2-7. FUEL SYSTEM

2-7-1. GENERAL DESCRIPTION OF FUEL SYSTEM

What makes the diesel engine fuel system different from the EFI is that it does not have a fuel pump, but is fitted with an ECD pump which is gear-driven directly by the engine to introduce the fuel.

The ECD pump contains a fuel pressure-feed mechanism to finally inject the fuel through the nozzle.

Schematic Drawing of Fuel System

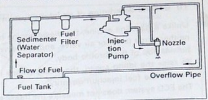


Fig. 2-7 Schematic Drawing of Fuel System

2-7-2. ECD PUMP

(1) ECD pump components

- For fuel injection quantity control
  - Solenoid spill valve
  - Engine speed sensor
  - Fuel temperature sensor
  - θ resistor
  - τ resistor
- For fuel injection timing
  - Timing control valve
  - Engine speed sensor
  - τ resistor

(2) Appearance

096500-0130

- **Equipped with a Fuel Temperature Sensor**

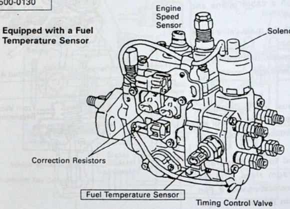


Fig. 2-8 Appearance of ECD-V3 Pump

2-7-3. FUEL PRESSURE-FEED AND INJECTION

The solenoid spill valve is located in the middle of the passage connecting the pump chamber and the plunger pressure chamber.
The valve is a normal open type by the operation of the spool spring (return spring) in the solenoid spill valve, and closes when its coil is energized.

(1) Suction

When the plunger moves down, the fuel enters the pressure chamber.

- Suction port.................. Open
- Distribution port........... Closed
- Solenoid spill valve ..... Closed (energized)

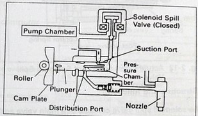


Fig. 2-9 Suction

(2) Injection

Turning and rising, the plunger compresses and feeds the fuel.

- Suction port.................. Closed
- Distribution port........... Open
- Solenoid spill valve ..... Closed (energized)

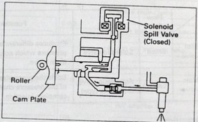


Fig. 2-10 Injection

(3) End of injection

As soon as the solenoid spill valve is deenergized, it opens. The pressurized fuel remaining in the plunger chamber is compressed back to the pump chamber, completing the pressure-feed cycle.

- Suction port.................. Closed
- Distribution port........... Open
- Solenoid spill valve ..... Open (deenergized)

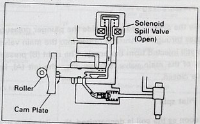


Fig. 2-11 End of Injection

2-7-4. SOLENOID SPILL VALVE (SPV)

A pilot type solenoid valve is used to ensure high pressure resistance, high response and a large spill (discharge) quantity.

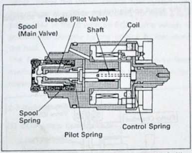


Fig. 2-12 Actual Cross-section of Solenoid Spill Valve

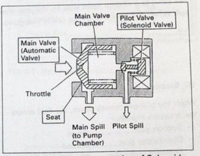


Fig. 2-13 Schematic Cross-section of Solenoid Spill Valve

⟨⟨Structure and function⟩⟩

The solenoid spill valve consists of a main valve and a pilot valve, and each has the function described below:

	Flow Rate	Type	Function
Pilot valve	Small	Solenoid valve	Produces differential hydraulic pressure which actuates the main valve.
Main valve	Large	Automatic valve (hydraulic type)	Spills the pressurized fuel out of the pressure chamber to complete injection.

⟨⟨Actuation⟩⟩

(1) Pressure-feed

While the pressurized fuel inside the plunger pressure chamber passes through the throttle orifice into the main valve chamber, it is still injected from the nozzle. The right (B) pressure bearing area of the main valve is larger than the left (A), keeping the valve closed.

(2) Pilot spill

As soon as the coil is deenergized, the pilot valve opens, and a small quantity of fuel in the main valve chamber flows out

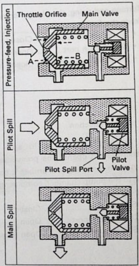


Fig. 2-14

through the pilot spill port. This reduces the internal hydraulic pressure of the main valve chamber.

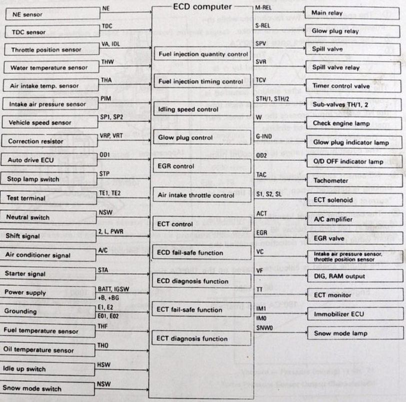
(3) Main spill

Differential hydraulic pressure lifts the main valve to spill a large quantity of fuel through the seat. The inside pressure of the plunger pressure chamber decreases, and the injection cycle is completed.

2-8. CONTROL SYSTEM

(1) General description of control system

The ECD computer detects the vehicle running conditions from signals issued by the sensors, and controls the fuel injection quantity, etc. accordingly.



(2) NE sensor (engine speed sensor) output signal

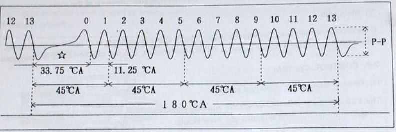
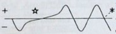


Fig. 2-15 NE Sensor Output Signal

① The engine makes two revolutions while the injection pump completes one stroke.

② The engine revolves once at 360°CA.

③ 

The part indicated by ☆ is called sinking.

The NE sensor input after sinking occurred is counted as "1". The count increases each time the NE sensor input crosses the zero level. Part marked with ☆ is called sinking.

④ The detected sinking is counted as "0".

⑤ The count number range is $0 \leq$ count number ≤ 14.

⑥ NE sensor signal interval time: t
Sinking is detected when "previous time t" $\leq$ "current time x 0.4375".

⑦ The computer cannot identify P-P when the voltage at 100 rpm is below 45 mV. This minimum value required for detection is called the threshold voltage.

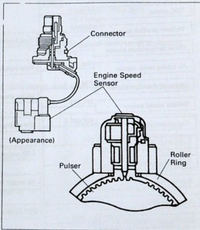


Fig. 2-16 NE Sensor

⑧ The engine speed is calculated based on the 180°CA time.

$$\text{Engine speed} = \frac{60 \times 1000}{180°\text{CA time (ms)} \times 2}$$

<Example> $$\frac{60 \times 1000}{30 \times 2} = 1000 \text{ rpm}$$

(3) Water temperature, intake air temperature and fuel temperature sensors

The water temperature sensor detects the cooling water temperature, and is installed on the cylinder block.
The sensor converts the resistance value, which changes according to the temperature, into a voltage.
The intake air temperature sensor is equipped with an air cleaner and the fuel temperature sensor is installed on the side of the pump. These operate in the same manner as the water temperature sensor.

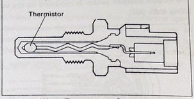
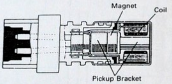


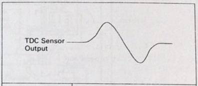
Fig. 2-17 Water Temperature Sensor

(4) Crankshaft position sensor (TDC sensor) output signal



One pulse signal is generated per engine revolution.

Fig. 2-18 Crankshaft Position Sensor

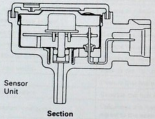


Condition	Threshold Voltage
400 rpm	125 ± 50 mV
6000 rpm	650 ± 250 mV

Fig. 2-19

(5) Turbo pressure sensor

This solid state type pressure sensor uses crystal's (silicone's) property that allows the resistance to vary under pressure. It converts the intake air pressure (absolute pressure) into an electric signal, then amplifies it into a voltage signal to the computer.



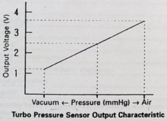


Fig. 2-20 Turbo Pressure Sensor

(6) Throttle position sensor

The throttle position sensor is mounted on the venturi, and detects both accelerator opening (VA) and idling state (Idℓ).

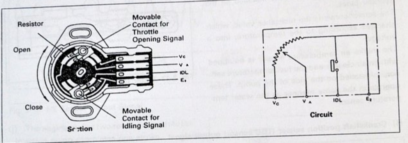


Fig. 2-21 Throttle Position Sensor

3. FUEL INJECTION QUANTITY CONTROL

Correcting the basic fuel injection quantity calculated based on the engine condition (accelerator opening, engine speed, etc.) in response to the water temperature, the fuel temperature, the intake air temperature and pressure, etc., the engine control computer transmits the optimum output signal for the engine condition to the solenoid spill valve of the ECD pump to control the following factors:

(1) Optimum fuel injection quantity based on accelerator opening and engine speed
(2) Fuel quantity increase at cold starting
(3) Slow increase of fuel quantity at acceleration and deceleration
(4) Fuel quantity increase at supercharging
(5) Fuel quantity reduction at higher altitudes.

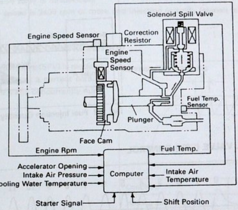


Fig. 3-1 Fuel Injection Quantity Control System

Device Name	Function
Turbo pressure sensor	Detects the air intake pipe pressure.
Throttle position sensor	Detects the accelerator opening.
Engine speed sensor	Detects the engine speed.
Water temperature sensor	Detects the cooling water temperature.
Intake air temperature sensor	Detects the intake air temperature.
Speed sensor	Detects the vehicle speed.
Air conditioner amplifier (A/C signal)	Detects the operating state of the air conditioner.
Neutral start switch	Detects the "N" and "P" positions of the transmission shift lever.
Starter	Detects that the engine is running (cranking).
Solenoid spill valve	Controls the fuel injection quantity.
Engine control computer	Calculates the fuel injection quantity based on signals from the sensors, and sends a signal to the solenoid spill valve.
Fuel Temp. Sensor	Detect fuel temperature.

3-1. GENERAL DESCRIPTION OF FUEL INJECTION QUANTITY CONTROL

The cam position of the cam plate determines the fuel injection start timing.
Fuel injection stops after the solenoid spill valve is deenergized (opens) and the pressurized fuel spills out (is released) into the pump chamber. Consequently, the computer controls the fuel injection quantity by adjusting the fuel injection end timing.

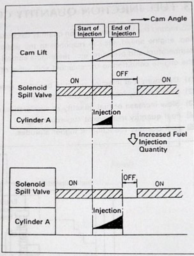


Fig. 3-2 Fuel Injection Quantity Control

3-2. SOLENOID SPILL VALVE (SPV) CONTROL

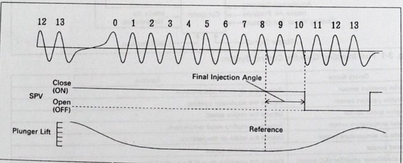


Fig. 3-3 Solenoid Spill Valve Control

3-2-1. SOLENOID SPILL VALVE "CLOSE" CONTROL

(1) As soon as the count number reaches 13 after sinking has been detected, the solenoid spill valve is energized (closes).

(2) The solenoid spill valve is designed to close at a starting engine speed of 150 rpm or less.

3-2-2. SOLENOID SPILL VALVE "OPEN" CONTROL

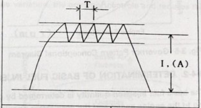
(1) The solenoid spill valve is deenergized (opens) after the final injection angle has been calculated based on NE signal No. "0".

(2) Solenoid spill valve "OFF" control
① When the engine speed is 4825 rpm or over (maximum injection angle cut).
② When the spill valve relay is deactivated.
③ When the engine speed is 2400 rpm or more and injection quantity (signal) is less than a certain level.

3-3. SOLENOID SPILL VALVE DRIVING METHOD

Because the solenoid spill valve (SPV) is required to provide a quick response, a current control system is used to drive it and concurrently minimize response lag.

Current Characteristic



Condition	+B = 14V
Holding current (I)	2.1 ± 0.05 A
Frequency (reference) (T)	I/T = 10 ~ 30 KHz

Fig. 3-4 Solenoid Spill Valve Driving Method

3-4. BASIC CALCULATION OF FUEL INJECTION QUANTITY CONTROL

The fuel injection quantity is determined based on two values: the "basic fuel injection quantity" which is obtained by correcting the value calculated from the engine speed and the accelerator opening according to signals from the sensors; and the "maximum fuel injection quantity" which limits the fuel injection quantity to the intake air quantity.

3-4-1. DETERMINATION OF FINAL FUEL INJECTION QUANTITY

(Other than starting)

Final fuel injection quantity = MIN (Basic fuel injection quantity or maximum fuel injection quantity) at 17.25°CA or over

(Note: MIN means that minimum value is selected for final fuel injection quantity.)

(At starting, NE < 900 rpm)

Final fuel injection quantity = MIN (Starting fuel quantity, basic fuel quantity or maximum fuel quantity) at 17.25°CA or over

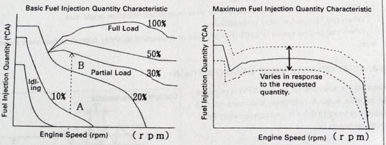


Fig. 3-5 Governor Pattern Conceptional Diagram

3-4-2. DETERMINATION OF BASIC FUEL INJECTION QUANTITY

The basic fuel injection quantity is determined by comparing the "governor pattern" selected according to the engine speed and the accelerator opening, and the "constant fuel injection quantity" calculated based on the engine condition.

Basic fuel injection quantity = MIN (governor pattern or slow increase of fuel injection quantity)

(1) Fuel injection quantity in starting range

This quantity is to improve cold starting performance, and is controlled by determining the pseudo-accelerator opening based on the engine cooling water temperature.

① When water temperature is below 10°C: Pseudo-accelerator opening applied.

② When water temperature is 10°C or higher: The accelerator opening depends on the starter ON time.

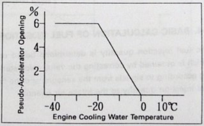


Fig. 3-6 Fuel Injection Quantity in Starting Range

(2) Slow increase of fuel injection quantity at acceleration

For example, if the accelerator opening changes from A to B during acceleration as shown in Fig. 3-7, the basic fuel injection quantity abruptly increases.
To prevent torque variation, the governor controls and raises the quantity gradually.
However, this does not take place under the following conditions:

① Vehicle speed: 5 km/h or less
② Starter ON
③ Idle switch ON
④ Accelerator released
⑤ Others

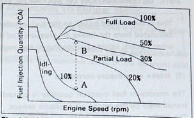


Fig. 3-7 Slow Increase of Fuel Injection Quantity at Acceleration

(3) Slow decrease of fuel injection quantity at deceleration

For example, if the accelerator opening changes from B to A during deceleration, the basic fuel injection quantity suddenly decreases. To prevent torque variation, the governor controls and reduces the quantity gradually.

3-5. MAXIMUM FUEL INJECTION QUANTITY

The maximum fuel injection quantity is determined in response to the intake air into the engine calculated based on the engine speed, the intake air pressure and temperature, etc.

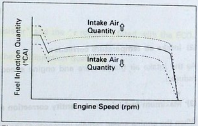


Fig. 3-8 Maximum Fuel Injection Quantity Governor Pattern

3-5-1. DETERMINATION OF MAXIMUM FUEL INJECTION QUANTITY

This is determined based on the fuel injection quantity reflecting the "sum of correction values" calculated from the intake air pressure and temperature, the fuel temperature, etc. and the governor pattern selected according to the engine speed.

(1) Intake air pressure correction

The maximum fuel injection quantity is corrected by calculating the intake air quantity from a signal transmitted by the intake air pressure sensor.
The intake air correction factor is reduced in the following cases.
① When EGR system is turned OFF from ON.
② When IDL contact is turned OFF (open) from ON (closed).

① when the EGR is turned off; or
② when the IDL is turned off.

Correction factor when the fail-safe function is operating
If the crankshaft angle sensor or intake air pressure sensor is malfunctioning, the certain value of correction factor is selected.

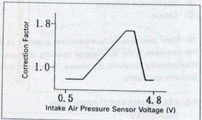


Fig. 3-9

(2) Intake air temperature correction

As the intake air temperature and engine speed increases, the maximum fuel injection quantity is reduced.

(3) Maximum fuel injection quantity correction at acceleration

When the engine speed rapidly increases at the engine speed between 1000 and 2000 rpm, the maximum fuel injection quantity decreases.

(4) Corrected fuel injection quantity at deceleration

When the engine speed rapidly decreases at the speed between 1300 rpm and 500 rpm, the fuel injection quantity is increased.

(5) Fuel injection quantity correction according to fuel temperature

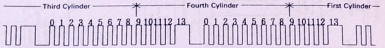
The lower the engine speed is, and the higher the fuel temperature is, the larger the fuel injection quantity will be.

3-6. FUEL INJECTION QUANTITY CORRECTION ACCORDING TO ENGINE SPEED

Fuel injection quantity variation, which occurs depending on the engine speed even if the same injection angle is maintained, is corrected.
The fuel injection quantity variation occurs because as engine speed increases inside pressure of the injection pump, the fuel injection quantity also increases by the response delay of the solenoid spill valve.

3-7. IDLING VIBRATION REDUCTION

To reduce engine vibration during idling, the time is compared between the cylinders, and the fuel injection quantity in each cylinder is adjusted (increased or reduced) when the time difference is large.



3-8. ECT CONTROL (VEHICLES WITH AN AUTOMATIC TRANSMISSION)

The fuel injection quantity is decreased during ECT shifting.
This control does not take place when the NE sensor or throttle position sensor is faulty.

3-9. FUEL INJECTION QUANTITY CORRECTION

The fuel injection quantity is corrected by the "θ resistor" and the "τ resistor" fitted with the ECD pump.
The higher the resistance of the resistor, the larger the fuel injection quantity.

4-2. FUEL INJECTION TIMING CONTROL

The timing control valve (TCV) control signal (duty ratio) is changed until the actual crankshaft angle calculated from a TDC signal issued by the crank position sensor matches the target crank angle computed based on input signals from the engine speed sensor, etc.

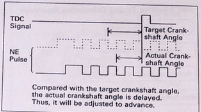


Fig. 4-4 Fuel Injection Timing Control

⟨⟨**Reference: What is the duty ratio?**⟩⟩
The ratio of the TCV ON time (t) to the unit time (T)

$$\text{Duty ratio} = \frac{t}{T} \times 100$$

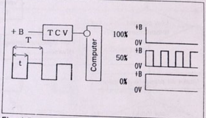


Fig. 4-5

4-3. TIMING CONTROL VALVE

Once current flows through the coil, the stator core becomes an electromagnet which in turn compresses the spring and attracts the moving core to open the fuel passage connecting the high-pressure and low-pressure chambers.
The larger the TCV control duty ratio is, the wider the passage opens. Consequently, the timer piston moves right, delaying the fuel injection timing.

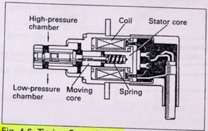


Fig. 4-6 Timing Control Valve

4-4. CRANKSHAFT POSITION SENSOR

When the crankshaft projection passes on the crankshaft position sensor during engine revolution, the magnetic field varies, generating a signal on the sensor. The signal is created once per engine revolution, and sent to the computer as TDC signal.

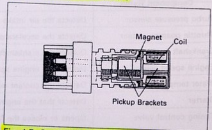


Fig. 4-7 Crankshaft Position Sensor

4-5. FUEL INJECTION TIMING CORRECTION

The "τ resistor" equipped with the ECD pump corrects the fuel injection timing. The higher the resistance of the resistor, the more the fuel injection timing advances.

4-6. TARGET CRANKSHAFT ANGLE CALCULATION

(1) Other than starting

Target crankshaft angle = Basic target crankshaft angle + Intake air pressure correction advance + Cold acceleration advance

(2) During feedback at starting (starter ON and 400 rpm or over)

Target crankshaft angle = Target crankshaft angle at starting

4-6-1. BASIC TARGET CRANKSHAFT ANGLE

As shown in Fig. 4-7, the fuel injection timing is calculated based on the engine speed and the accelerator opening.

With the engine speed constant, the fuel injection timing advances as the accelerator opening (engine load) increases.

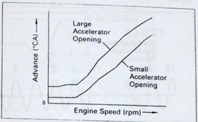


Fig. 4-8 Basic Target Crankshaft Angle

4-6-2. INTAKE AIR PRESSURE CORRECTION ADVANCE

The intake air pressure correction advance is calculated from the intake air pressure (signal from the intake air pressure sensor) and the engine speed.

(1) Maximum correction advance = 6°CA

(2) When the engine speed is 3200 rpm or higher = 0°CA

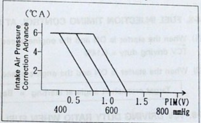


Fig. 4-9 Intake Air Pressure Correction Advance

4-6-3. COLD CORRECTION ADVANCE

The correction advance is calculated from the cooling water temperature and the engine speed.

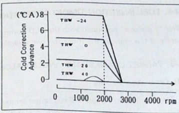
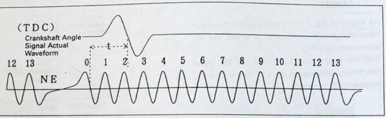


Fig. 4-10 Cold Correction Advance

4-7. HOW TO CALCULATE THE ACTUAL CRANKSHAFT ANGLE

The actual crankshaft angle can be calculated from the time t between NE pulse No. 0 and the TDC signal.



4-8. FUEL INJECTION TIMING CONTROL AT STARTING

(1) When the starter is ON and the engine speed is below 115 rpm
TCV driving duty = 6.14%

(2) When the starter is ON and the engine speed is 115 rpm or higher

Target crankshaft angle at starting = Basic crankshaft angle at starting

4-9. TCV DRIVING DUTY RATIO WHEN FUEL INJECTION TIMING CONTROL IS DISCONTINUED

Under the following conditions, the TCV driving duty ratio is fixed:

(1) At starting 6.14%
(2) When the crankshaft angle sensor is faulty 19.5%
(3) When the engine stalls, NE = 0 rpm or the ignition switch is in the OFF position 6.14%

4-10. TIMING CONTROL VALVE (TCV) DRIVING METHOD

4-10-1. SPV (SOLENOID SPILL VALVE) SYNCHRONOUS CONTROL

To suppress pulsation of the inside pressure of the pump which is caused by activating or deactivating the TCV, the TCV is designed to synchronize with the operation timing of the SPV.

(Conditions)

(1) When the engine speed is between 600 rpm and 1375 rpm

(2) During feedback control

(Control method)

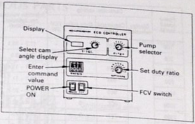
At the NE pulse number subsequent to the SPV open pulse number, the TCV is driven on 20~40 Hz.

4-10-2. OTHER THAN SPV SYNCHRONOUS CONTROL

(1) When the starter is ON and the engine speed is 600 rpm or less ...... 20 Hz (50 ms)

(2) When the engine speed is 1375 rpm or higher .... 40 Hz (25 ms)

7-9. ADJUSTING THE CAM ANGLE



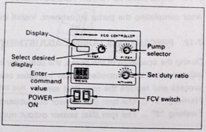
Connect the pressure sensor and attachment onto the test bench nozzle and holder (cylinder A). Set the controller to a specified setting. Read out from the controller display the actual angle at the time the pump is driven at a specified rpm. Then, select the cam angle correction (τ) resistor so that the difference between the PA (°) in the cam angle correction (τ) resistor table and the actual angle is under 0.25.

Pump speed (rpm)	Controller setting				Actual angle
	Display selection	Command value	Duty ratio setting	FCV SW	
350	Cam angle	96C	100	-	From display

〈 Cam angle correction resistor (τ) table 〉 096500-0131

PA (°)	τ correction resistor part No.	Resistance value (KΩ)	PA (°)	τ correction resistor part No.	Resistance value (KΩ)
12.48	096525-0230	0.068	15.73	096525-0091	0.487
12.87	096525-0250	0.100	15.89	096525-0101	0.523
13.10	096525-0260	0.121	16.12	096525-0111	0.576
13.22	096525-0270	0.133	16.29	096525-0121	0.619
13.44	096525-0280	0.154	16.52	096525-0131	0.681
13.63	096525-0290	0.174	16.69	096525-0141	0.732
13.83	096525-0300	0.196	16.86	096525-0151	0.787
14.04	096525-0310	0.221	17.03	096525-0240	0.845
14.22	096525-0011	0.243	17.08	096525-0161	0.866
14.41	096525-0021	0.267	17.25	096525-0171	0.931
14.60	096525-0031	0.294	17.46	096525-0181	1.020
14.75	096525-0041	0.316	17.62	096525-0191	1.100
14.96	096525-0051	0.348	17.83	096525-0201	1.210
15.18	096525-0061	0.384	18.02	096525-0211	1.330
15.34	096525-0071	0.412	18.17	096525-0221	1.430
15.56	096525-0081	0.453			

7-10. ADJUSTING THE INJECTION VOLUME



Remove the pressure sensor and attachment from the test bench nozzle and holder (cylinder A). At this time, connect the controller connector to the pressure sensor and attachment. Set the controller to a specified setting. Using a measuring cylinder, measure the injection amount for each cylinder at the time the pump is driven at a specified rpm.

Pump speed (rpm)	Controller setting				Injection volume per cylinder (cc/200st)	Amount of difference (cc/200st)
	Display selection	Command value	Duty ratio setting	FCV SW		
100	-	A88	0	-	17.7 ~ 20.1	1.2
350		96C	0	-	3.1 ~ 3.5	0.5
500		9C8	0	-	11.1 ~ 11.4	0.5
900		955	0	-	10.1 ~ 11.1	-
1000		9E5	0	-	20.0 ~ 20.7	0.5
1800		8CC	0	-	11.4 ~ 12.0	0.5
2300		777	0	-	4.5 ~ 7.5	-
2350		4E0	0	-	2.0 max.	-

* Perform the 350 rpm adjustment using the θ correction resistor (refer to the table below), and the 1800 rpm adjustment using the adjustment screw (the injection volume increases when the screw is turned in). (If adjustments must be made using the adjustment screw, use a screw driver or a pair of pliers to remove the cap.)

〈 θ correction resistor table 〉

Resistance value (KΩ)	Marking (bottom 3 digits)	Part No.	Resistance value (KΩ)	Marking (bottom 3 digits)	Part No.
0.154	001	096526-0011	0.681	017	096526-0171
0.174	002	096526-0021	0.732	018	096526-0181
0.196	003	096526-0031	0.782	019	096526-0191
0.221	004	096526-0041	0.866	020	096526-0201
0.243	005	096526-0051	0.931	021	096526-0211
0.267	006	096526-0061	1.020	022	096526-0221
0.294	007	096526-0071	1.100	023	096526-0231
0.316	008	096526-0081	1.210	024	096526-0241
0.348	009	096526-0091	1.330	025	096526-0251
0.383	010	096526-0101	1.430	026	096526-0261
0.412	011	096526-0111	1.580	027	096526-0270
0.453	012	096526-0121	1.780	028	096526-0281
0.487	013	096526-0131	1.960	029	096526-0291
0.523	014	096526-0141	2.210	030	096526-0301
0.576	015	096526-0151	2.490	031	096526-0311
0.619	016	096526-0161			

When a θ correction resistor that is one rank higher (larger resistance value) is used, the injection volume will increase as shown below.

0.08cc/200st (at Np=350 rpm) 0.12cc/200st (at Np=1000 rpm)

7-11. CONFIRMING AFTER ADJUSTMENT

After completing the pump adjustment, install the θ and τ resistors and connector clips.

7-12. PRECAUTIONS DURING ADJUSTMENT

During the operation of the pump, the controller constantly checks the rpm (Ne) sensor output. During adjustment, if the controller display indicates one of the conditions listed below, stop the adjustment process and replace the rpm (Ne) sensor.

Flashing "1" ... The rpm (Ne) sensor output number is less than the specified number.

Flashing "2" ... The rpm (Ne) sensor output number is more than the specified number.

8. TIGHTENING TORQUE OF VARIOUS PARTS