

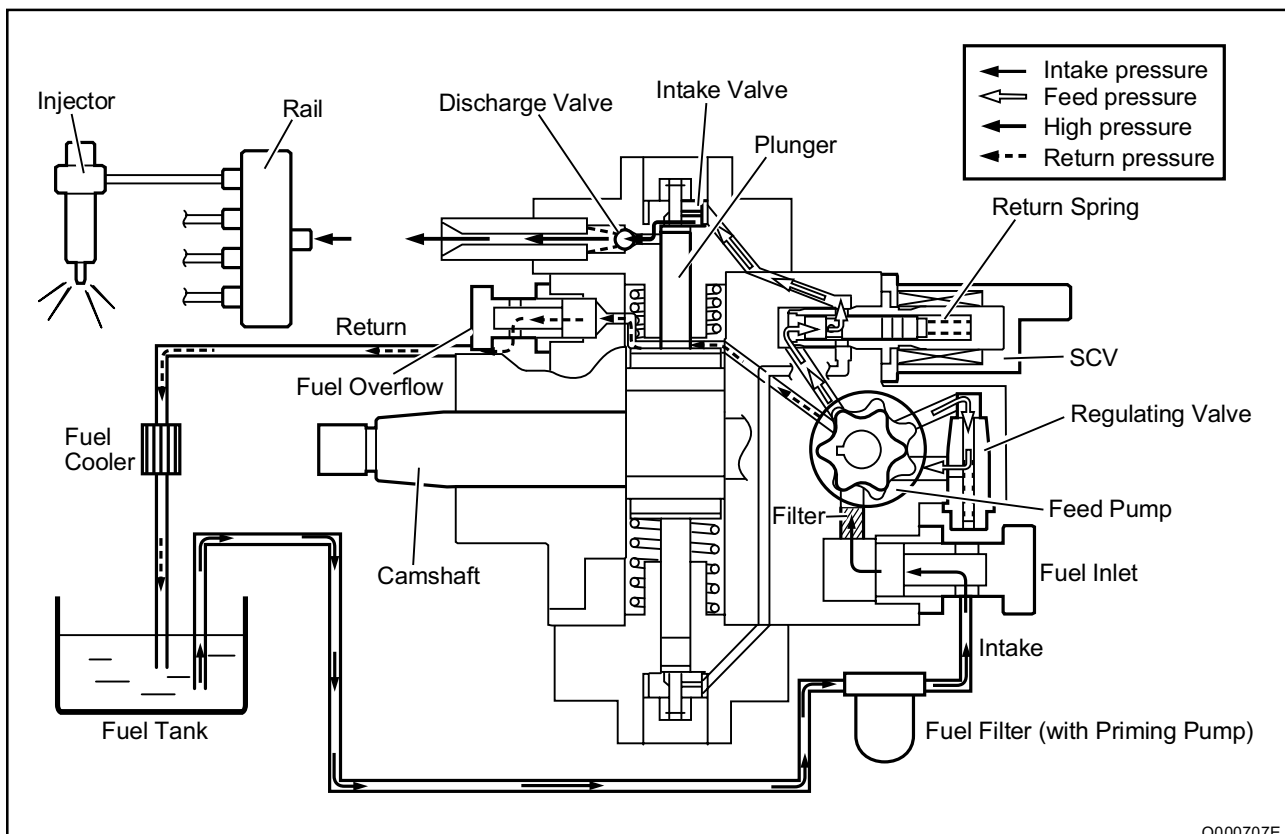
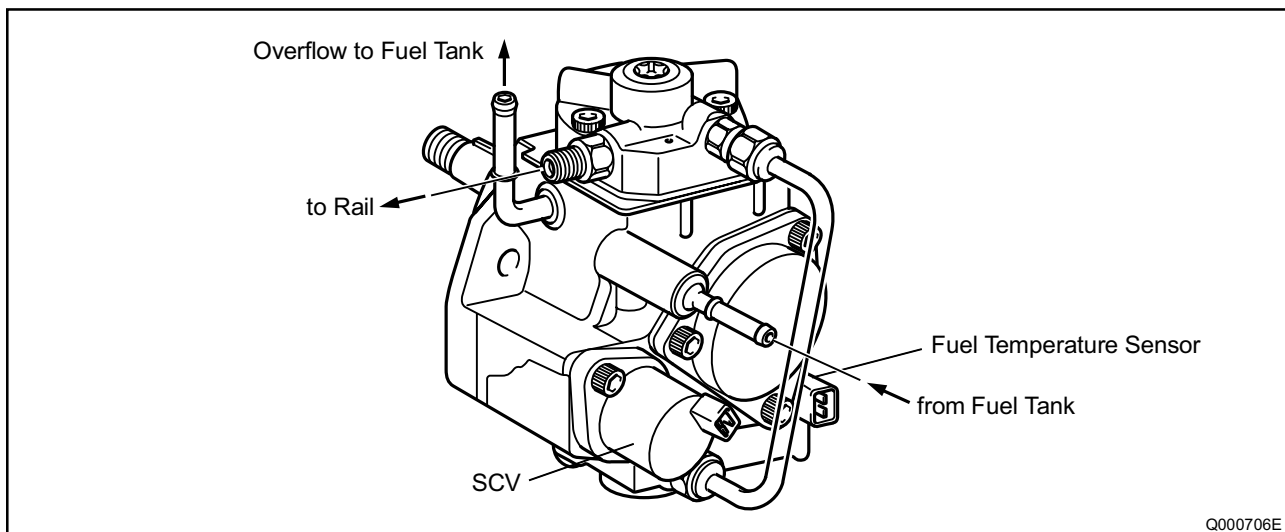
### 3. CONSTRUCTION AND OPERATION

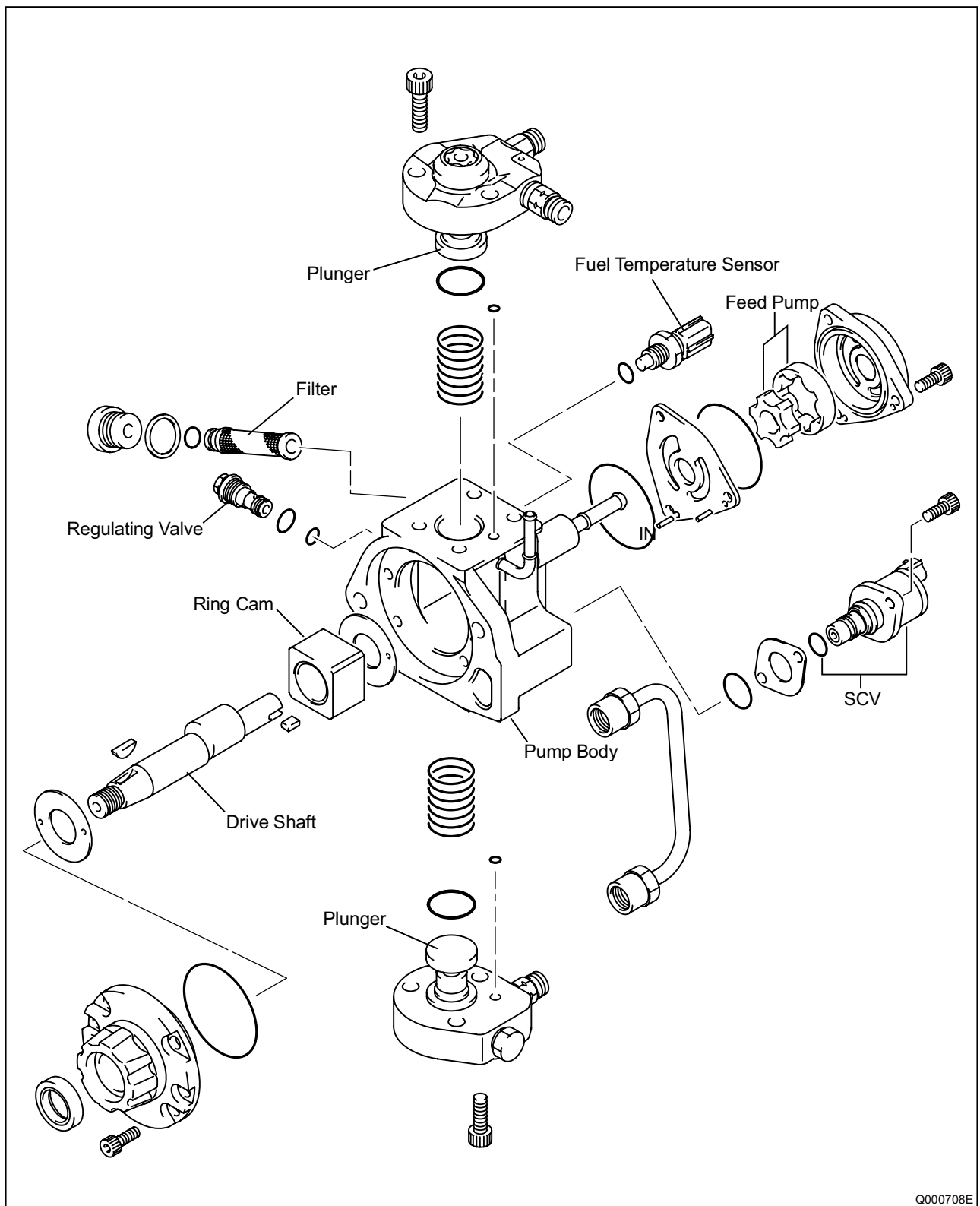
#### 3-1. DESCRIPTION OF MAIN COMPONENTS

##### A. Supply Pump (HP3)

###### a. Outline

- The supply pump consists primarily of the pump body (eccentric cam, ring cam, and plungers), SCV (Suction Control Valve), fuel temperature sensor, and feed pump.
- The two plungers are positioned vertically on the outer ring cam for compactness.
- The engine drives the supply pump at a ratio of 1:2. The supply pump has a built-in feed pump (trochoid type), and draws the fuel from the fuel tank, sending it to the plunger chamber.
- The internal camshaft drives the two plungers, and they pressurize the fuel sent to the plunger chamber and send it to the rail. The quantity of fuel supplied to the rail is controlled by the SCV, using signals from the engine ECU. The SCV is a normally closed type (the intake valve closes during de-energization).

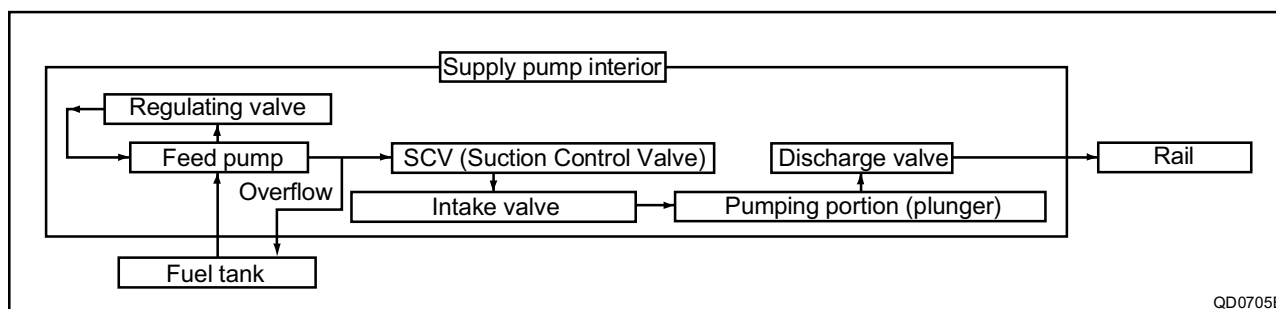




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b. Supply Pump Internal Fuel Flow

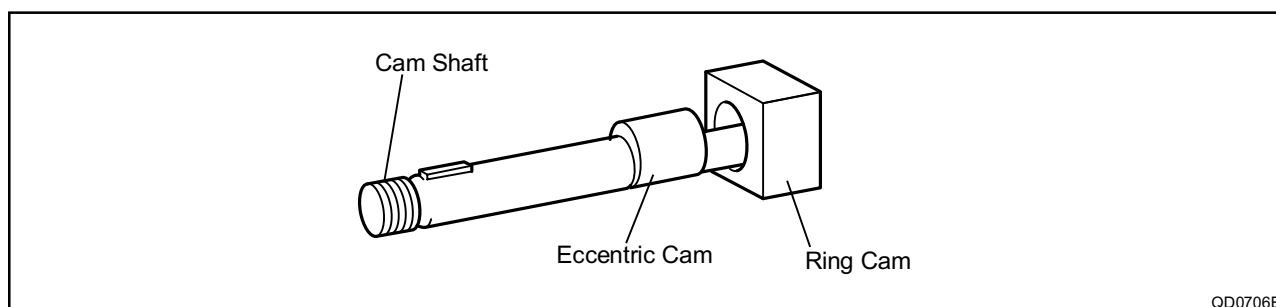
The fuel that is drawn from the fuel tank passes through the route in the supply pump as illustrated, and is fed into the rail.



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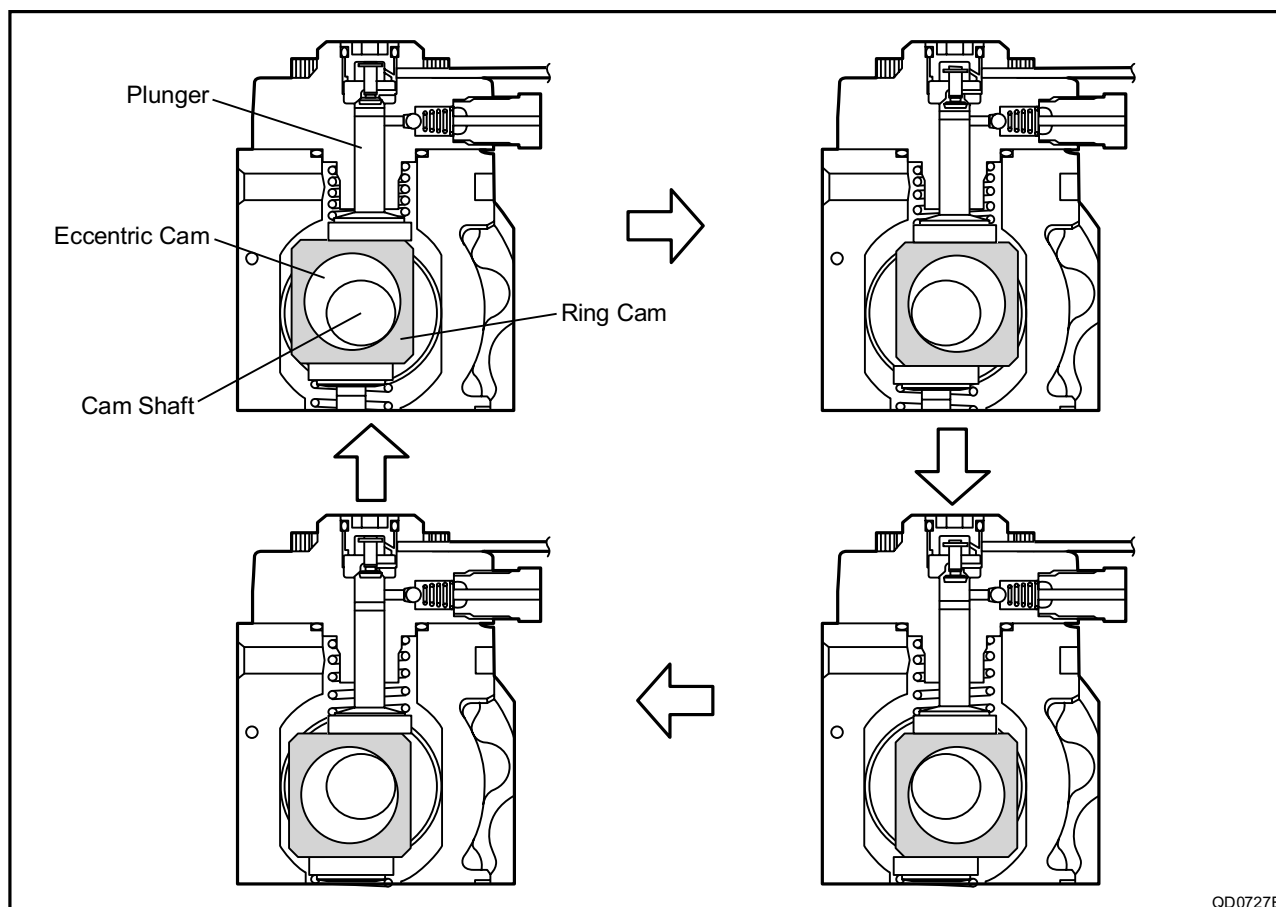
c. Construction of Supply Pump

The eccentric cam is attached to the drive shaft. The eccentric cam is connected to the ring cam.



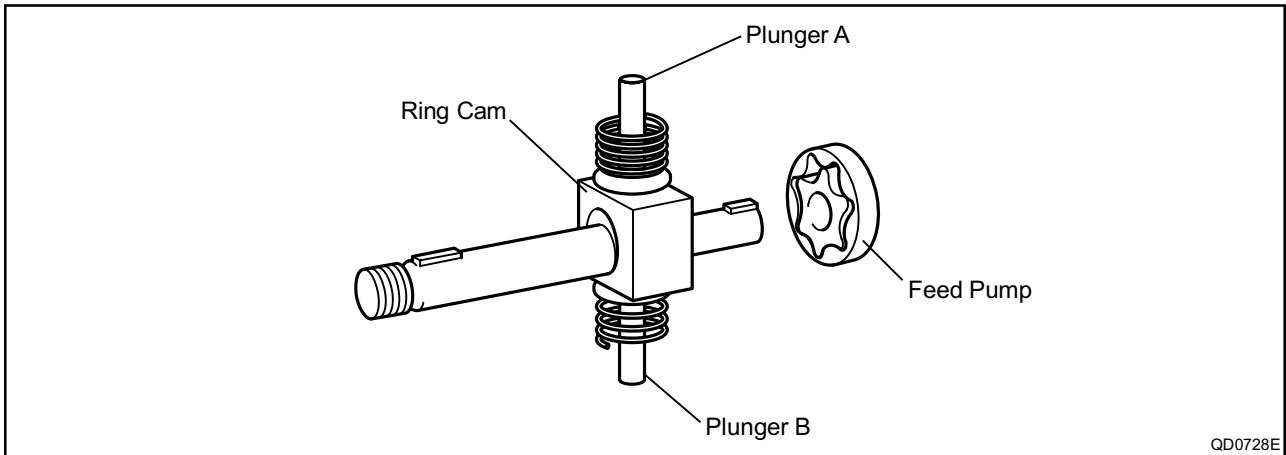
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- As the drive shaft rotates, the eccentric cam rotates eccentrically, and the ring cam moves up and down while rotating.



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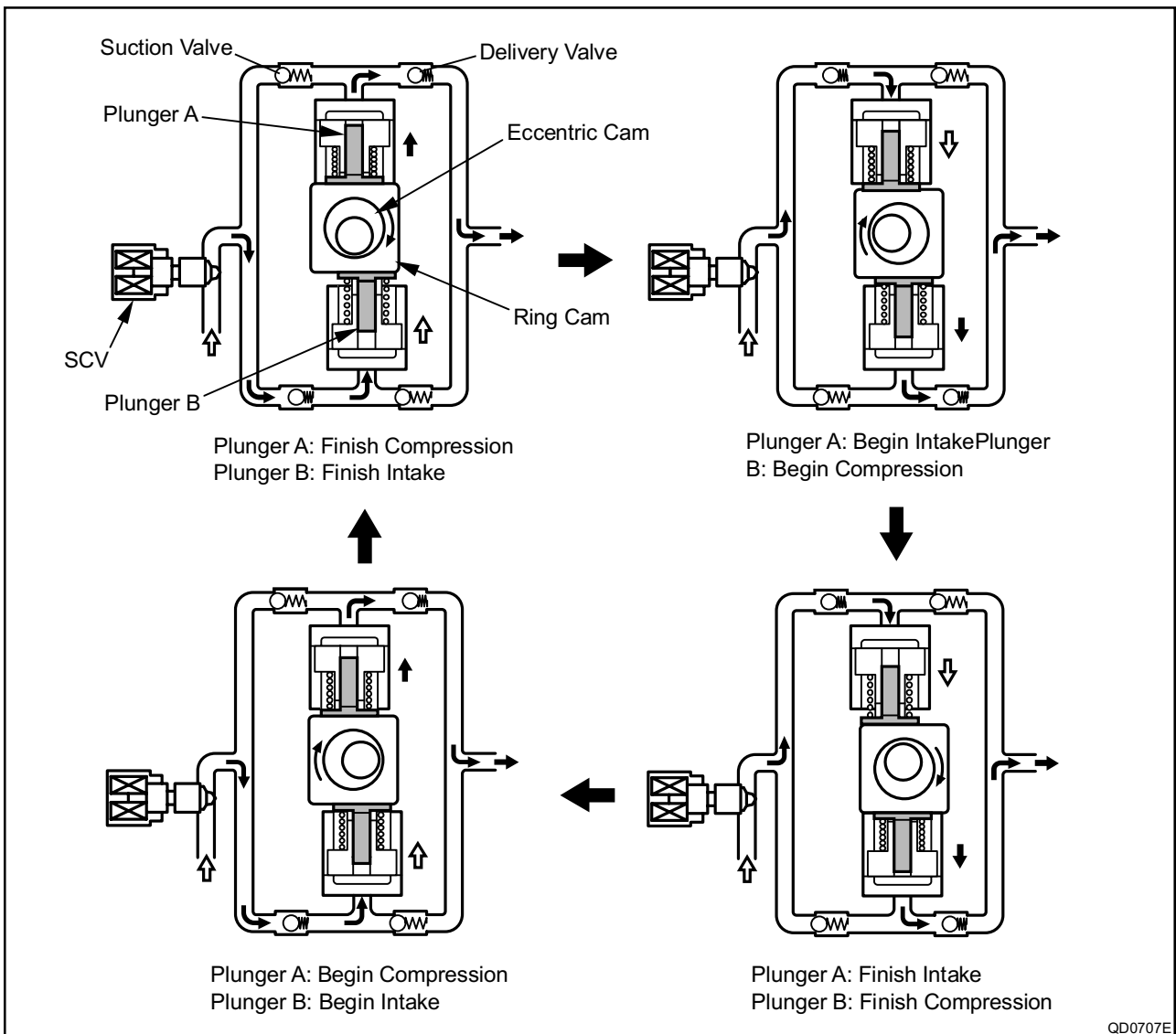
- The plunger and the suction valve are attached to the ring cam. The feed pump is connected to the rear of the drive shaft.



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d. Operation of the Supply Pump

As shown in the illustration below, the rotation of the eccentric cam causes the ring cam to push Plunger A upwards. Due to the spring force, Plunger B is pulled in the opposite direction to Plunger A. As a result, Plunger B draws in fuel, while Plunger A pumps it to the rail.

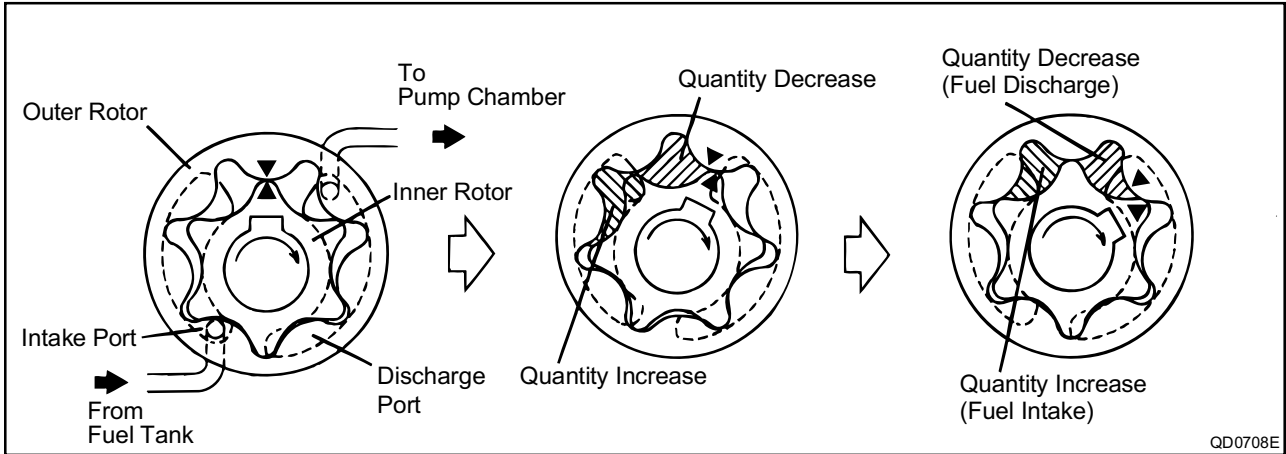


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## B. Description of Supply Pump Components

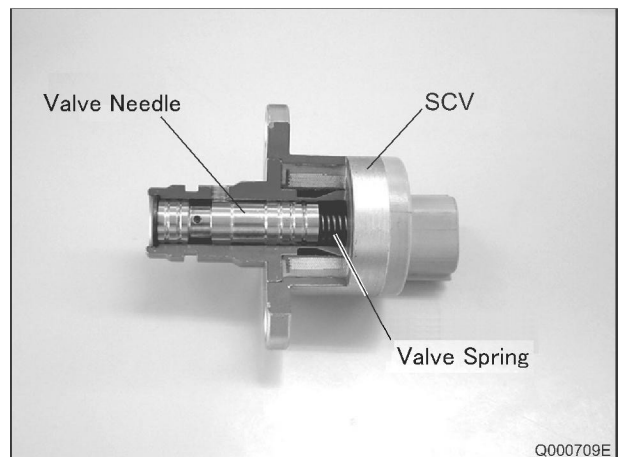
### a. Feed Pump

The trochoid type feed pump, which is integrated in the supply pump, draws fuel from the fuel tank and feeds it to the two plungers via the fuel filter and the SCV (Suction Control Valve). The feed pump is driven by the drive shaft. With the rotation of the inner rotor, the feed pump draws fuel from its suction port and pumps it out through the discharge port. This is done in accordance with the space that increases and decreases with the movement of the outer and inner rotors.



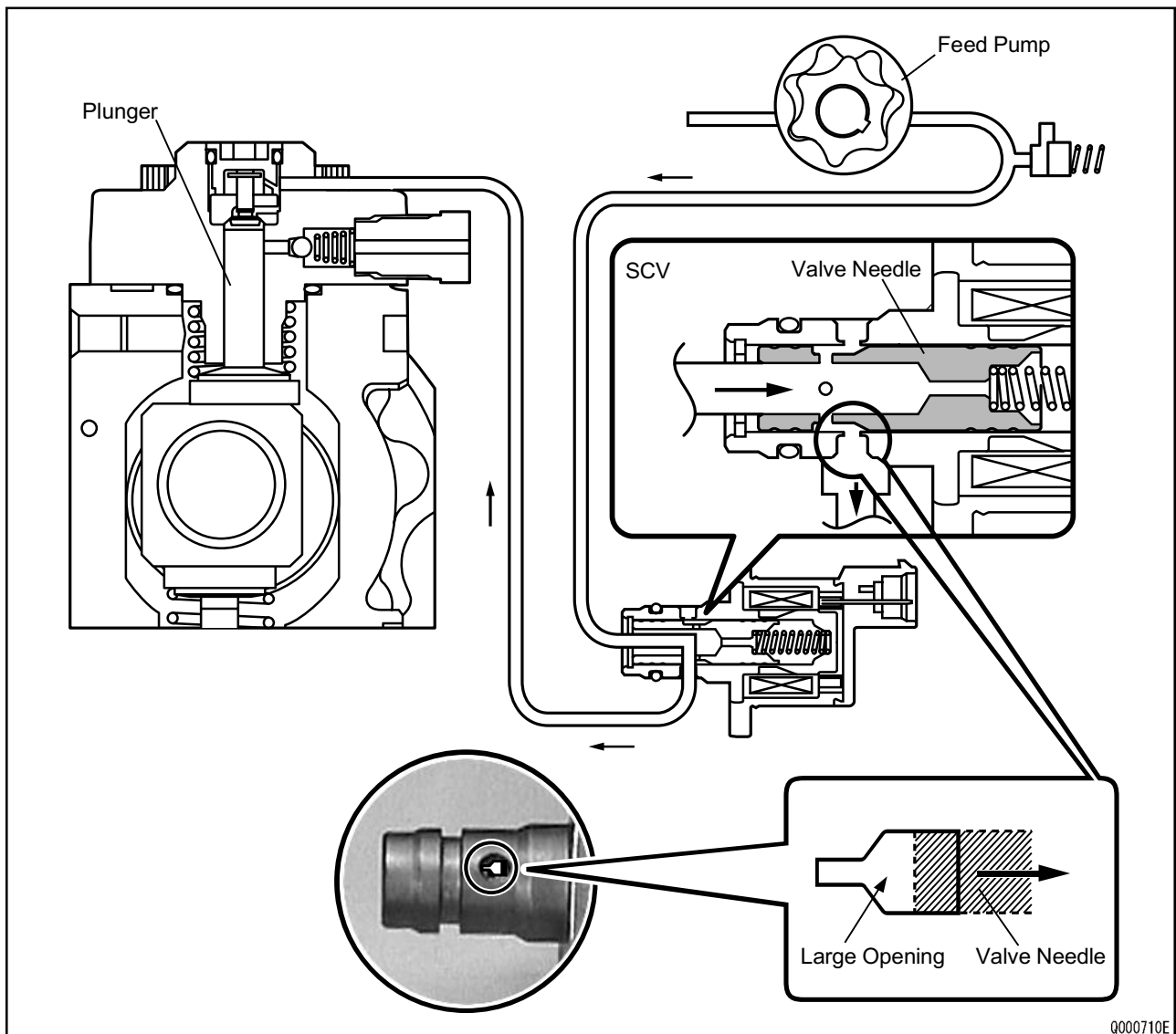
### b. SCV: Suction Control Valve

- A linear solenoid type valve has been adopted. The ECU controls the duty ratio (the duration in which current is applied to the SCV), in order to control the quantity of fuel that is supplied to the high-pressure plunger.
- Because only the quantity of fuel that is required for achieving the target rail pressure is drawn in, the actuating load of the supply pump decreases.
- When current flows to the SCV, variable electromotive force is created in accordance with the duty ratio, moving the valve needle to the right side, and changing the opening of the fuel passage to regulate the fuel quantity.
- With the SCV ON, the valve spring contracts, completely opening the fuel passage and supplying fuel to the plungers. (Full quantity intake and full quantity discharge)
- When the SCV is OFF, the force of the valve spring moves the valve needle to the left, closing the fuel passage (normally closed).
- By turning the SCV ON/OFF, fuel is supplied in an amount corresponding to the actuation duty ratio, and fuel is discharged by the plungers.



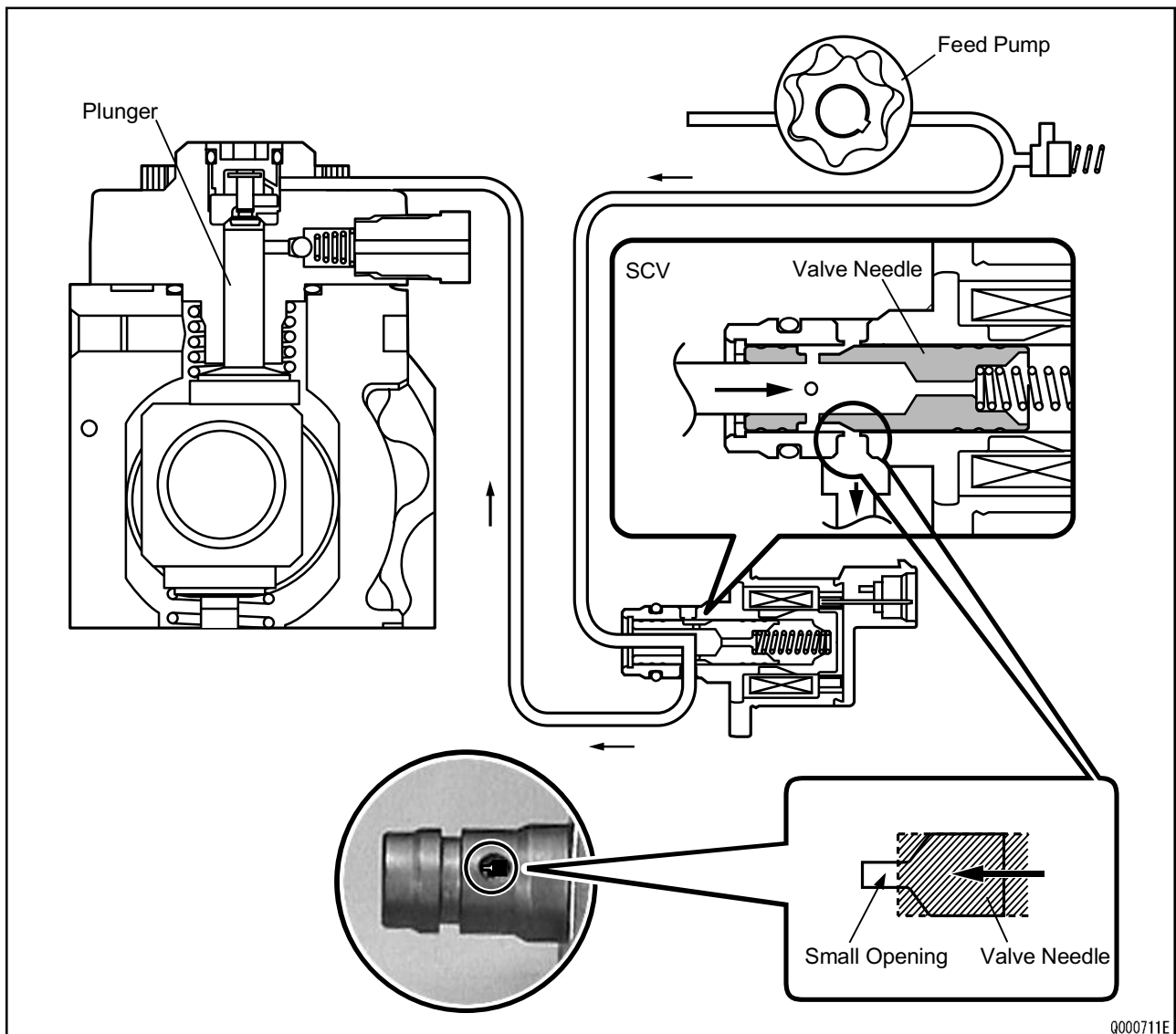
A) In case of long duty ON

Long duty ON => large valve opening => maximum intake quantity



B) In case of short duty ON

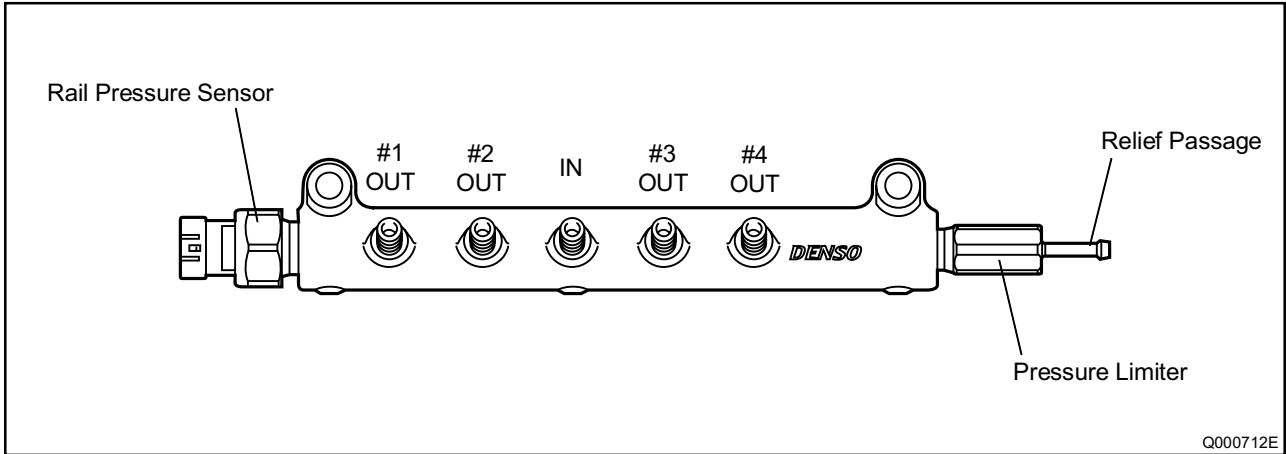
Short duty ON => small valve opening => minimum intake quantity



### C. Rail

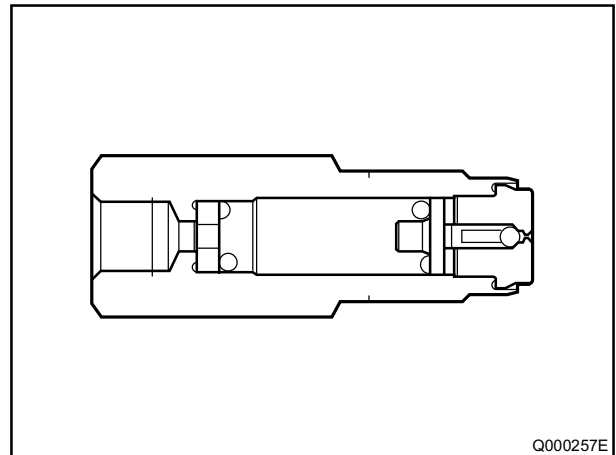
#### a. Outline

- Stores pressurized fuel (0 to 160 MPa) that has been delivered from the supply pump and distributes the fuel to each cylinder injector. A rail pressure sensor and a pressure discharge valve (low-pressure valve) are adopted in the rail.
- The rail pressure sensor (Pc sensor) detects fuel pressure in the rail and sends a signal to the engine ECU, and the pressure limiter controls the excess pressure. This ensures optimum combustion and reduces combustion noise.

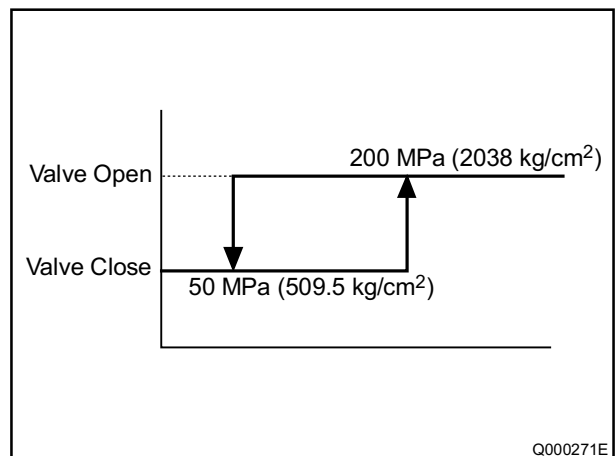


#### b. Pressure Limiter

The pressure limiter opens to release the pressure if an abnormally high pressure is generated.



- When the rail pressure reaches approximately 200 MPa (2038 kg/cm<sup>2</sup>), it trips the pressure limiter (the valve opens). When the pressure drops to approximately 50 MPa (509.5 kg/cm<sup>2</sup>), the pressure limiter returns to its normal state (the valve closes) in order to maintain the proper pressure.



#### D. Injector (X2 revised type)

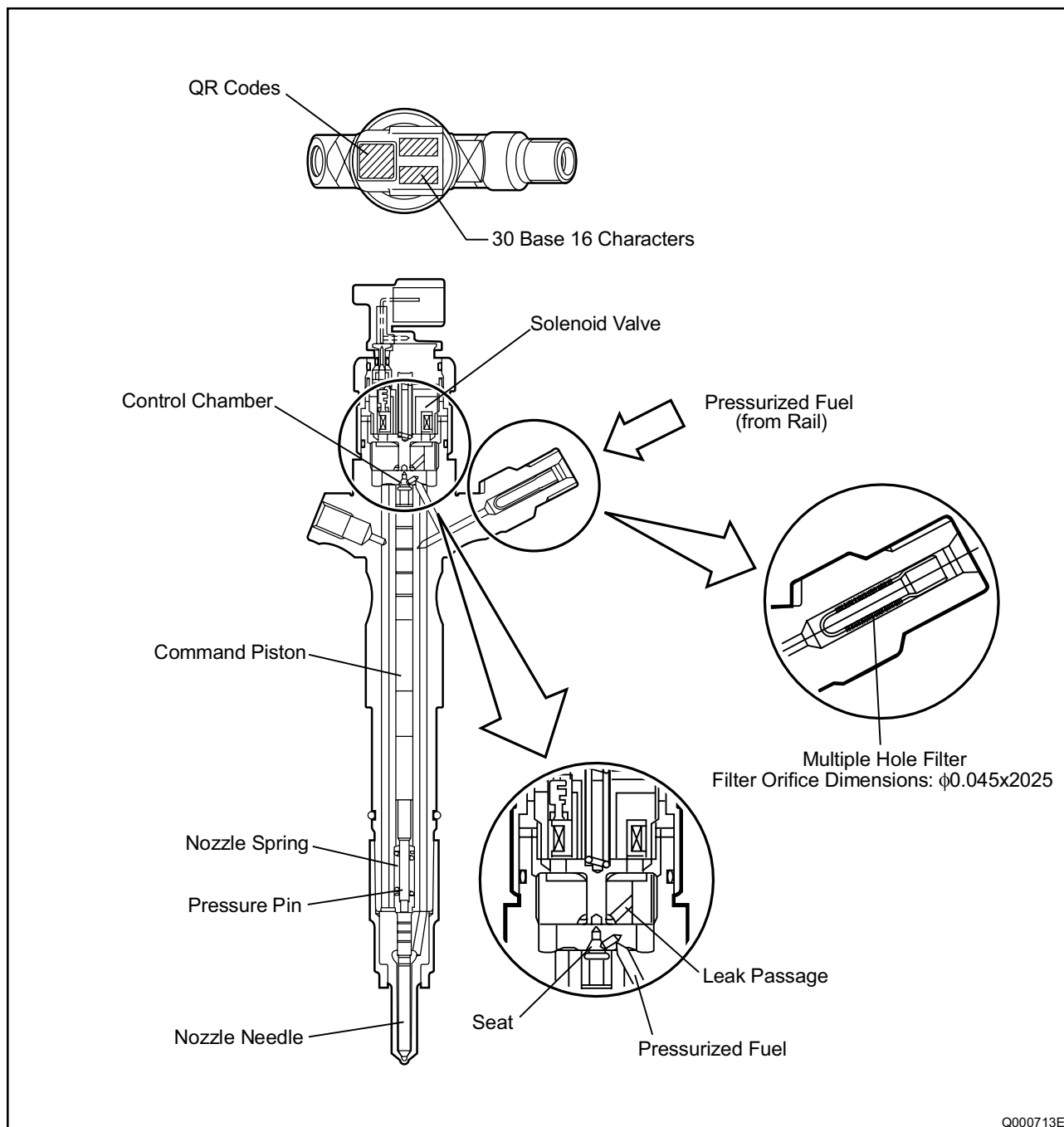
##### a. Outline

The injectors inject the high-pressure fuel from the rail into the combustion chambers at the optimum injection timing, rate, and spray condition, in accordance with commands received from the ECU.

##### A) Characteristics

- A compact, energy-saving solenoid-control type TWV (Two-Way Valve) injector has been adopted.
- QR codes displaying various injector characteristics and the ID codes showing these in numeric form (30 base 16 characters) are engraved on the injector head. The 1KD-FTV common rail system optimizes injection volume control using this information. When an injector is newly installed in a vehicle, it is necessary to enter the ID codes in the engine ECU using the DST-2.

##### b. Construction



c. Operation

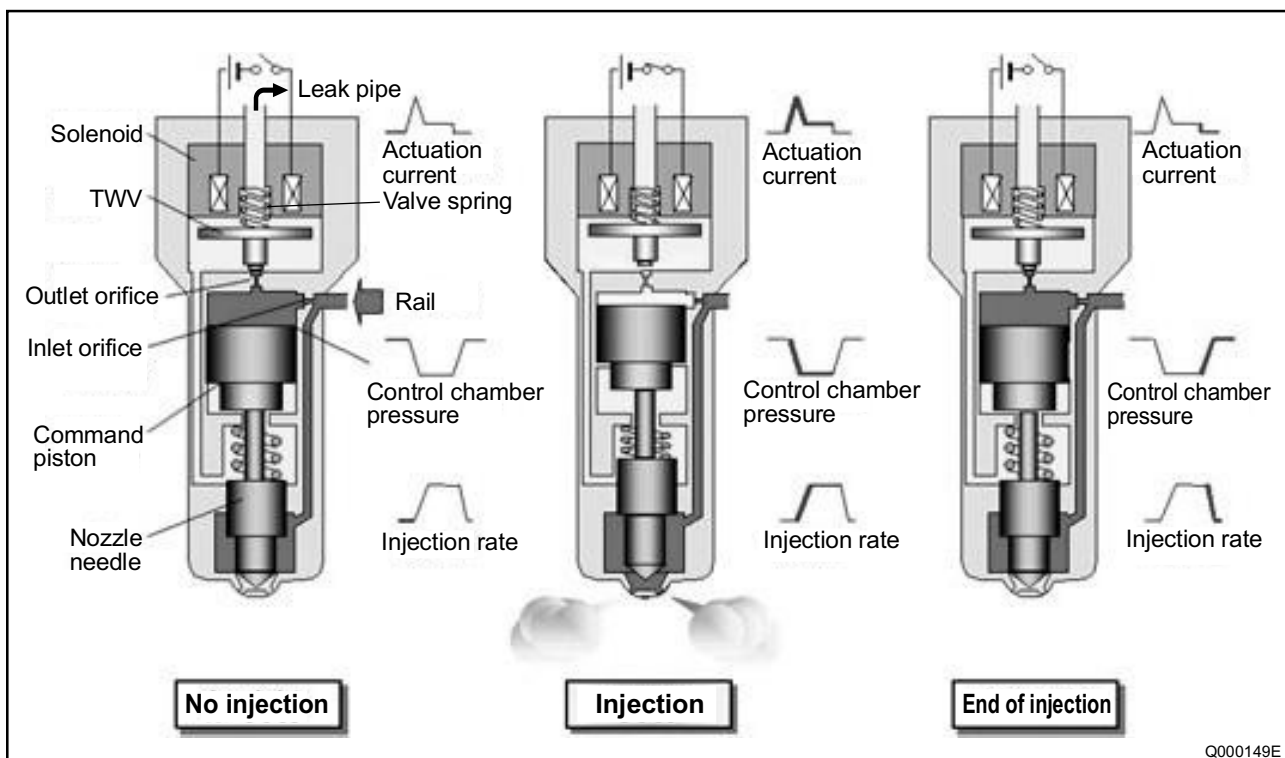
The TWV (Two-Way Valve) solenoid valve opens and closes the outlet orifice to control both the pressure in the control chamber, and the start and end of injection.

A) No injection

When no current is supplied to the solenoid, the spring force is stronger than the hydraulic pressure in the control chamber. Thus, the solenoid valve is pushed downward, effectively closing the outlet orifice. For this reason, the hydraulic pressure that is applied to the command piston causes the nozzle spring to compress. This closes the nozzle needle, and as a result, fuel is not injected.

B) Injection

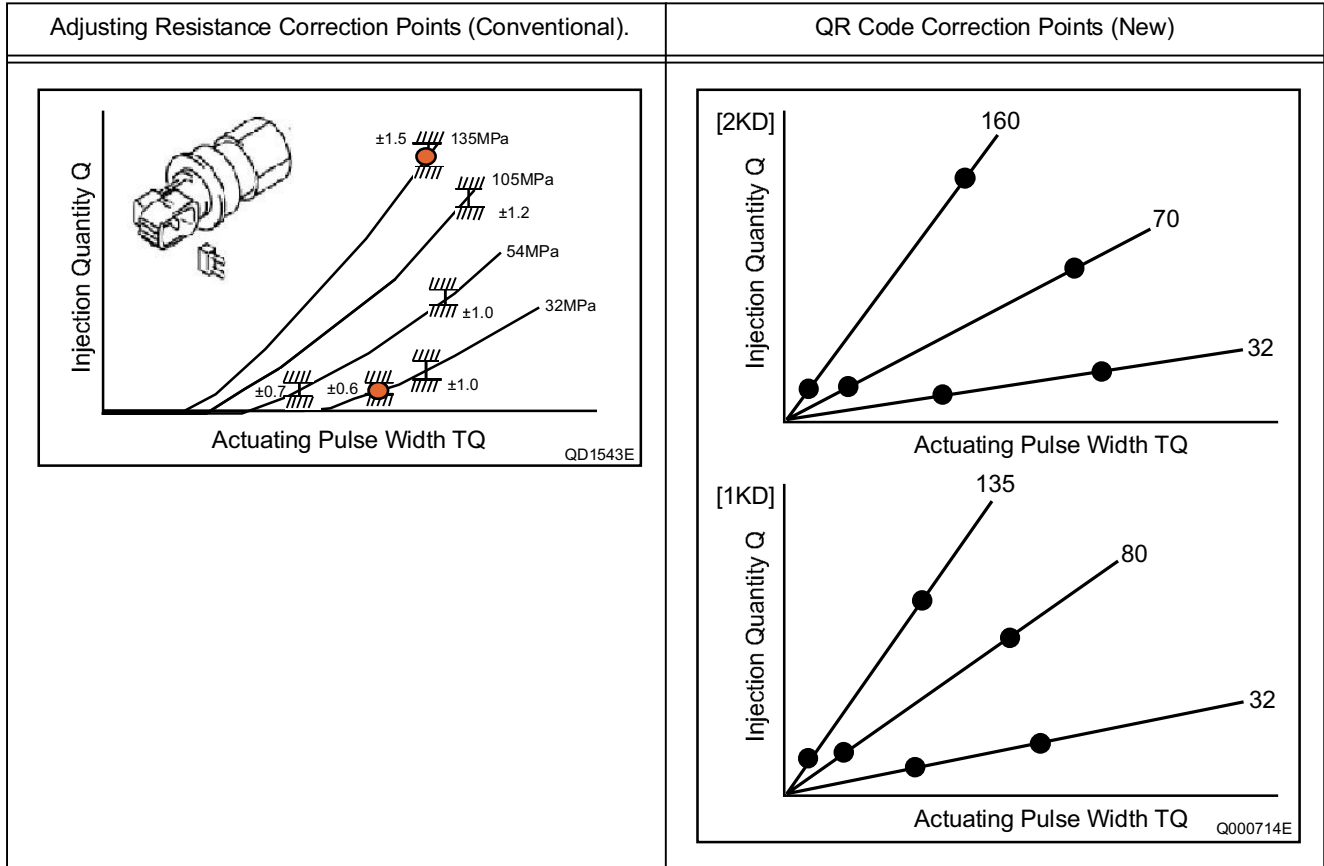
- When current is initially applied to the solenoid, the attraction force of the solenoid pulls the solenoid valve up, effectively opening the outlet orifice and allowing fuel to flow out of the control chamber. After the fuel flows out, the pressure in the control chamber decreases, pulling the command piston up. This causes the nozzle needle to rise and the injection to start.
- The fuel that flows past the outlet orifice flows to the leak pipe and below the command piston. The fuel that flows below the piston lifts the piston needle upward, which helps improve the nozzle's opening and closing response.
- When current continues to be applied to the solenoid, the nozzle reaches its maximum lift, where the injection rate is also at the maximum level. When current to the solenoid is turned OFF, the solenoid valve falls, causing the nozzle needle to close immediately and the injection to stop.



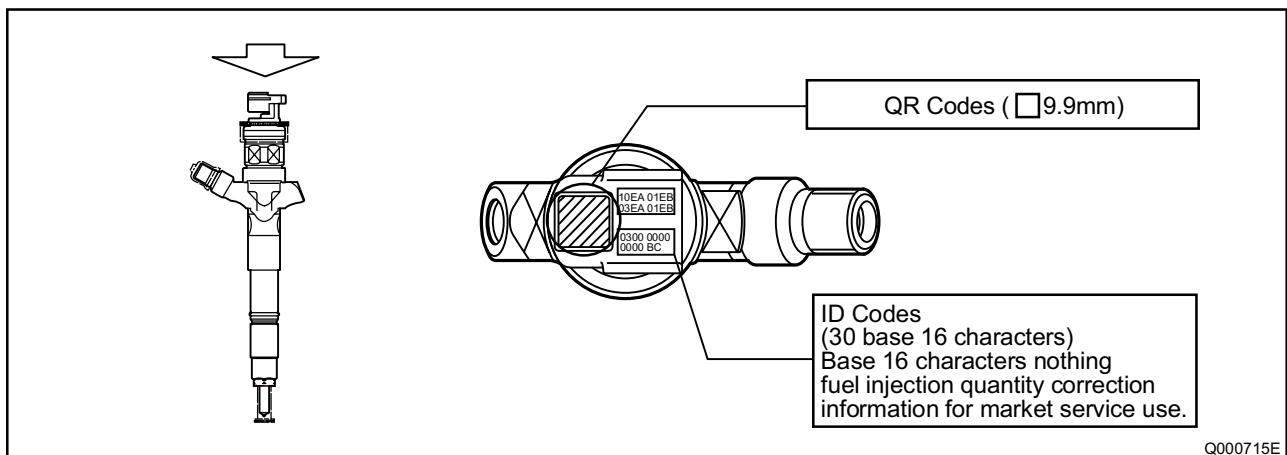
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d. QR codes

- Conventionally, adjusting resistors were used for fuel injection quantity correction. However, QR \*1 (Quick Response) codes have been adopted to enhance correction precision.
- Using QR codes has resulted in a substantial increase in the number of fuel injection quantity correction points, and thus the injection quantity control precision has improved. The characteristics of the engine cylinders have been further unified, contributing to improvements in combustion efficiency, reductions in exhaust gas emissions and so on.



\*1: Location of QR codes

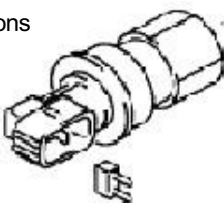
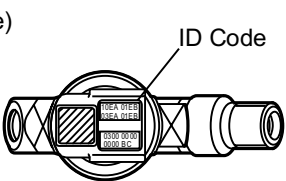
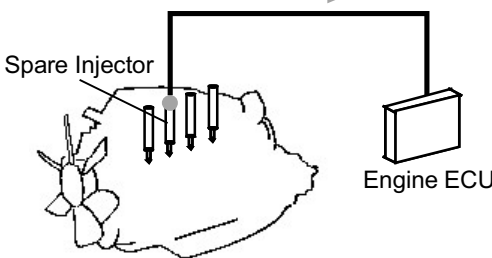
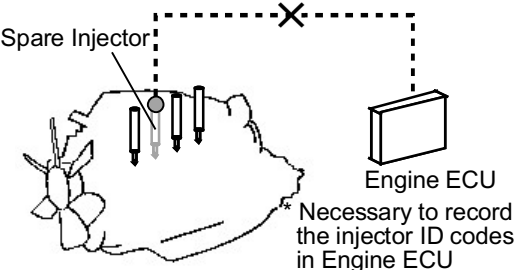
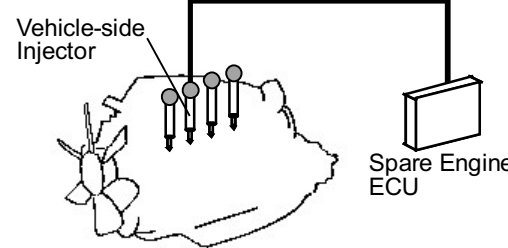
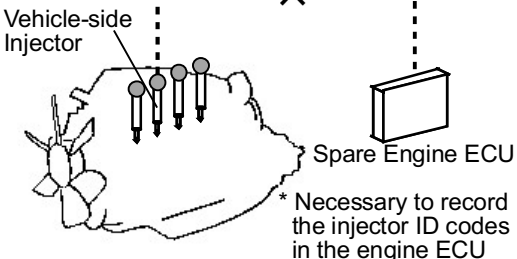


e. Repair Procedure Changes

Differences in comparison with the conventional adjusting correction resistor injectors are as shown below.

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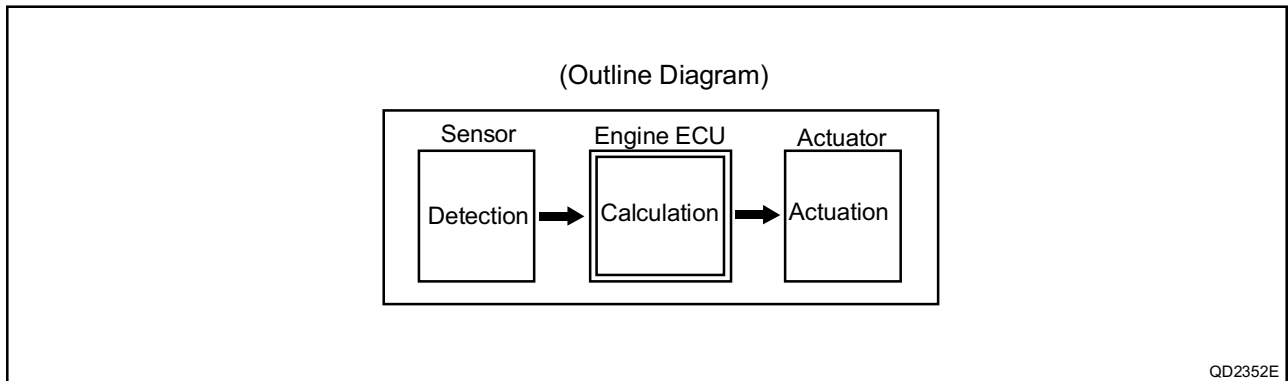
- When replacing injectors with QR codes, or the engine ECU, it is necessary to record the ID codes (QR codes) in the ECU. (If the ID codes of the installed injector are not registered correctly, engine failure such as rough idling and noise will result.)

|                          | Conventional (Injector with Correction Resistor)                                                                                                            | New (Injector with QR Codes)                                                                                                                                                   |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                          | <p>5<sup>2</sup> (25) combinations</p>  <p>QD1532E</p>                     | <p>256<sup>12</sup> (almost infinite) combinations</p>  <p>Q000716E</p>                     |
| Replacing the Injector   | <p>"Electrical recognition of correction resistance"</p>  <p>QD1534E</p>  | <p>"No correction resistance, so no electrical recognition capability"</p>  <p>QD1536E</p>  |
| Replacing the Engine ECU | <p>"Electrical recognition of correction resistance"</p>  <p>QD1535E</p> | <p>"No correction resistance, so no electrical recognition capability"</p>  <p>QD1537E</p> |

## E. Engine ECU (Electronic Control Unit)

### a. Outline

This is the command center that controls the fuel injection system and engine operation in general.



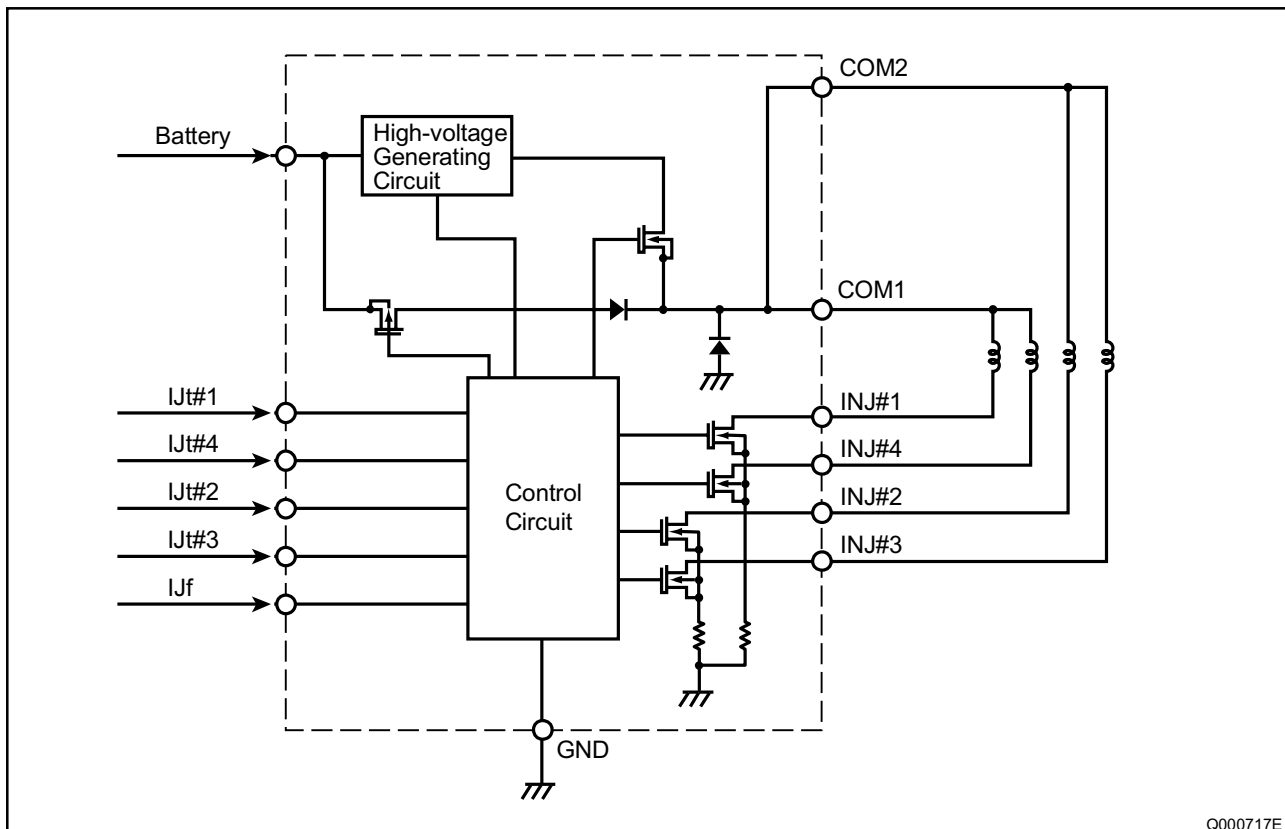
## F. EDU (Electronic Driving Unit)

### a. Outline

The EDU has been adopted to support the high-speed actuation of the injectors. The high-speed actuation of the injector solenoid valve is made possible through the use of a high-voltage generating device (DC/DC converter).

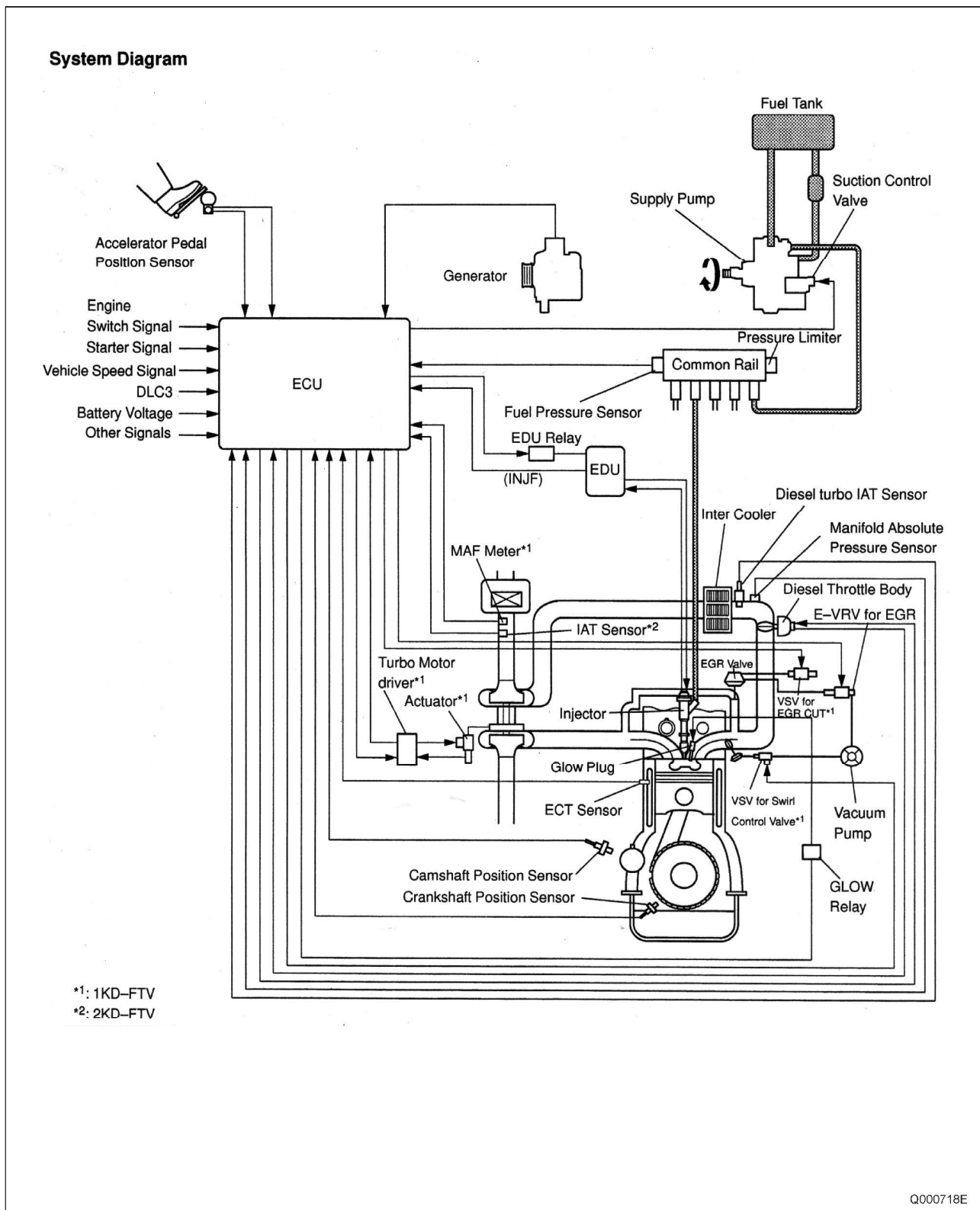
### b. EDU Operation

The high-voltage generating device converts the battery voltage into high voltage. The engine ECU sends signals to terminals B through E of the EDU in accordance with the signals from the sensors. Upon receiving these signals, the EDU outputs signals to the injectors via terminals N through K. At this time, terminal F outputs the IJf injection verification signal to the ECU. The pressure discharge valve is controlled by PRD signals coming to terminal R.



### 3-2. DESCRIPTION OF CONTROL SYSTEM COMPONENTS

#### A. Engine Control System Diagram



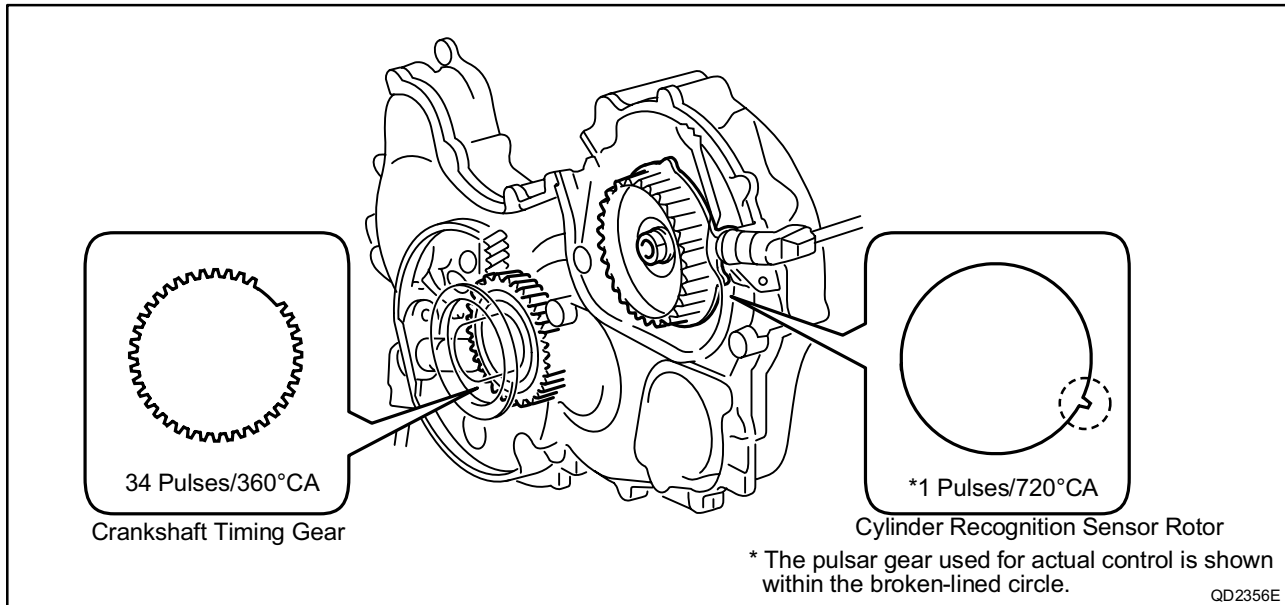
## B. Description of Sensors

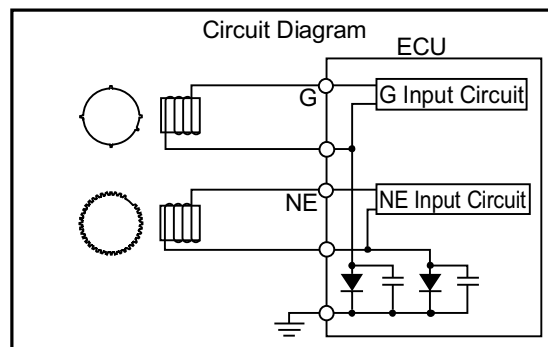
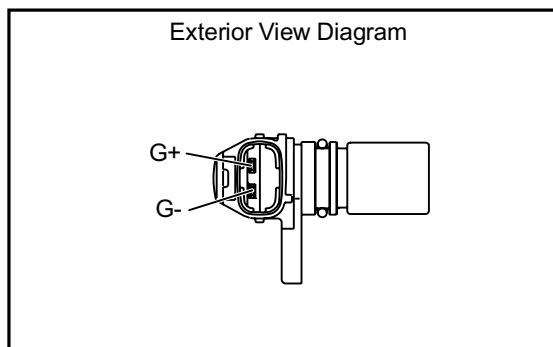
### a. Crankshaft Position Sensor (NE)

An NE pulsar attached to the crankshaft timing gear outputs a signal for detecting the crankshaft angle and engine speed. The pulsar gear contains 34 gears, with 2 gears missing (for 2 pulses), and the sensor outputs 34 pulses for 360°CA.

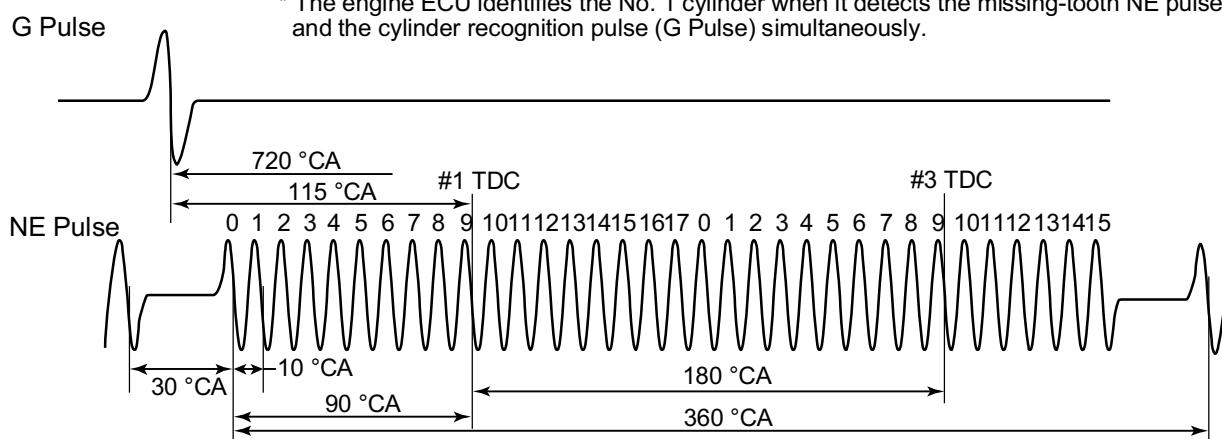
### b. Cylinder Recognition Sensor (G)

A cylinder recognition sensor (G pulsar) is attached to the supply pump timing gear, and outputs a cylinder recognition signal. The sensor outputs 1 pulse for each 2 engine revolutions.





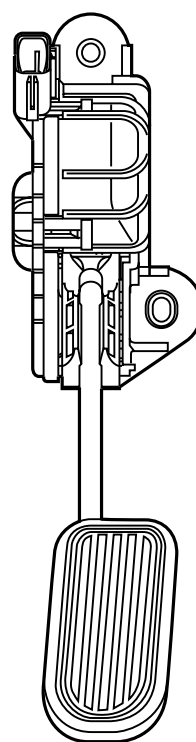
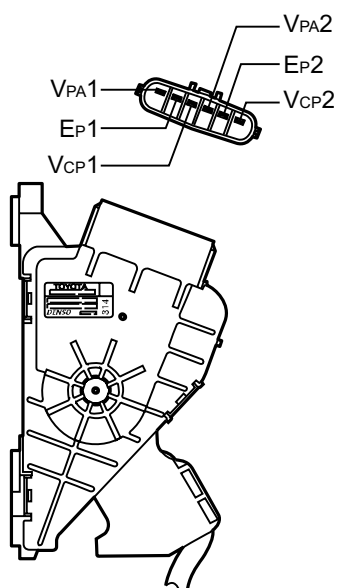
\* The engine ECU identifies the No. 1 cylinder when it detects the missing-tooth NE pulse and the cylinder recognition pulse (G Pulse) simultaneously.



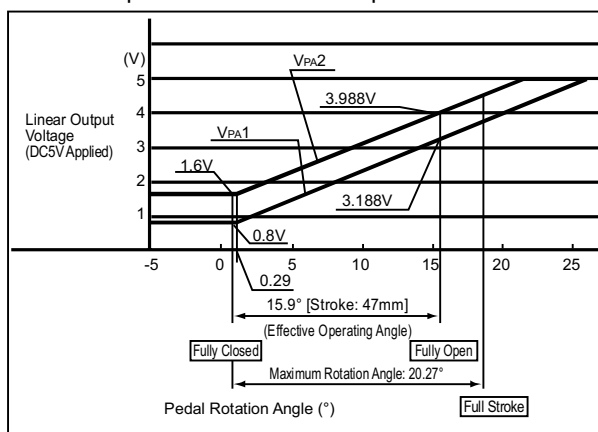
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### c. Accelerator Position Sensor

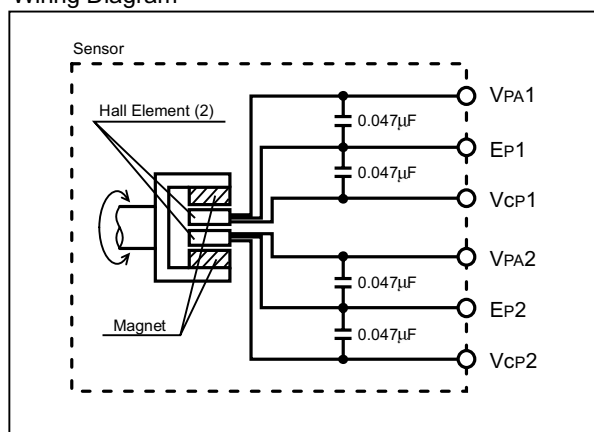
The accelerator position sensor is a non-contact point type sensor with a lever that rotates in unison with the accelerator pedal. The voltage (VPA1, VPA2) of the output terminal varies in accordance with the rotational angle of the lever. As a safety measure against problems such as an open circuit, the sensor contains two output voltage systems. (The output voltage has an offset of 0.8V.)



Linear Output Characteristics Graph



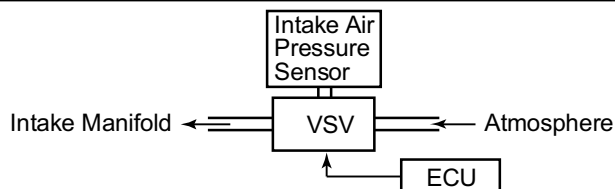
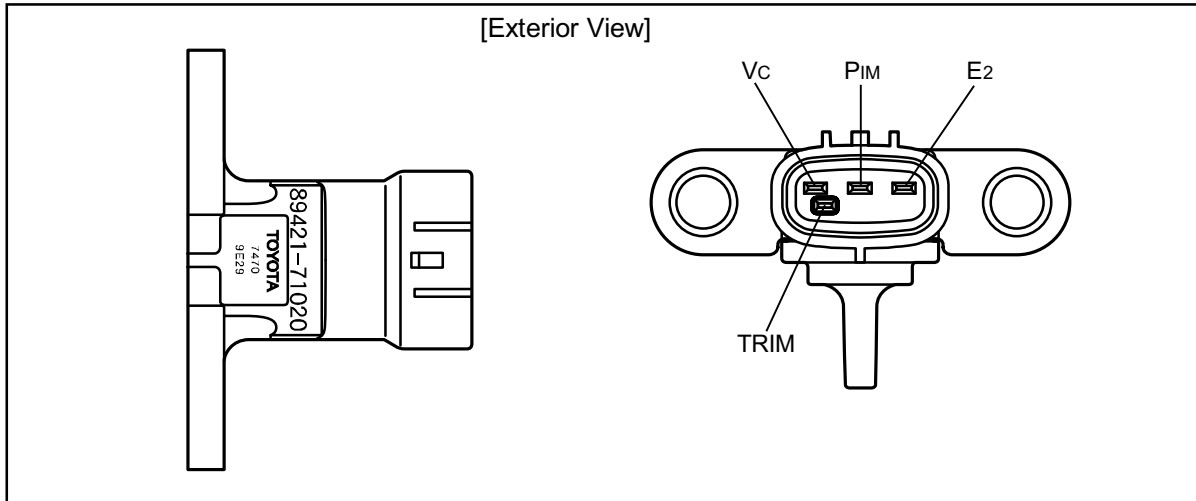
Wiring Diagram



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d. Intake Air Pressure Sensor

This is a type of semi-conductor pressure sensor. It utilizes the characteristics of the electrical resistance changes that occur when the pressure applied to a silicon crystal changes. Because a single sensor is used to measure both intake air pressure and atmospheric pressure, a VSV is used to alternate between atmospheric and intake air pressure measurement.



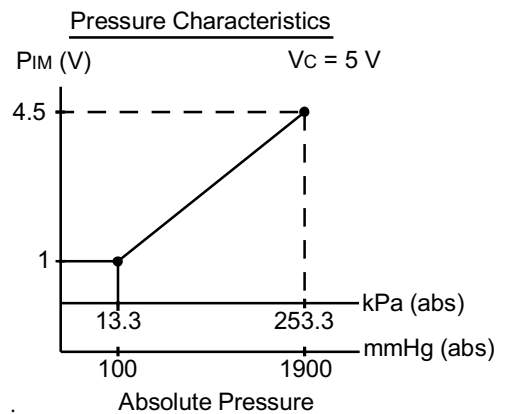
**Atmospheric Pressure Measurement Conditions:**

The VSV turns ON for 150msec to detect the atmospheric pressure when one of the conditions "(1)" to "(3)" given below is present.

- (1) Engine speed = 0rpm
- (2) Starter is ON
- (3) Idle is stable

**Intake Air Pressure Measurement Conditions:**

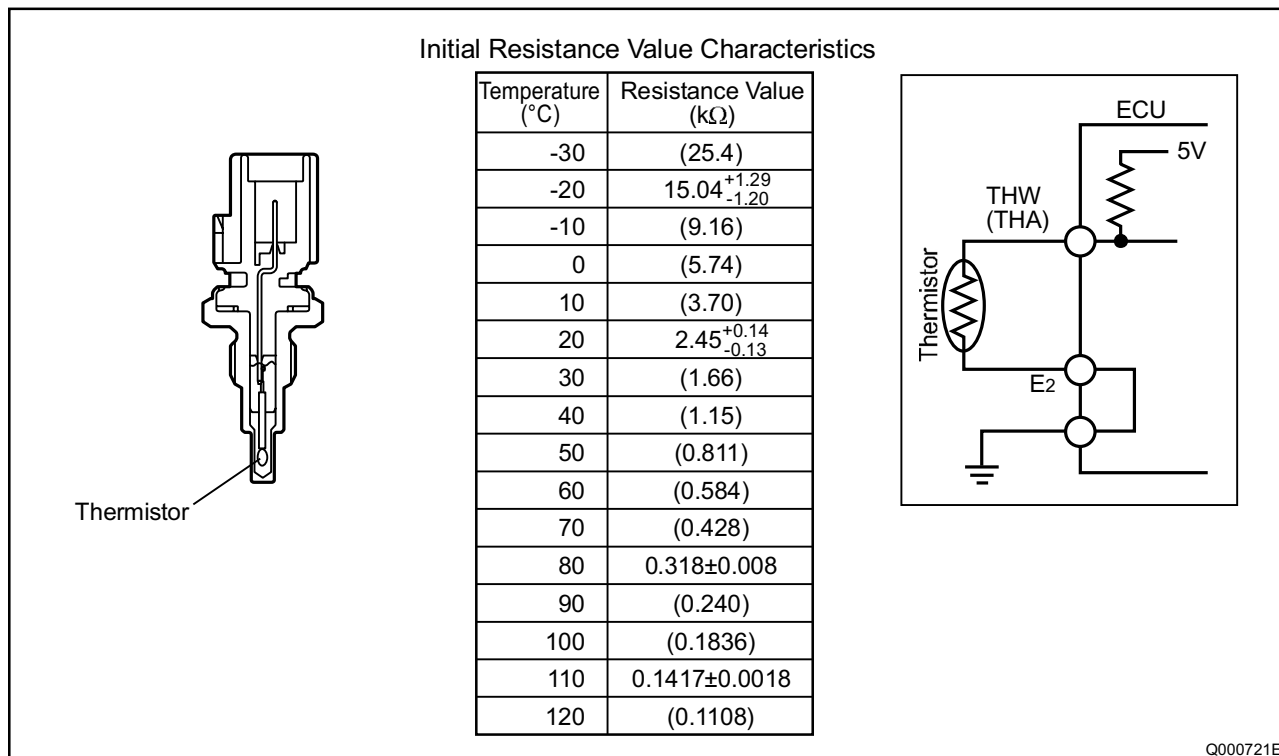
The VSV turns OFF to detect the intake air pressure if the atmospheric pressure measurement conditions are absent.



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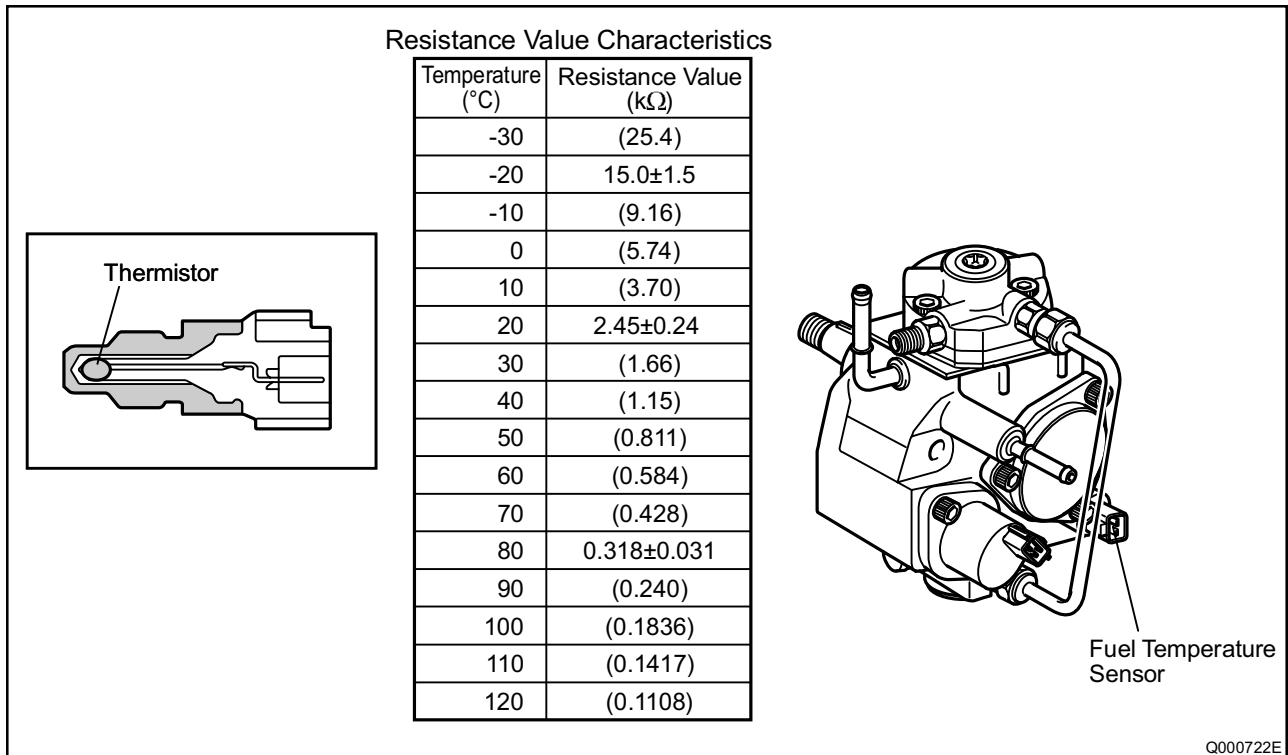
e. Coolant Temperature Sensor (THW)

- The coolant temperature sensor (Pc sensor) is attached to the engine cylinder block and detects the engine coolant temperature.
- The sensor uses a thermistor. The thermistor has a characteristic in which the resistance changes with the temperature, and the change in resistance value is used to detect the coolant temperature changes.
- Its characteristic is that the resistance value decreases as the temperature increases.



f. Fuel Temperature Sensor (THF)

- The fuel temperature sensor is mounted on the supply pump, and detects the fuel temperature, sending a signal to the engine ECU.
- The detection component utilizes a thermistor.



## C. Various Types of Controls

### a. Outline

This system effects fuel injection quantity and injection timing control more appropriately than the mechanical governor and timer used in the conventional injection pump. The engine ECU performs the necessary calculations in accordance with the sensors installed on the engine and the vehicle. It then controls the timing and duration of time in which current is applied to the injectors, in order to realize both optimal injection and injection timing.

### b. Fuel Injection Rate Control Function

Pilot injection control injects a small amount of fuel before the main injection.

### c. Fuel Injection Quantity Control Function

The fuel injection quantity control function replaces the conventional governor function. It controls the fuel injection to an optimal injection quantity based on the engine speed and accelerator position signals.

### d. Fuel Injection Timing Control Function

The fuel injection timing control function replaces the conventional timer function. It controls the injection to an optimal timing based on the engine speed and the injection quantity.

### e. Fuel Injection Pressure Control Function (Rail Pressure Control Function)

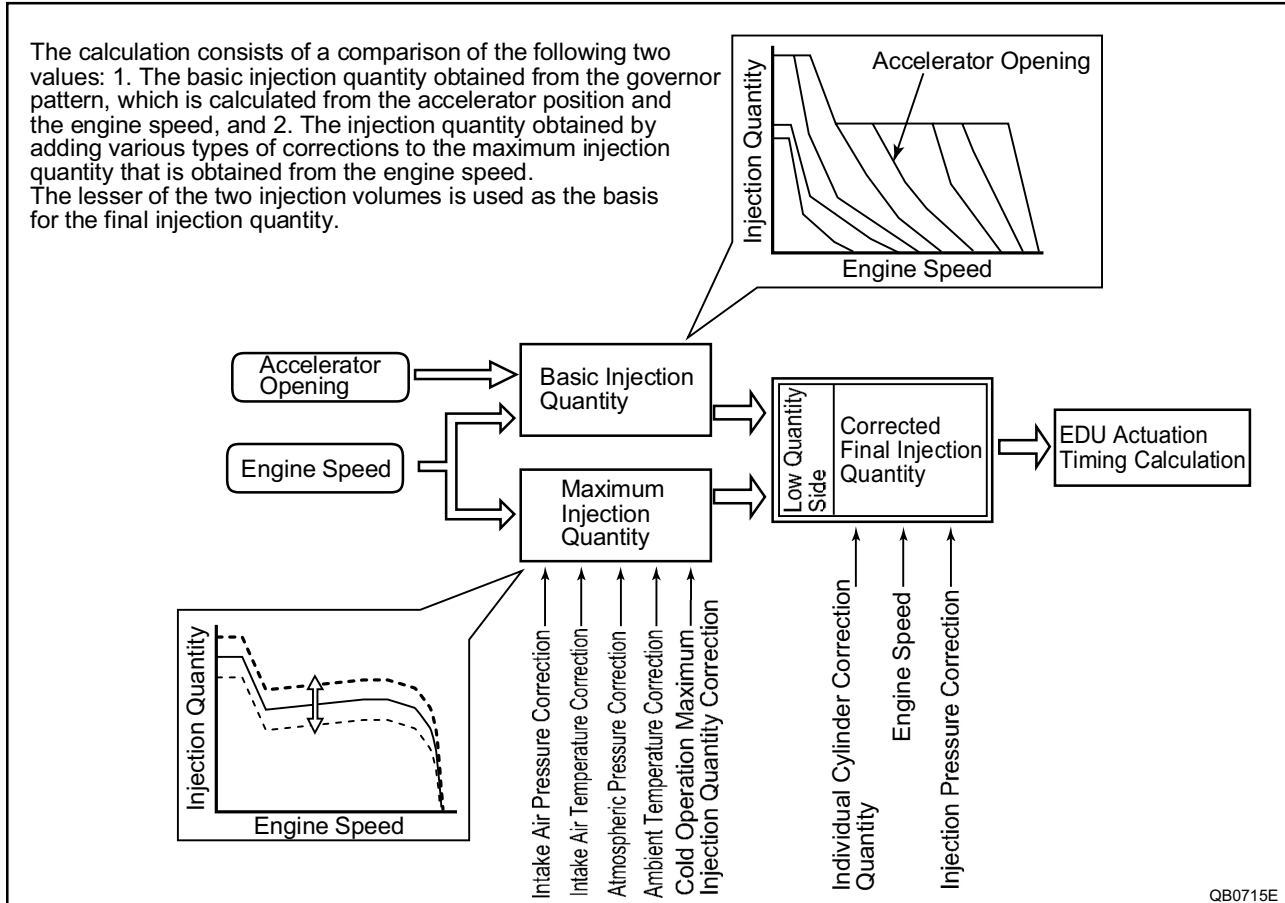
The fuel injection pressure control function (rail pressure control function) controls the discharge volume of the pump by measuring the fuel pressure at the rail pressure sensor and feeding it back to the ECU. It effects pressure feedback control so that the discharge volume matches the optimal (command) value set in accordance with the engine speed and the injection quantity.

## D. Fuel Injection Quantity Control

### a. Outline

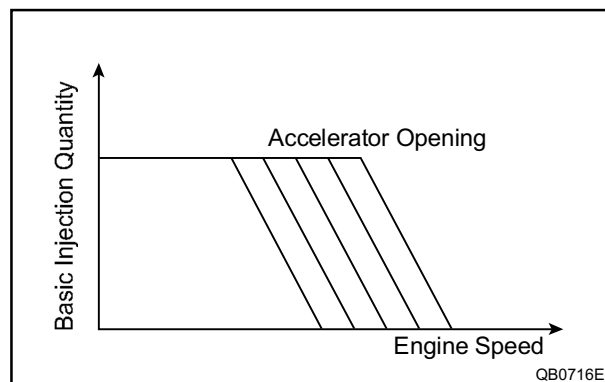
This control determines the fuel injection quantity by adding coolant temperature, fuel temperature, intake air temperature, and intake air pressure corrections to the basic injection quantity calculated by the engine ECU, based on the engine operating conditions and driving conditions.

### b. Injection Quantity Calculation Method



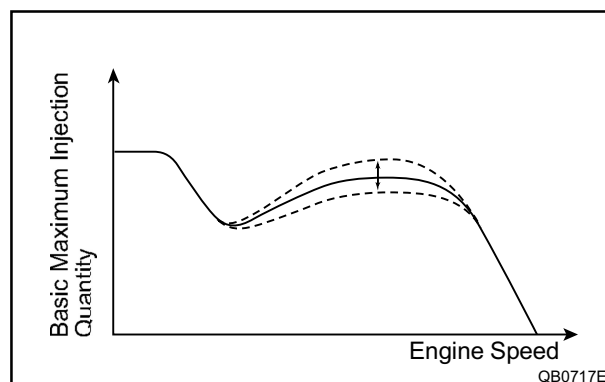
c. Basic Injection Quantity

The basic injection quantity is determined by the engine speed (NE) and the accelerator opening. The injection quantity is increased when the accelerator position signal is increased while the engine speed remains constant.



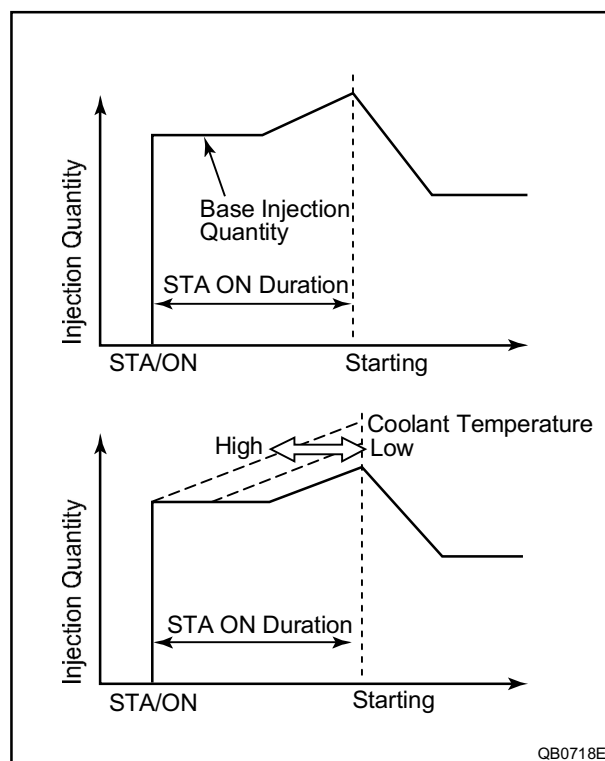
d. Maximum Injection Quantity

The maximum injection quantity is calculated by adding the intake air pressure correction, intake air temperature correction, atmospheric pressure correction, ambient temperature correction, and the cold operation maximum injection quantity correction to the basic maximum injection quantity determined by the engine speed.



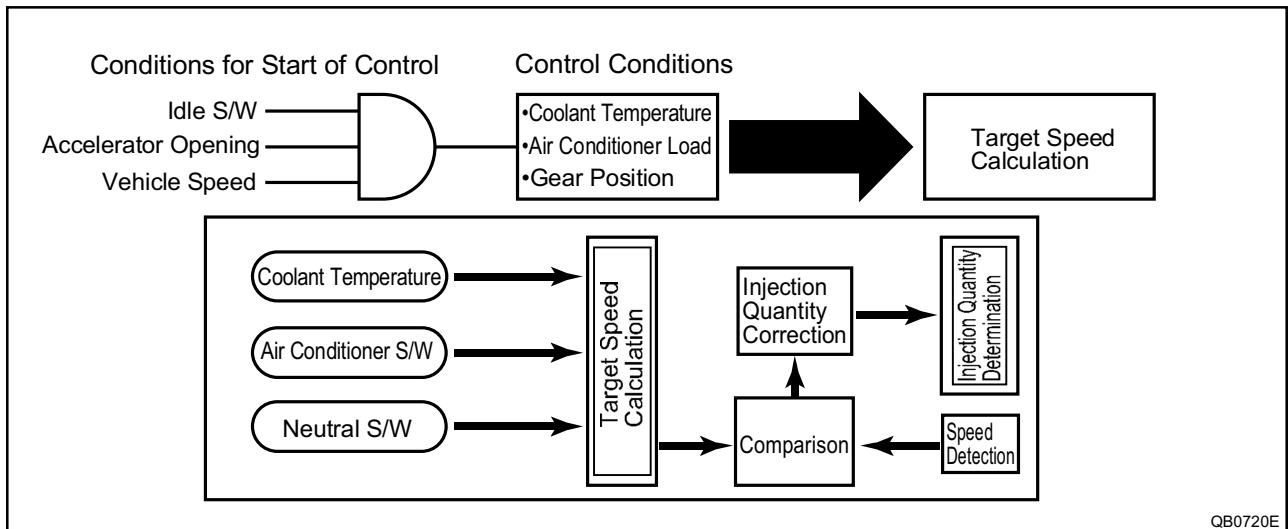
e. Starting Injection Quantity

When the starter switch is turned ON, the injection quantity is calculated in accordance with the starting base injection quantity and the starter ON time. The base injection quantity and the inclination of the quantity increase/decrease change in accordance with the coolant temperature and the engine speed.



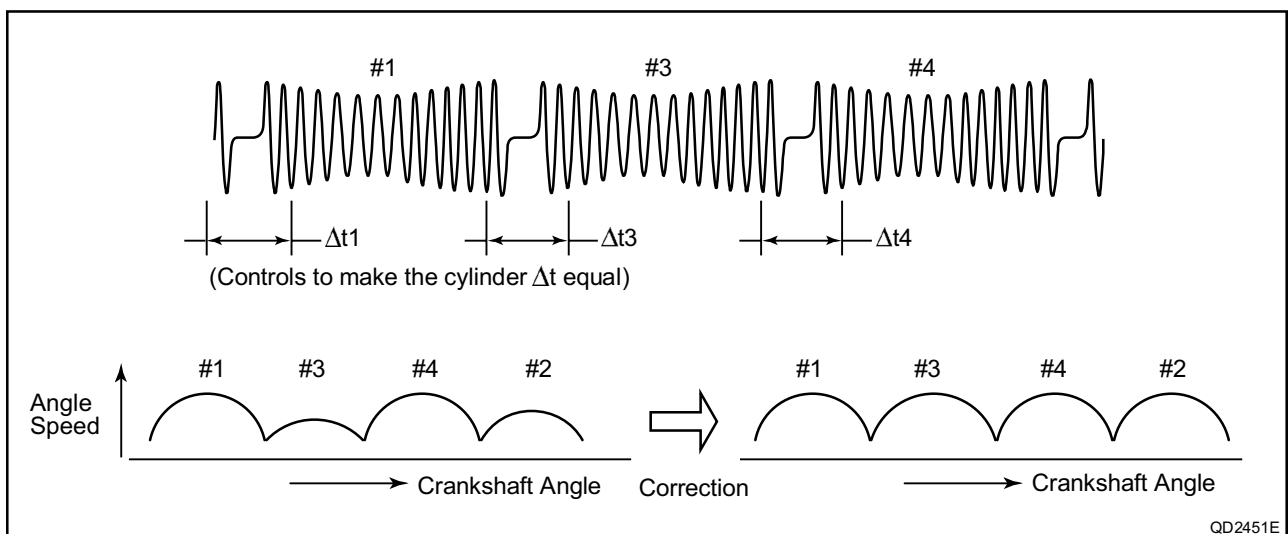
f. Idle Speed Control (ISC) System

This system controls the idle speed by regulating the injection quantity in order to match the actual speed to the target speed calculated by the engine ECU.



g. Idle Vibration Reduction Control

To reduce engine vibrations during idle, this function compares the angle speeds (times) of the cylinders and regulates the injection quantity for the individual cylinders if there is a large difference, in order to achieve a smooth engine operation.



## E. Fuel Injection Timing Control

### a. Outline

Fuel injection timing is controlled by varying the timing in which current is applied to the injectors.

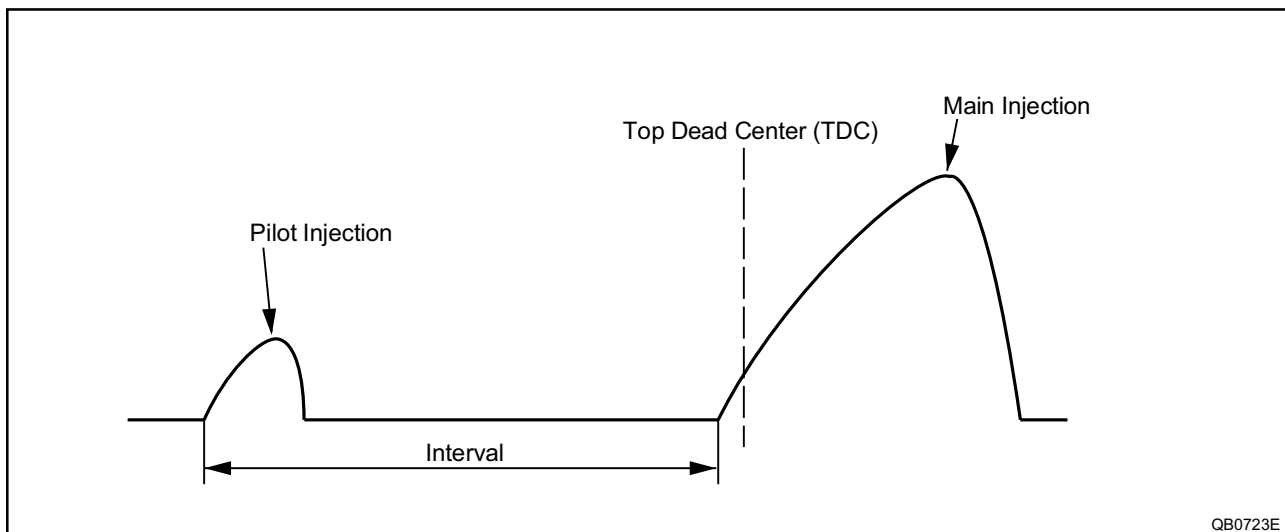
### b. Main and Pilot Injection Timing Control

#### (1) Main Injection Timing

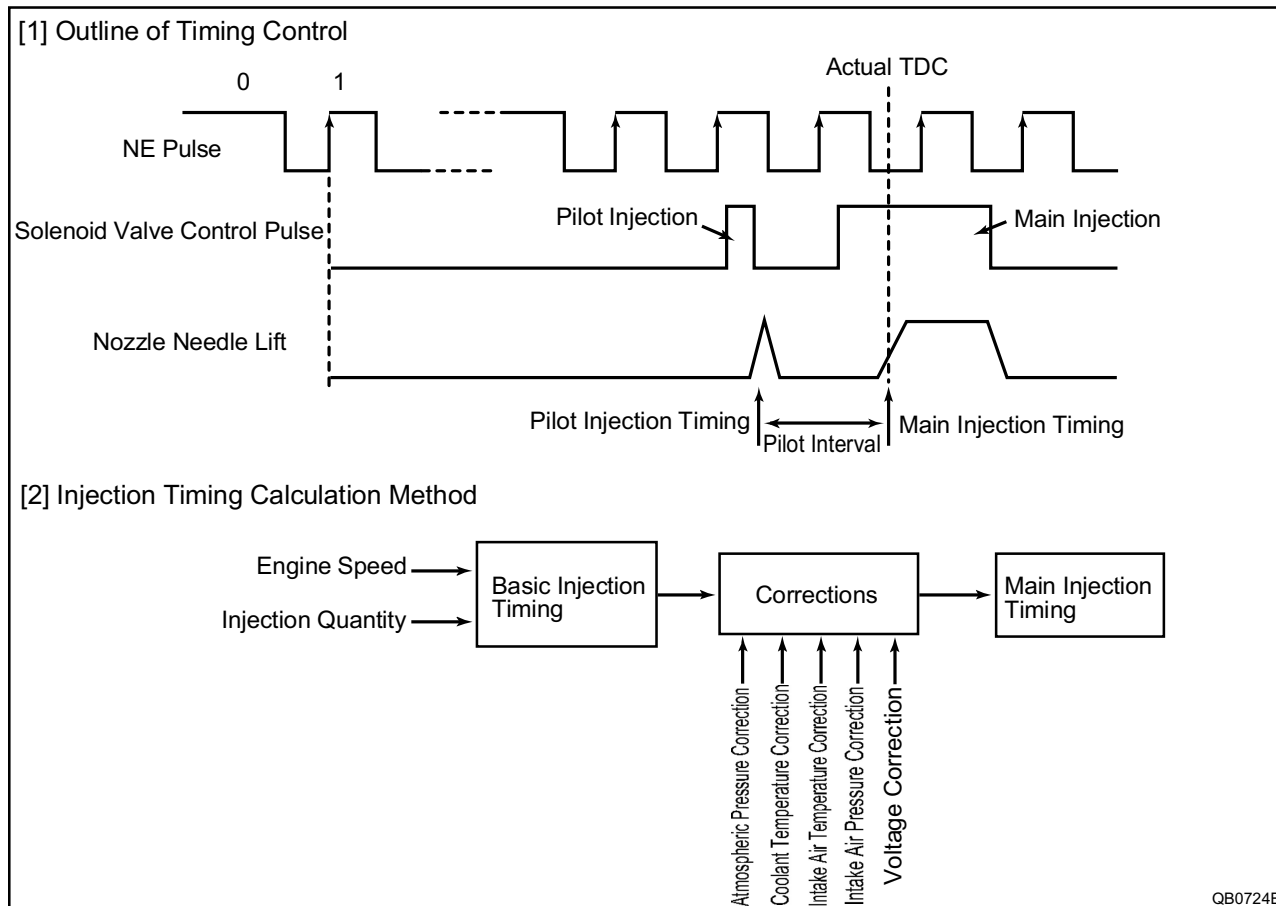
The engine ECU calculates the basic injection timing based on the engine speed and the final injection quantity, and adds various types of corrections in order to determine the optimal main injection timing.

#### (2) Pilot Injection Timing (Pilot Interval)

Pilot injection timing is controlled by adding a pilot interval to the main injection timing. The pilot interval is calculated based on the final injection quantity, engine speed, coolant temperature, ambient temperature, and atmospheric pressure (map correction). The pilot interval at the time the engine is started is calculated from the coolant temperature and engine speed.



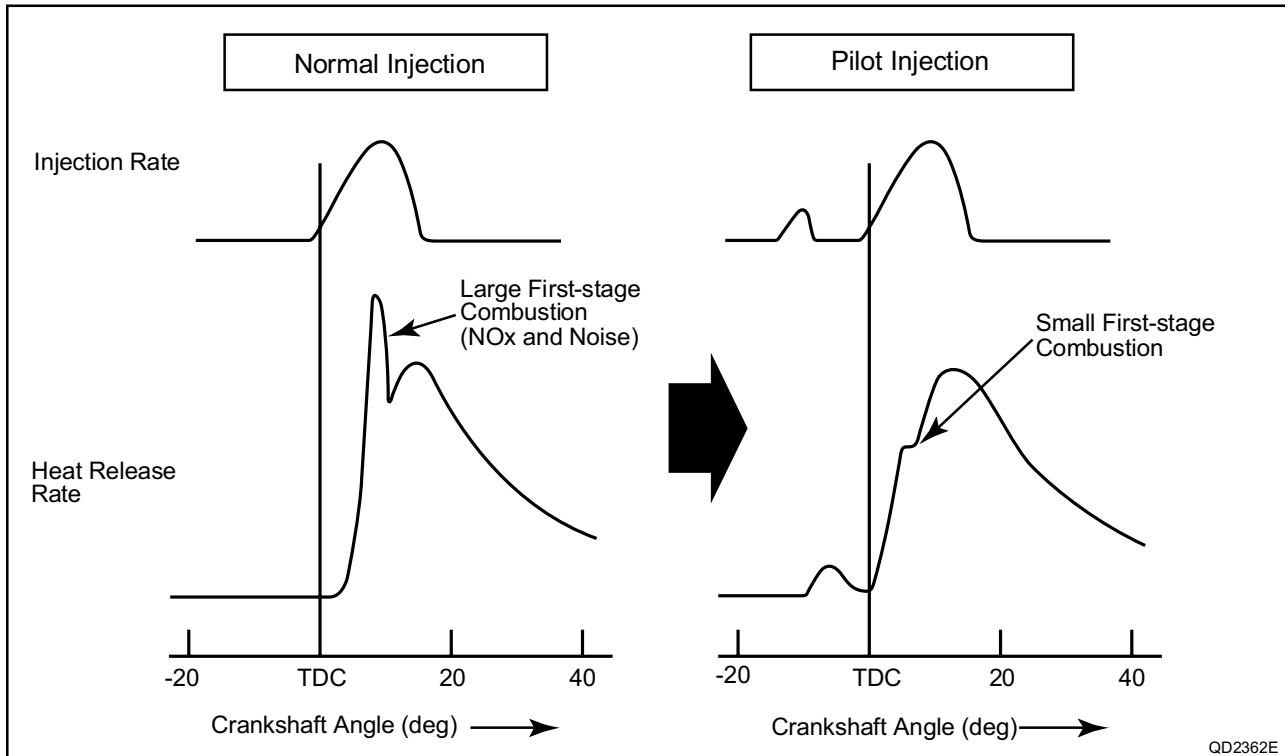
c. Injection Timing Calculation Method



## F. Fuel Injection Rate Control

### a. Outline

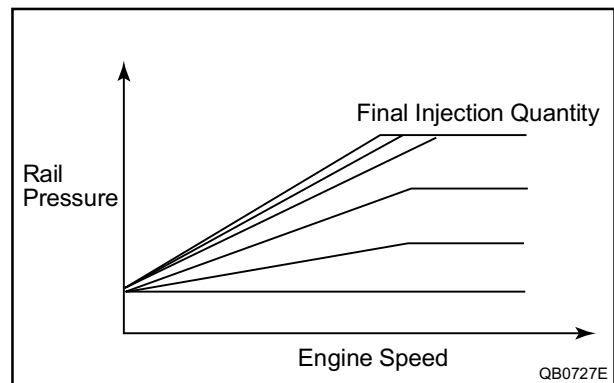
While the injection rate increases with the adoption of high-pressure fuel injection, the ignition lag, which is the delay from the time fuel is injected to the beginning of combustion, cannot be shortened to less than a certain value. As a result, the quantity of fuel that is injected until main ignition occurs increases, resulting in an explosive combustion at the time of main ignition. This increases both NO<sub>x</sub> and noise. For this reason, pilot injection is provided to minimize the initial ignition rate, prevent the explosive first-stage combustion, and reduce noise and NO<sub>x</sub>.



## G. Fuel Injection Pressure Control

### a. Fuel Injection Pressure

The engine ECU determines the fuel injection pressure based on the final injection quantity and the engine speed. The fuel injection pressure at the time the engine is started is calculated from the coolant temperature and engine speed.

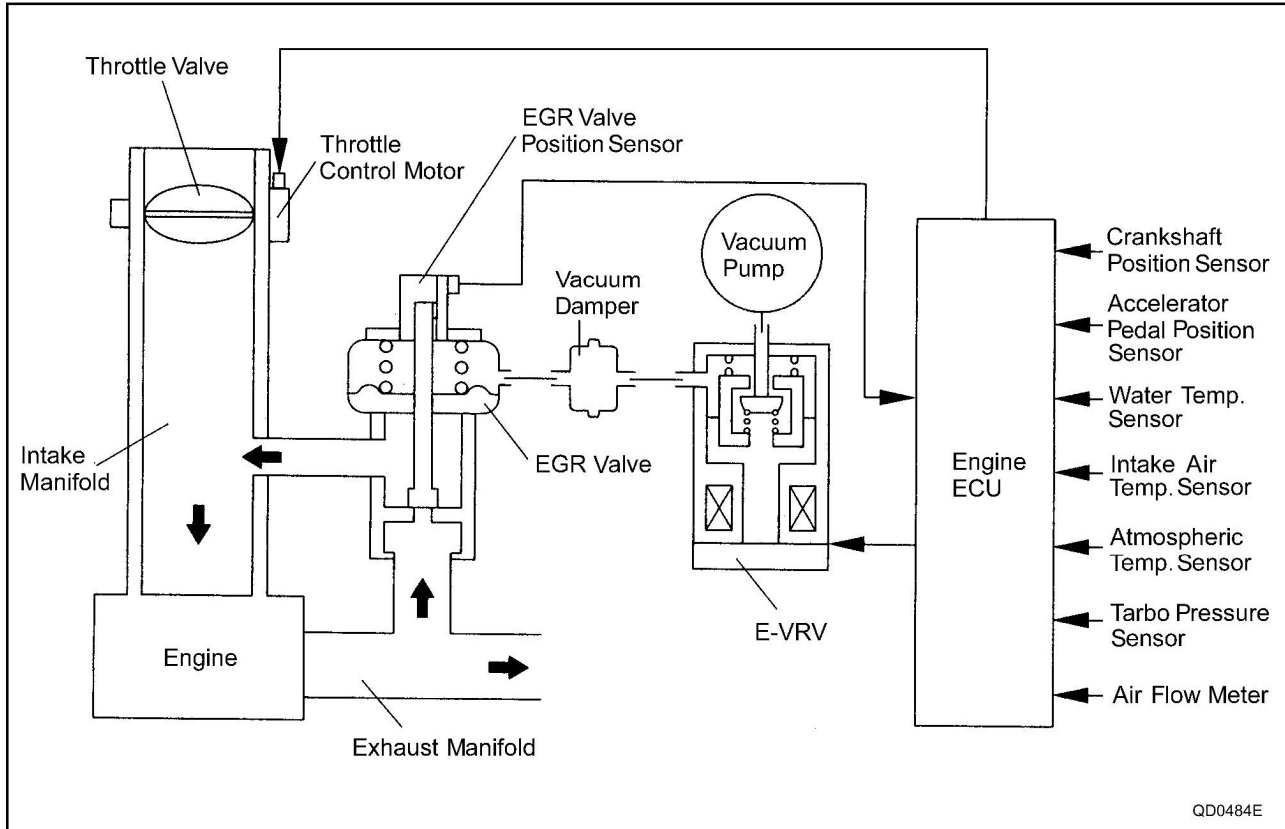


### 3-3. EGR CONTROL SYSTEM

#### A. Outline and Operation

##### a. Outline

By sensing the engine driving conditions and actual amount of EGR valve opening, the engine ECU electrically operates the E-VRV, which controls the magnitude of vacuum introduced into diaphragm of EGR valve and throttle opening position with stepping motor and the amount of recirculating exhaust gas is regulated.



b. Operation Principle of E-VRV

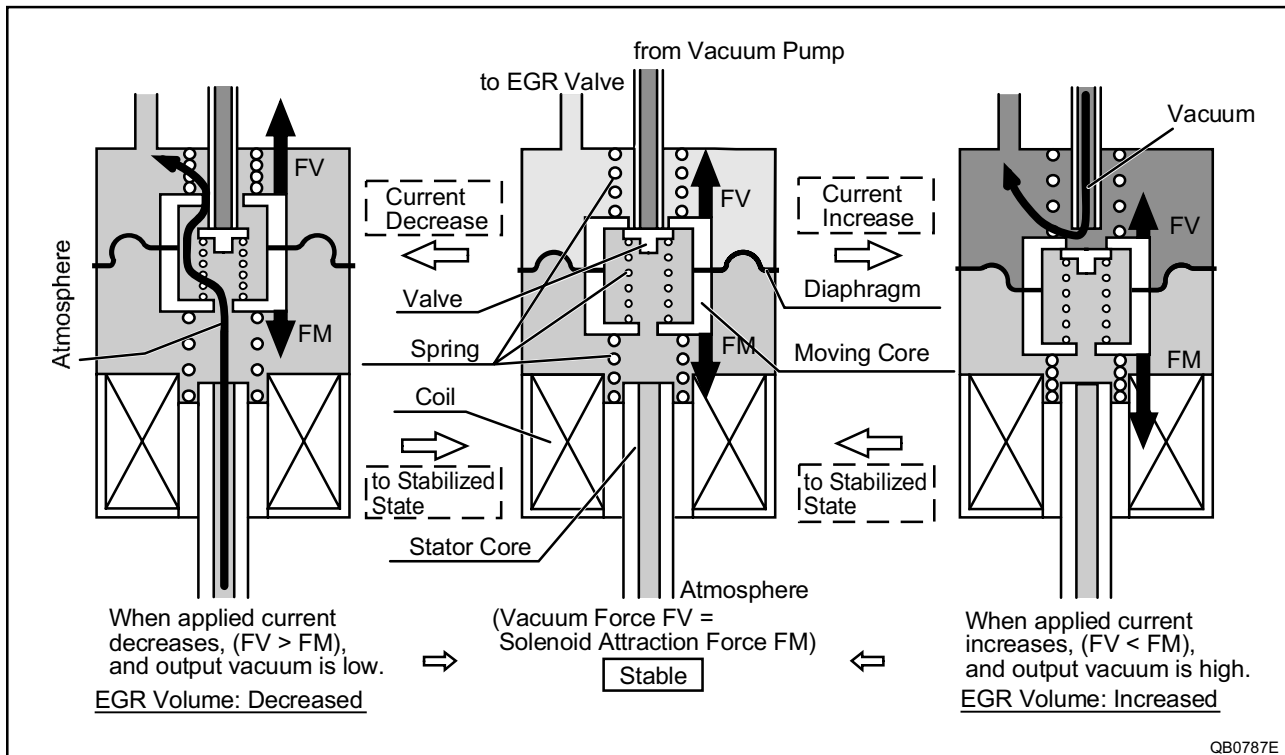
(1) To increase the EGR volume:

In the stable condition shown in the center diagram, when the current\* applied to the coil increases, the attraction force FM of the coil increases. When this force becomes greater than the vacuum force FV that acts on the diaphragm, the moving core moves downward. Because the port that connects the vacuum pump to the upper diaphragm chamber opens in conjunction with the movement of the moving core, the output vacuum becomes higher and the EGR volume increases. Meanwhile, because "increased output vacuum equals increased FV", the moving core moves upward with the increase in FV. When FM and FV are equal, the port closes and the forces stabilize. Because the vacuum circuit of the EGR is a closed loop, it maintains the vacuum in a stabilized state, providing there are no changes in the amperage.

\*1: The engine ECU outputs sawtooth wave signals with a constant frequency. The value of the current is the effective (average) value of these signals.

(2) To decrease the EGR volume:

A decrease in the current that is applied to the coil, causes the FV to become greater than the FM. As a result, the diaphragm moves upward. The moving core also moves upward in conjunction with the movement of the diaphragm, causing the valve that seals the upper and lower diaphragm chambers to open. This causes the atmosphere in the lower chamber to flow into the upper chamber, thus lowering the output vacuum and reducing the EGR volume. Because "decreased output vacuum equals decreased FV", the moving core moves downward with the decrease in FV. When FM and FV are equal, the port closes and the forces stabilize.



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### 3-4. DIESEL THROTTLE (ELECTRONICALLY CONTROLLED INTAKE AIR THROTTLE MECHANISM)

#### A. Outline and Operation

##### a. Outline

An electronically controlled intake air throttle valve mechanism has been adopted. Located in the intake manifold upstream of the EGR valve, this mechanism optimally controls the intake air throttle valve angle to control the flow of the EGR gas, and reduce noise and exhaust gas emissions. The diesel throttle Assy is made by another manufacturer.

##### b. Construction and Operation

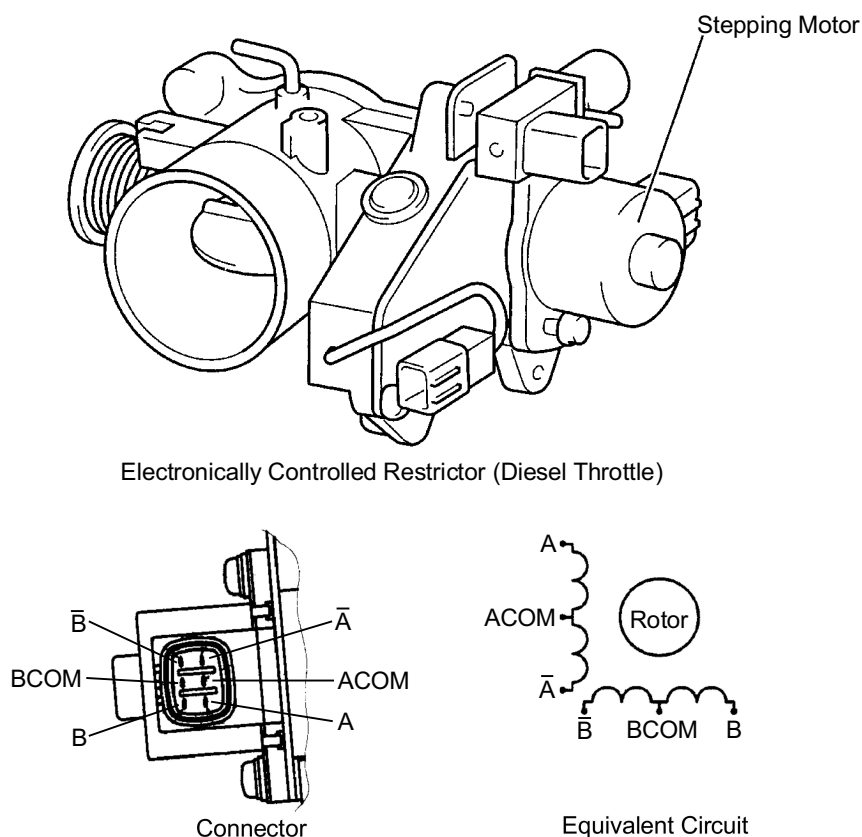
The signals from the engine ECU actuate the stepping motor, which regulates the opening of the intake air throttle valve.

#### A) EGR Control

To further increase the EGR volume when the EGR valve is fully open, the intake air throttle valve opening is reduced and the vacuum in the intake manifold is increased by restricting the flow of intake air.

#### B) Noise and Exhaust Gas Reduction

- When the engine is being started, the intake air throttle valve is opened fully to reduce the emission of white and black smoke.
- When the engine is being stopped, the intake air throttle valve is closed fully to reduce vibrations and noise.
- During normal driving, the opening is regulated in accordance with the operating conditions of the engine, the coolant temperature, and the atmospheric pressure.



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### 3-5. FUEL FILTER WARNING

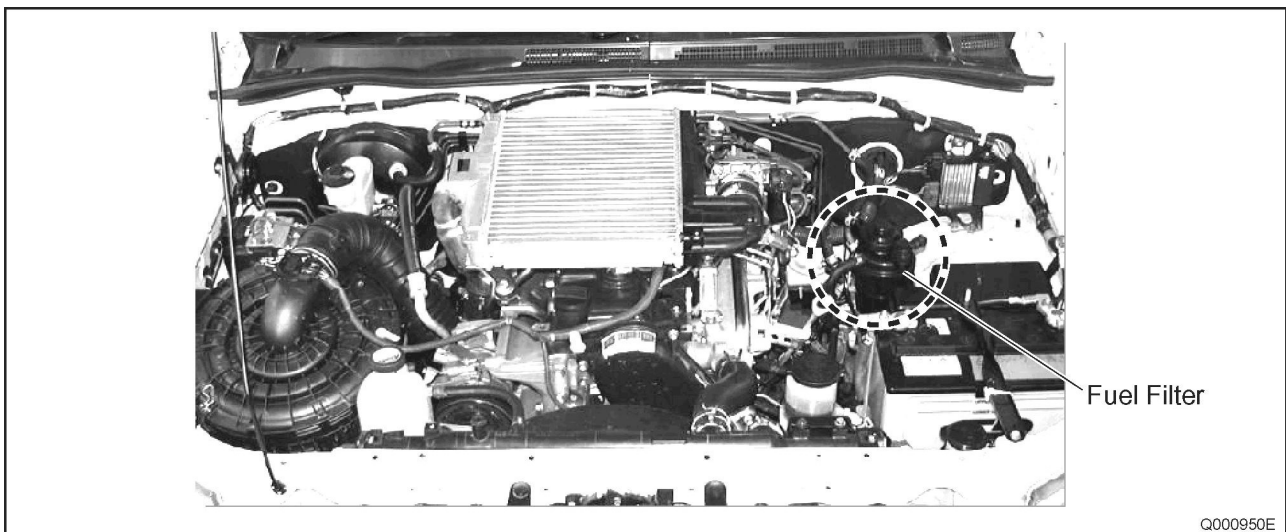
- A fuel filter warning light has been added to notify the driver when fuel filter clogging is detected. Although it does not form part of the common rail system, it is included for reference as a related fuel system function.

#### A. Role of the Fuel Filter in the Common Rail System

The role of the fuel filter is to remove foreign material and moisture from the fuel. In particular, the common rail system requires constantly high fuel quality as demonstrated in the following point, and the filter thus plays an extremely important role.

- Fuel lubricates the entire supply pump.
- The extremely high discharge pressure (maximum 160MPa) of the supply pump means that foreign material adhesion may result in sliding part and valve malfunction.

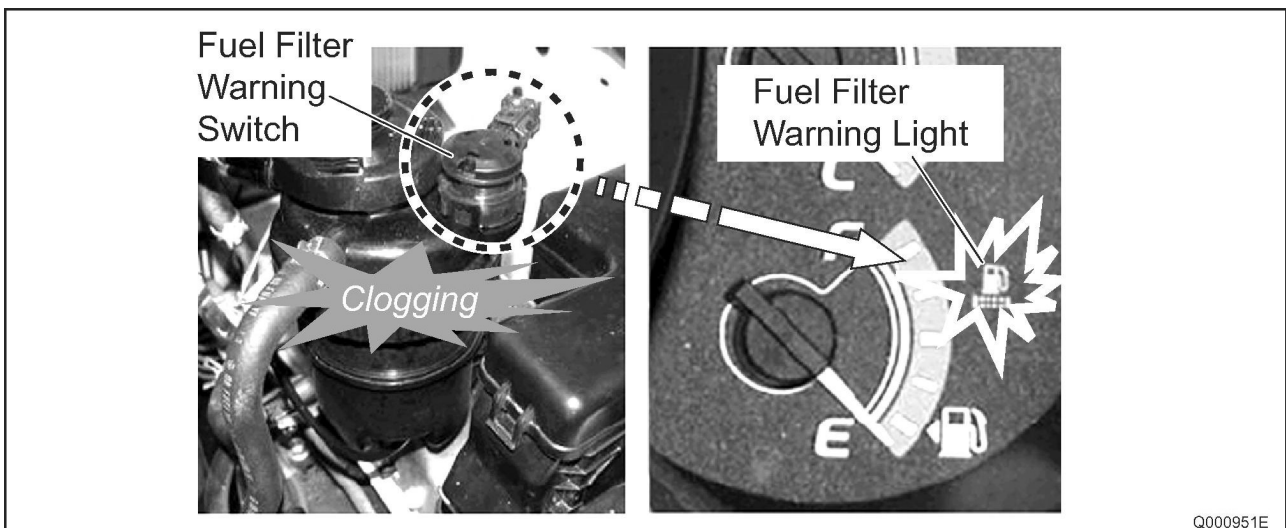
#### B. Installation Position



#### C. System Operation

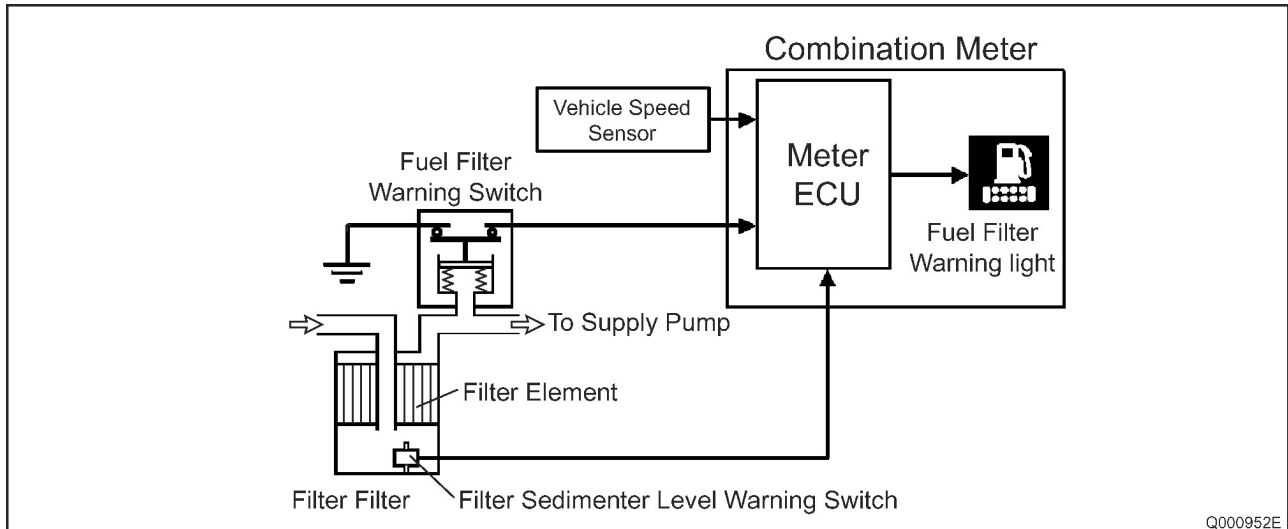
##### a. General Description

When the fuel filter clogs, the detection switch installed on the fuel filter operates to turn ON the fuel filter warning light on the instrument cluster.



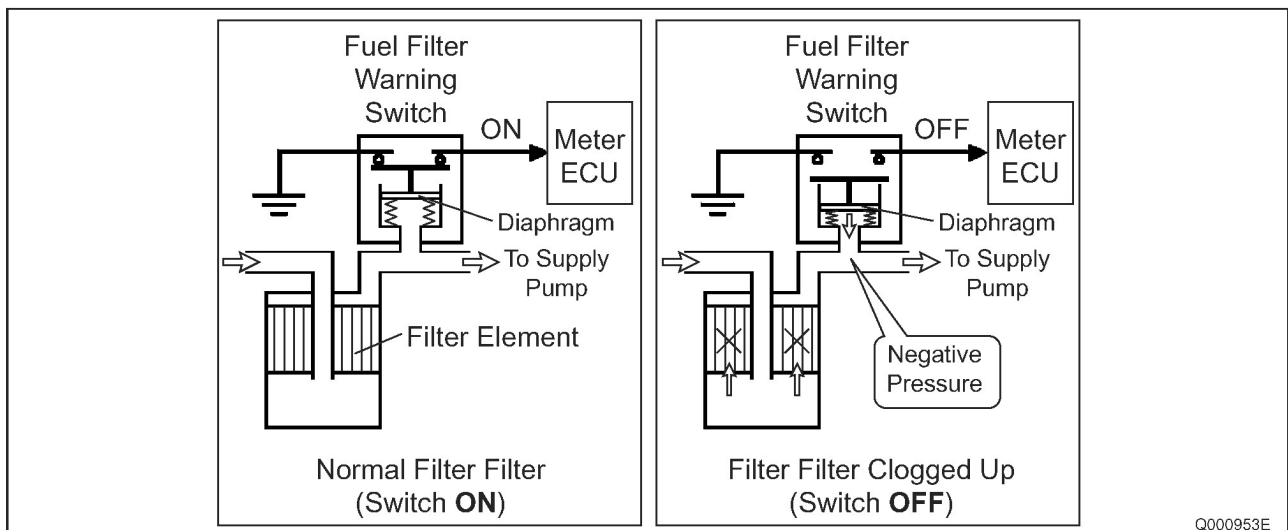
b. Complete Circuit

As shown below, signals from the two sensors installed on the filter (fuel filter warning switch and fuel sedimenter level warning switch) are input to the meter ECU, and the meter ECU actuates the fuel filter warning light.



c. Fuel Filter Clogging Warning Operation

- Normal operation (refer to the left side of the diagram below): The fuel filter warning switch contact is closed, and an ON signal is sent to the meter ECU.
- Abnormal operation (refer to the right side of the diagram below): The fuel filter warning switch contact is open, and an OFF signal is sent to the meter ECU.



d. Fuel Filter Warning Light Operation

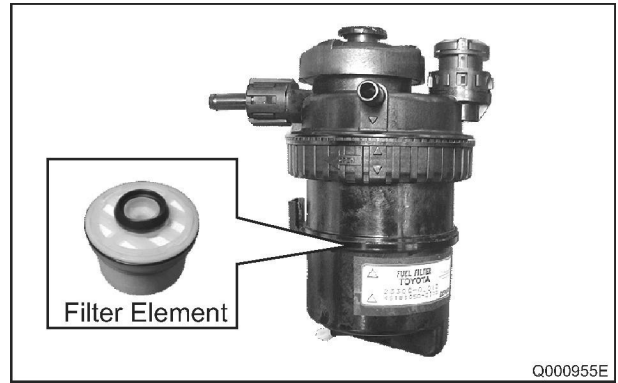
The light blinks in accordance with the sedimenter level warning switch, and turns ON in accordance with the fuel filter warning switch signal.

| Warning             | Warning Method |
|---------------------|----------------|
| Sedimenter Warning  | Blink          |
| Fuel Filter Warning | ON             |

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#### D. Fuel Filter Replacement (Reference)

- Replace the filter element when the filter is clogged. The shape of the filter element is shown in the diagram on the right.



- Loosen the case as shown in the diagram on the right, and replace the filter element. Filter elements are supplied via the TOYOTA route.

