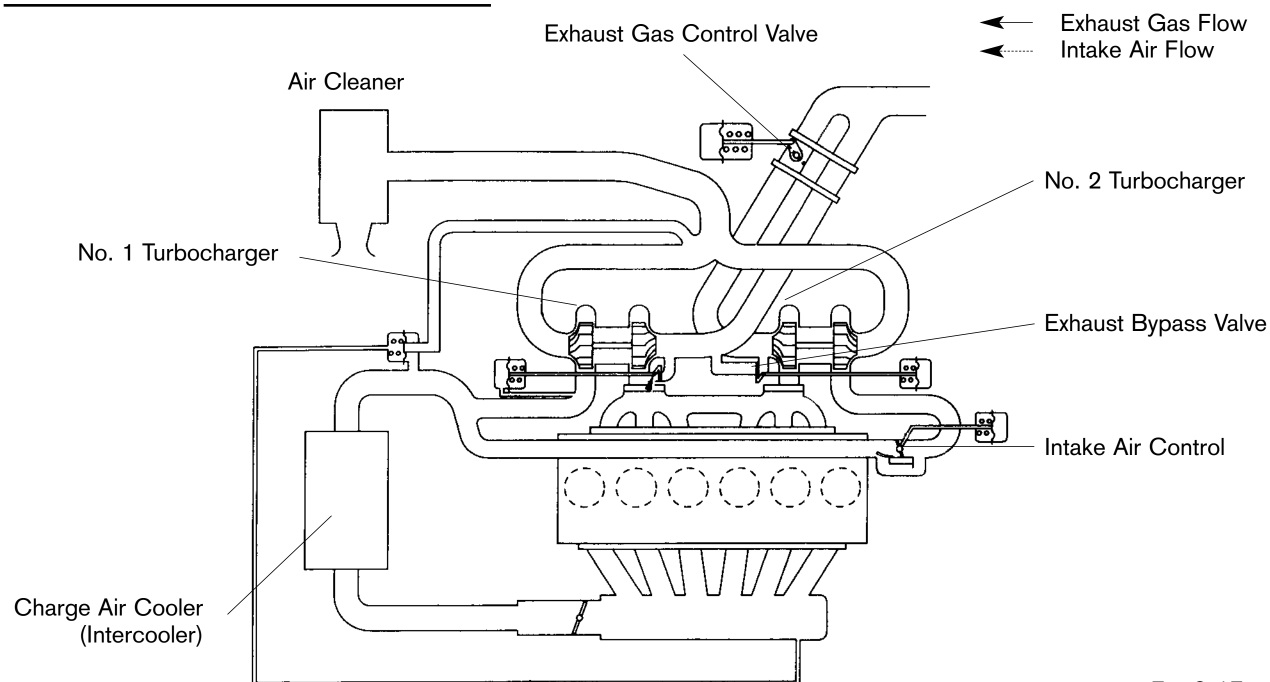


Fig. 9-17

T852f339B

Valve Condition (*Single-Turbocharging*)

Intake Air Control Valve	Exhaust Gas Control Valve	Exhaust Bypass Valve	Waste Gate Valve
Close	Close	Activated	Close

Single-Turbocharging/ Twin-Turbocharging Transition Operation

When the engine operation passes from the low-rpm to the high-rpm region, first the exhaust gas control valve opens; this is followed by the opening of the intake air control valve. When the exhaust gas control valve opens, it causes the No. 2 turbocharger turbine wheel, which had already begun its rotation, to quickly raise its rpm. Thus, the pressure of the intake air flowing through the No. 2 turbocharger becomes higher than that of the intake air of the No. 1 turbocharger.

Since this high pressure intake air pushes open the reed valve described below and flows to the No. 1 turbocharger side, further rise in pressure is averted. Then, when the intake air control valve opens, the highly pressurized intake air smoothly joins the intake air coming from the No. 1 turbocharger.

Conversely, when the engine operation passes from the high-rpm to low-rpm region, in order to stop the No. 2 turbocharger, the valves close in an order opposite to the one described above. The intake air control valve closes first, followed by the closing of the exhaust gas control valve.

Twin-Turbocharging Operation

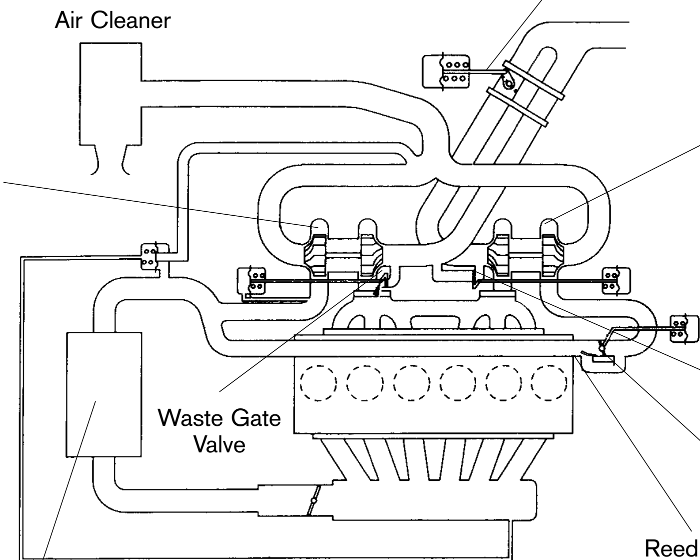


Fig. 9-18

T852f339C

Valve Condition (*Single-Turbocharging* ⟶ *Twin-Turbocharging Transition*)

Intake Air Control Valve	Exhaust Gas Control Valve	Exhaust Bypass Valve	Waste Gate Valve
Close ⟶ Open	Close ⟶ Open	Activated ⟶ Open	Close

Valve Condition (*Twin-Turbocharging* ⟶ *Single-Turbocharging Transition*)

Intake Air Control Valve	Exhaust Gas Control Valve	Exhaust Bypass Valve	Waste Gate Valve
Open ⟶ Close	Open ⟶ Close	Open	Activated ⟶ Close

Valve Condition (*Twin Turbocharging*)

Intake Air Control Valve	Exhaust Gas Control Valve	Exhaust Bypass Valve	Waste Gate Valve
Open	Open	Open	Activated

Operation of Twin-Turbocharging

The exhaust gas control valve and intake air control valve are open, allowing the No. 1 and No. 2 turbochargers to boost. At this time, even if the exhaust bypass valve operates, it cannot effect any boost pressure control, since it is located downstream of the No. 2 turbocharger. During a high rpm operation, it is the waste gate valve that executes the boost pressure control of the entire system, in place of the exhaust bypass valve.

Turbocharger Handling Precautions

The turbocharger is a precision-built part, but since its design is very simple, it is also very durable if a few simple precautions concerning its use and care are observed. The turbocharger operates under extremely severe conditions: the turbine wheel is exposed to exhaust gases whose temperatures reach as high as 900°C (1,652°F) when the engine is running at maximum load, and the rotating assembly rotates at speeds of up to 100,000. Therefore, that which has the greatest effect upon the performance and durability of the turbocharger is the lubrication of the bearings that support the turbine and compressor wheels. Consequently, to provide lasting, trouble-free operation, the following precautions must be observed: the engine oil becomes hot very quickly due to its use in both cooling and lubricating the turbocharger, so it deteriorates rapidly. For this reason, engine oil and oil filter maintenance should be carried out faithfully. The replacement intervals of the engine oil and oil filter are determined by the conditions under which the vehicle is used and/or the countries/regions in which the vehicle is to be sold. Therefore please refer to the appropriate Maintenance Procedures manuals for the correct replacement intervals. Be sure to use the appropriate types of engine oil for turbocharged engines.

Since the bearings are not sufficiently lubricated immediately after the engine is started, racing or sudden acceleration of the engine should be avoided. The following conditions are especially likely to lead to premature wearing of or damage to the bearings unless the engine is allowed to idle for at least 30 seconds after starting:

- Operating the engine immediately after the engine oil and/or oil filter are changed.

- Running the engine after it has not been used for more than about half a day.

- Starting the engine in cold weather.

Do not stop the engine immediately when pulling a trailer or after high-speed or uphill driving. Idle the engine for 20-120 seconds, depending on the severity of the driving conditions.

During high-speed driving, the turbine wheel is exposed to very hot exhaust gases, and its temperature rises extremely high. Since the temperature of the shaft linking the turbine wheel to the compressor wheel is cooled by oil and coolant, however, its temperature does not rise as high. Nevertheless, if the engine is stopped immediately after high-speed driving, circulation of oil and coolant will stop, and the temperature of the shaft will suddenly rise due to the high temperature of the turbine wheel. Therefore, letting the engine idle before shutting it off will allow the shaft to cool off gradually. (This is because the temperature of the exhaust gas is lower (300°~400°C (573°~752°F) during idling.)

Turbocharger Service Precautions

If the engine is run with the air cleaner, air cleaner case cover or hose removed, foreign particles entering will damage the turbine and compressor wheels because they rotate at extremely high speeds.

If the turbocharger malfunctions and must be replaced, first check the following items for the cause of the problem and remedy as necessary:

- Engine oil level and quality.
- Conditions under which the turbocharger was used.
- Oil lines leading to the turbocharger.

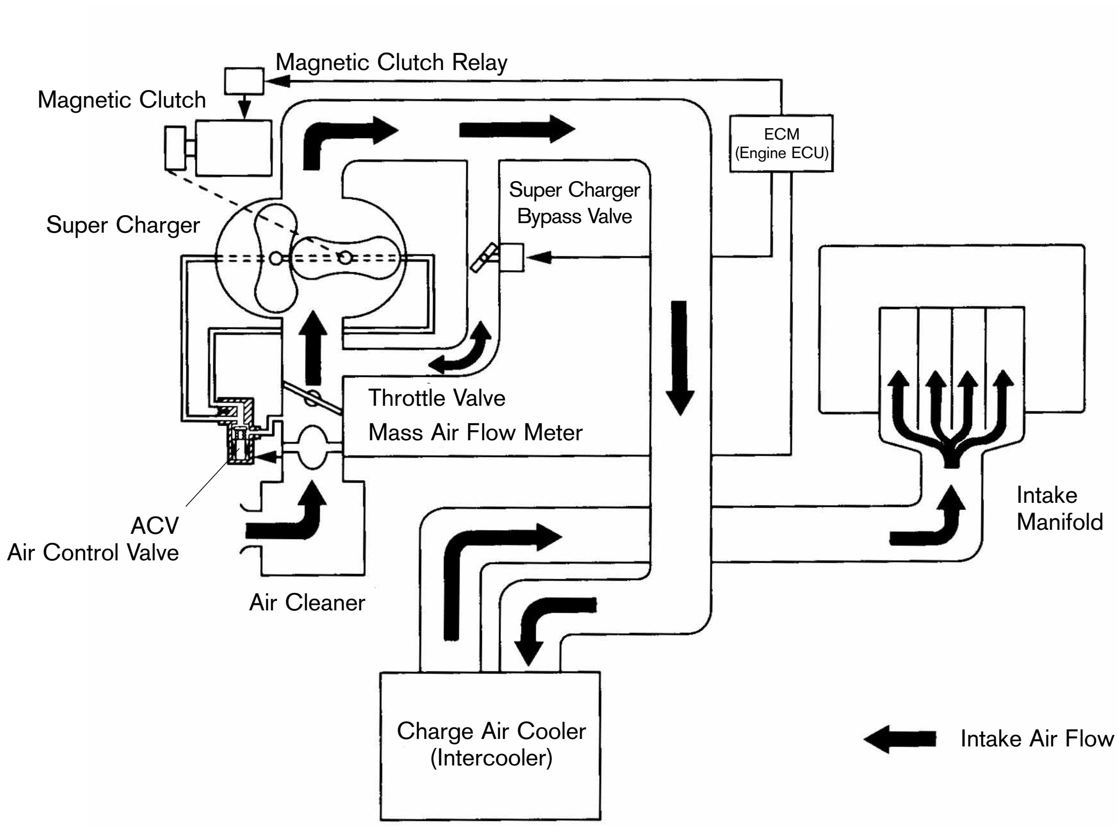
Before removing the turbocharger, plug the intake and exhaust ports and the oil inlet to prevent the entry of dirt or other foreign material.

Use caution when removing and reinstalling the turbocharger assembly. Do not drop it or bang it against anything or grasp it by easily deformed parts, such as the actuator or rod, when moving it.

When replacing the turbocharger, check for the accumulation of carbon sludge in the oil pipes and, if necessary, clean out or replace the oil pipes.

When replacing the turbocharger, put 20 cc (0.68 fl.oz.) of oil into the turbocharger oil inlet and turn the compressor wheel by hand several times to spread oil to the bearings.

When overhauling or replacing the engine, cut the fuel supply after reassembly and crank the engine for 30 seconds to distribute oil throughout the engine. Allow the engine to idle for 60 seconds.


Magnetic Clutch Relay
Magnetic Clutch
ECM
(Engine ECU)
Super Charger
Bypass Valve
Super Charger
Throttle Valve
Mass Air Flow Meter
ACV
Air Control Valve
Air Cleaner
Intake
Manifold
Charge Air Cooler
(Intercooler)
Intake Air Flow

Supercharging System

In the supercharging of a system, the supercharger pumps air into the cylinders. The supercharger is driven by a V-ribbed belt. This allows the supercharger to deliver boost pressure nearly instantly producing high horsepower at low engine rpm range.

The ECM determines supercharger boost pressure, based on engine running conditions, by operating the magnetic clutch, supercharger bypass valve, and Air Control Valve (ACV).

Supercharger speed is proportional to engine speed.

Supercharger Assembly

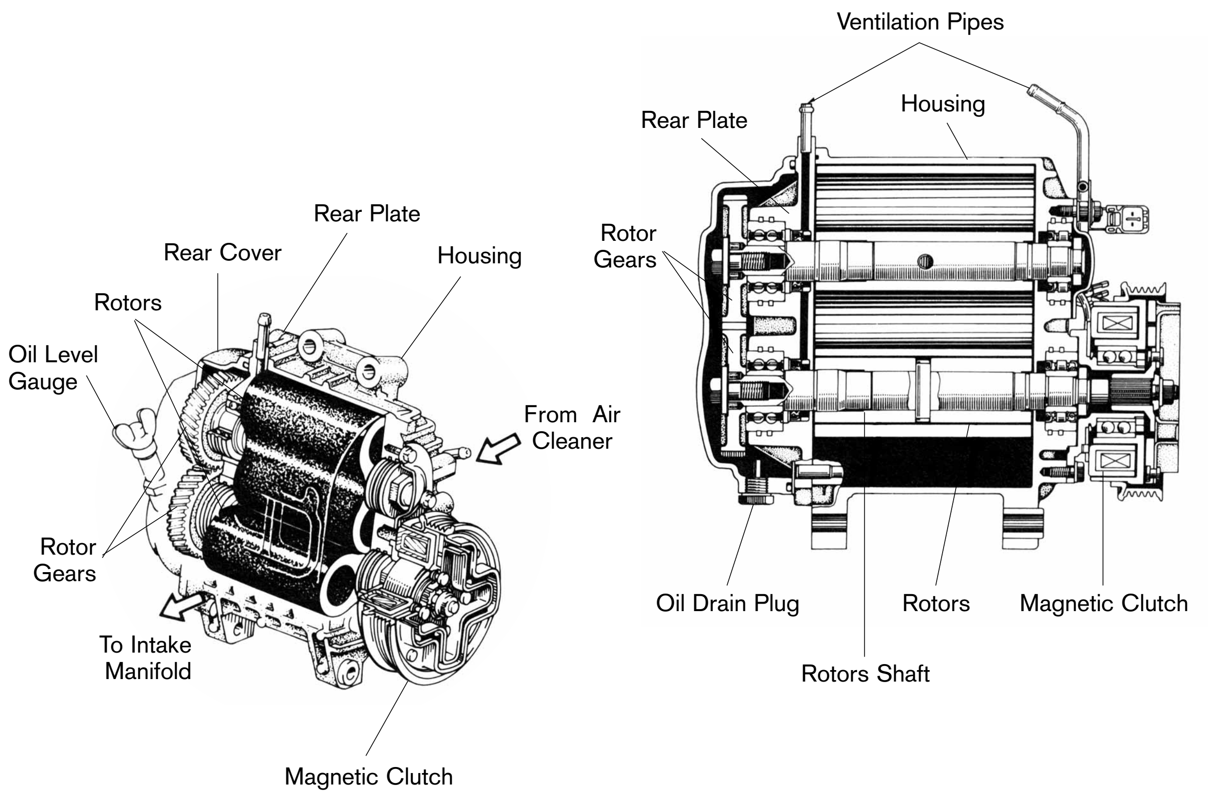


Fig. 9-20

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Supercharger

The major components of the supercharger are a magnetic clutch, two rotors, two rotor gears, a housing, a rear plate and rear cover. The supercharger has its own oil supply and requires a special oil for lubrication. The oil level must be checked periodically.

Supercharger Operation

Power is transmitted from the engine crankshaft pulley to a V-ribbed belt and the magnetic clutch, and finally to the lower rotor shaft. The upper and lower rotor shafts are geared together. The two rotors turn in opposite directions and force air between the housing and rotors as they rotate. Air is pumped out four times per rotor revolution.

Pump Action of the Rotors

Viewed from rear.

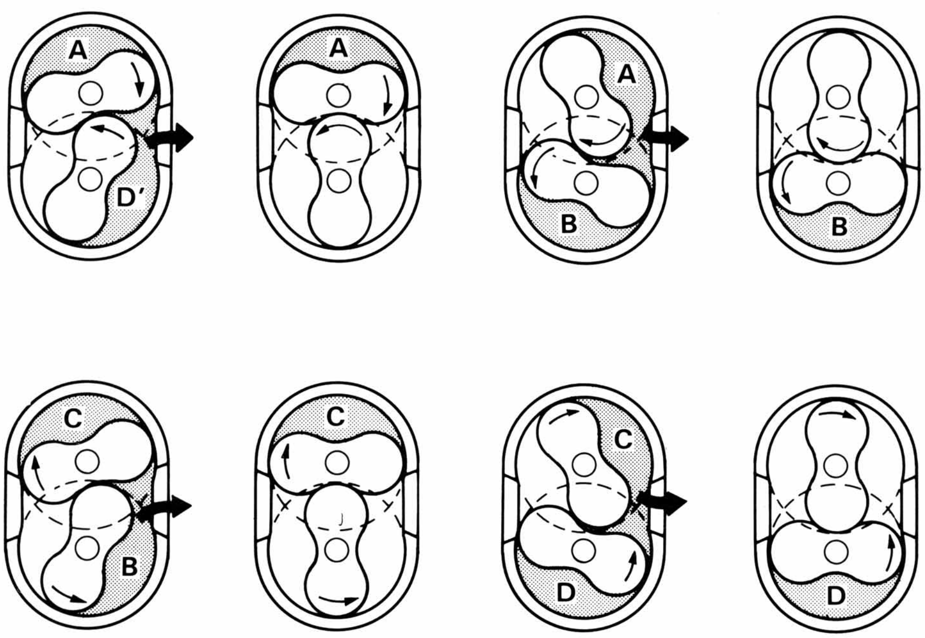

Fig. 9-21

T852f354

Rotors and Housing Assembly

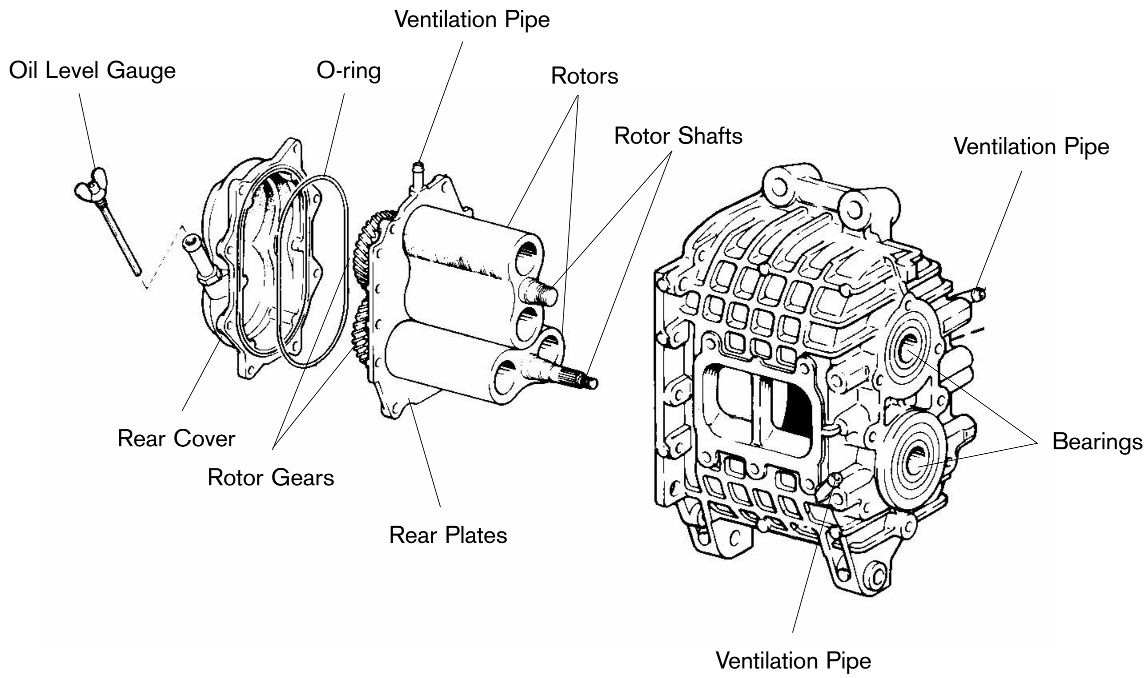

Fig. 9-22
T852f355

A rotor and gear are fitted to each of the two rotor shafts, which are in turn fitted to the rear plate via bearings. The rotors are made of aluminum, which is coated with a special fluoresin compound. The housing is made of aluminum. An air inlet duct is connected to the right and an air outlet duct to the left. Bearings are located in the front of the housing to support the rotor shafts.

The rotors are press-fit onto the rotor shafts and then fixed in position by pins and serations. The gears are pinned integrally to the rotor shaft so that the original rotor-to-rotor orientation will not be lost. For this reason, they cannot be disassembled. Component parts are therefore supplied as an assembly, with rotors and gears fitted to the rear plate as illustrated.

Rotor and Gear Assembly

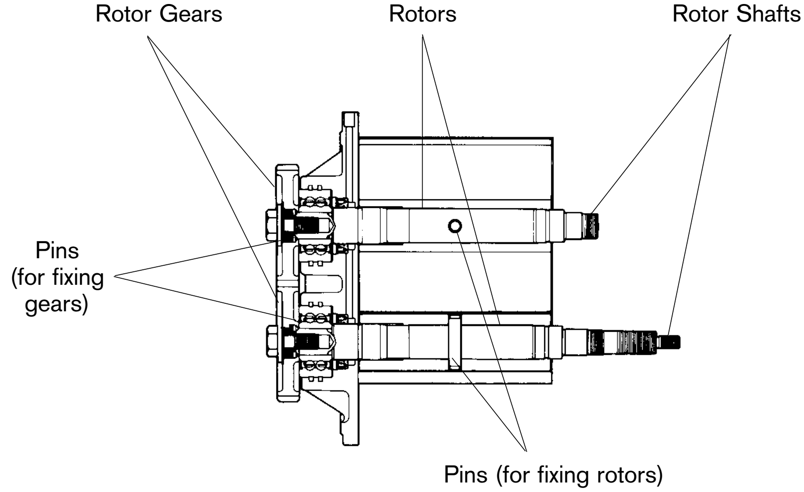

Fig. 9-23

T852f356

Ventilation Pipes

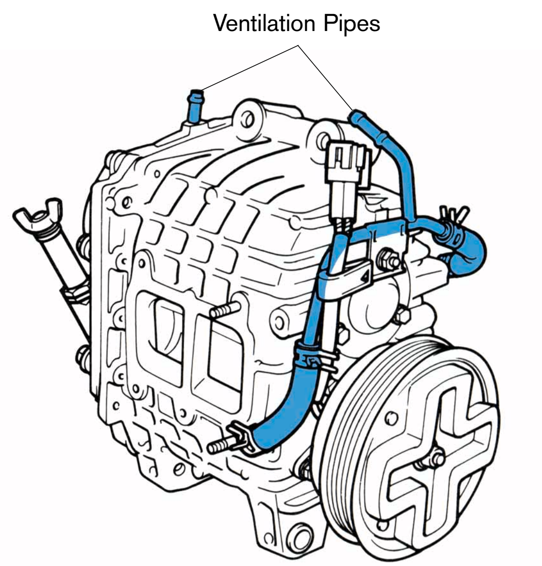

Fig. 9-24

T852f357

Ventilation Pipes

The gears and rear bearings are lubricated by Toyota brand supercharger oil. The front bearings are lubricated by grease. The pressure in the housing varies while the engine is operating. Ventilation pipes are provided to prevent oil leakage from the rear cover or grease leakage from the front bearings due to pressure fluctuation. Introduction of atmosphere into the ventilation pipes is controlled by the opening and closing of the Air Control Valve (ACV).

Magnetic Clutch

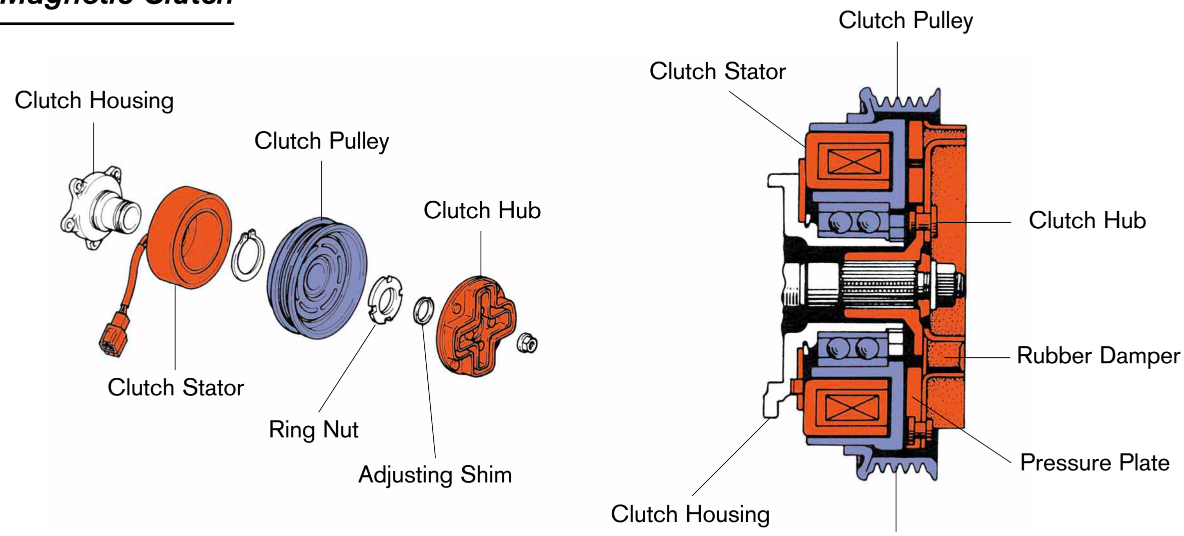

Fig. 9-25
T852f358

Magnetic Clutch

The magnetic clutch is turned on and off by the ECM. It is turned off to stop the supercharger when the engine is running under a light load. The magnetic clutch consists of the clutch stator, the clutch pulley, and the clutch hub. The clutch pulley turns around the clutch housing on a bearing incorporated in the pulley. The clutch hub is splined with the rotor shaft and turns as one complete unit. There is a rubber damper between the boss of the clutch hub and the pressure plate to allow the plate to move in the axial direction. When the magnetic clutch turns on or off, the rubber damper absorbs the shock due to the movement of the plate. The clutch stator is a solenoid. When the magnetic clutch is turned on, the pressure plate is pressed against the clutch pulley. Normally, a 0.5 mm (0.0197 in.) clearance is provided between the clutch hub and clutch pulley, as shown. A larger clearance due to wear, etc., may cause noise. The clearance is adjusted by changing the thickness of the adjusting shim.

The ECM turns the magnetic clutch on under the following conditions:

- Throttle valve opening angle is more than a certain angle (that is, during acceleration).
- Engine speed and intake air volume per engine revolution have increased.

Magnetic Clutch Operation

The magnetic clutch is on in the shaded area in the graph to the right (engine under heavy load).

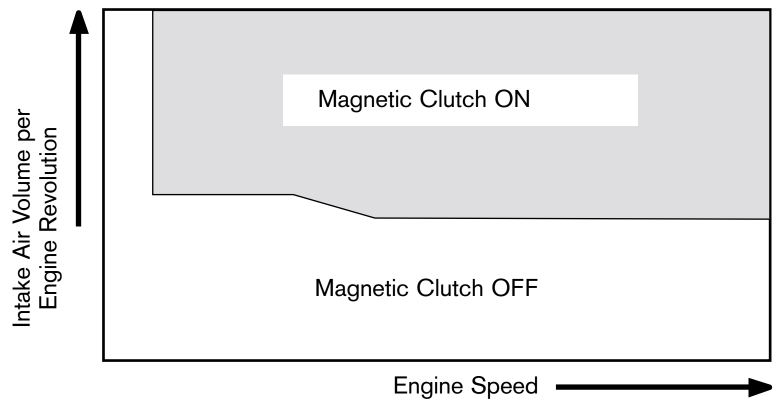

Fig. 9-26
T852f360

Air Control Valve

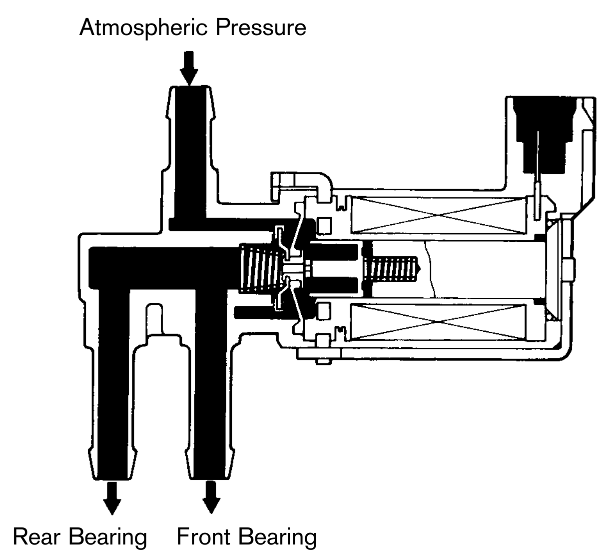

Fig. 9-27
T852f361

Air Control Valve (ACV)

In accordance with the signals received from the ECM, the ACV brings the pressure at the front and rear bearings closer to the atmospheric pressure. This prevents the bearing grease and oil from leaking out due to pressure fluctuation inside the supercharger housing.

Supercharger Bypass Valve

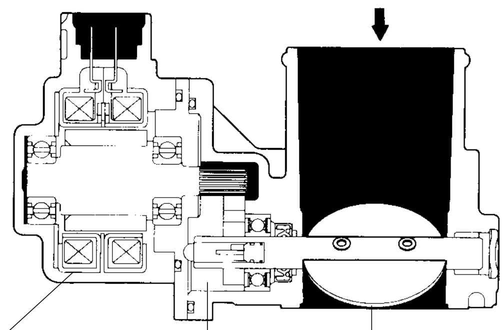

Fig. 9-28
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Supercharger Bypass Valve The supercharger discharge rate is regulated by a step motor type bypass valve which controls the amount of air that bypasses the supercharger. The step motor type supercharger bypass valve consists of a step motor, which is under the direct control of the ECM, and a valve that is driven by gears. In accordance with the running condition of the engine the ECM controls the step motor to regulate the amount of intake air to bypass and thus optimize the supercharger discharge rate. Compared to the 4A-GZE engine which uses a vacuum type supercharger bypass valve, the 2TZ-FZE engine with the step motor type supercharger bypass valve produces torque that is more linear in relation to the throttle opening angle.