7. EXHAUST SYSTEM

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EXHAUST SYSTEM

1. GENERAL

An engine's exhaust system must be able to freely discharge all high temperature exhaust gas after combustion to the outside air.
Exhaust resistance must be as low as possible in order to prevent a decrease in power and keep clean exhaust gas emissions, however exhaust noise must be kept at an acceptable level. Careful design is required to reconcile these two conflicting factors. Exhaust gas from the exhaust manifold can either be directly fed into the muffler or routed to a place which will not interfere with the operator by exhaust pipe. The most important point in all cases is to reduce exhaust back pressure to a minimum.

2. LIMITATION OF PERMISSIBLE EXHAUST BACK PRESSURE

See the TECHNICAL INFORMATION document for the specific limitation value of each engine model.
Position to measure exhaust back pressure is at the outlet of exhaust manifold. Use a manometer to measure it. Refer to Fig. 7-1.

Note:
Exhaust back pressure to be measured at rated rpm and load.

Generally speaking,

- Exhaust back pressure increases as engine speed increases. Increase in exhaust back pressure varies with muffler configuration.
- Mufflers with higher exhaust back pressures has higher output loss. (approximately 5%)
- Exhaust back pressure increases as exhaust piping has many bends, longer length, many restrictions and smaller muffler volume.

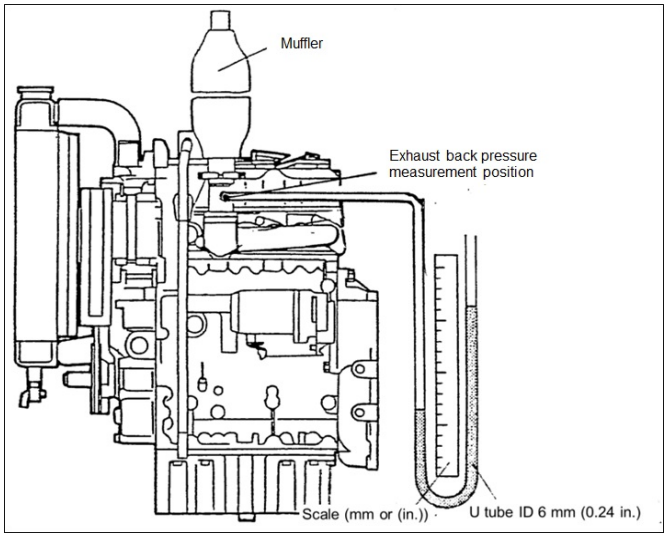


Fig. 7-1 Exhaust back pressure measurement position

3. CALCULATION OF EXHAUST BACK PRESSURE

Exhaust back pressure is caused by resistance of muffler and exhaust pipe (length, pipe diameter, number of bend and bending radius) and gas volume. Exhaust back pressure can be determined by the following formula.

1) Gas volume and resistance
a) Gas volume and speed

$$\nu = [VE / (\pi \times D^2/4)] \div 3600$$

VE : Gas volume (m^3/hr)
(See attached TECHNICAL DATA)
ν : Gas speed (m/s)
D : Internal diameter of exhaust pipe (m)

b) Resistance

● Straight pipe (resistance per one meter)⊿P (mmAq)

$\Delta P = \lambda \times (L / D) \times (\gamma \times \nu^2) / (2 \bullet g)$

L : Pipe length = 1m
D : Inside diameter of pipe (m)
γ : Specific gravity of gas at 673 K { 400 °C (752 °F) } 0.5 (kg/m^3)
ν : Gas speed (m/sec)
g : 9.8
λ : Friction coefficient = 0.030

● Elbow (resistance per one elbow) ⊿P' (mmAq)

$\Delta P' = \zeta \times \gamma \times \nu^2 / 2 \bullet g$

ζ :Short elbow = 0.51
Long elbow = 0.36

Result of calculations by the above formula are on next page (Fig. 7-2)

2) Resistance of mufflers (PM)

3) Total resistance (P)

$P = \Delta P \times L + \Delta P' \times N + PM$

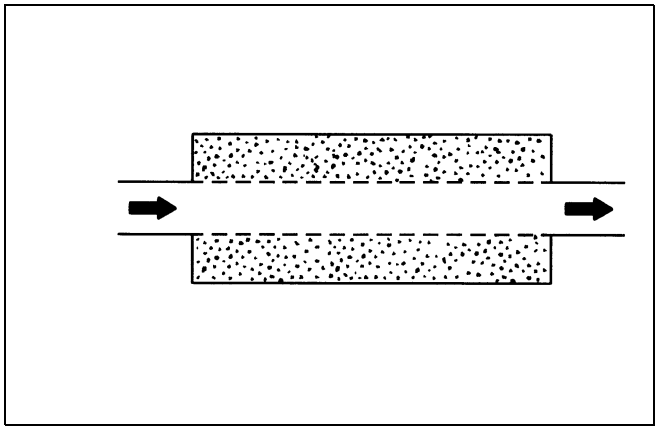
L : Pipe length (m)
N : Number of elbow

4. MUFFLER

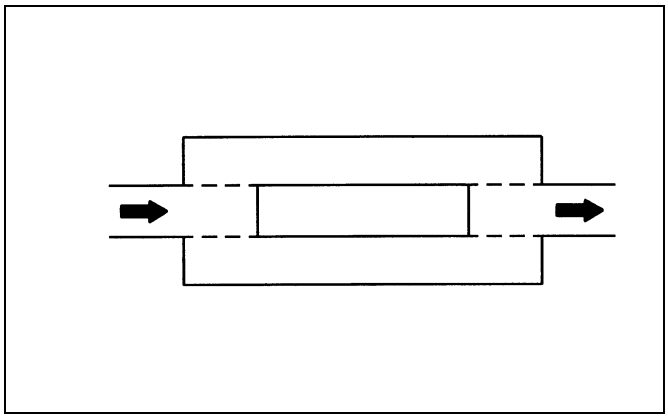
High temperature and high pressure exhaust gas is intermittently discharged by fuel combustion, generating pressure waves inside the exhaust pipe which results in noise.
Mufflers are used to reduce this noise. There are three major types of mufflers described.

Muffler types :

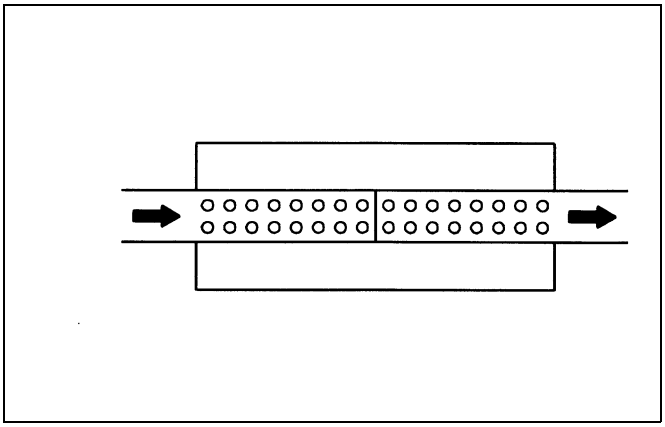
● Absorption type
A perforated pipe is surrounded by glass fiber and other noise absorbing materials.



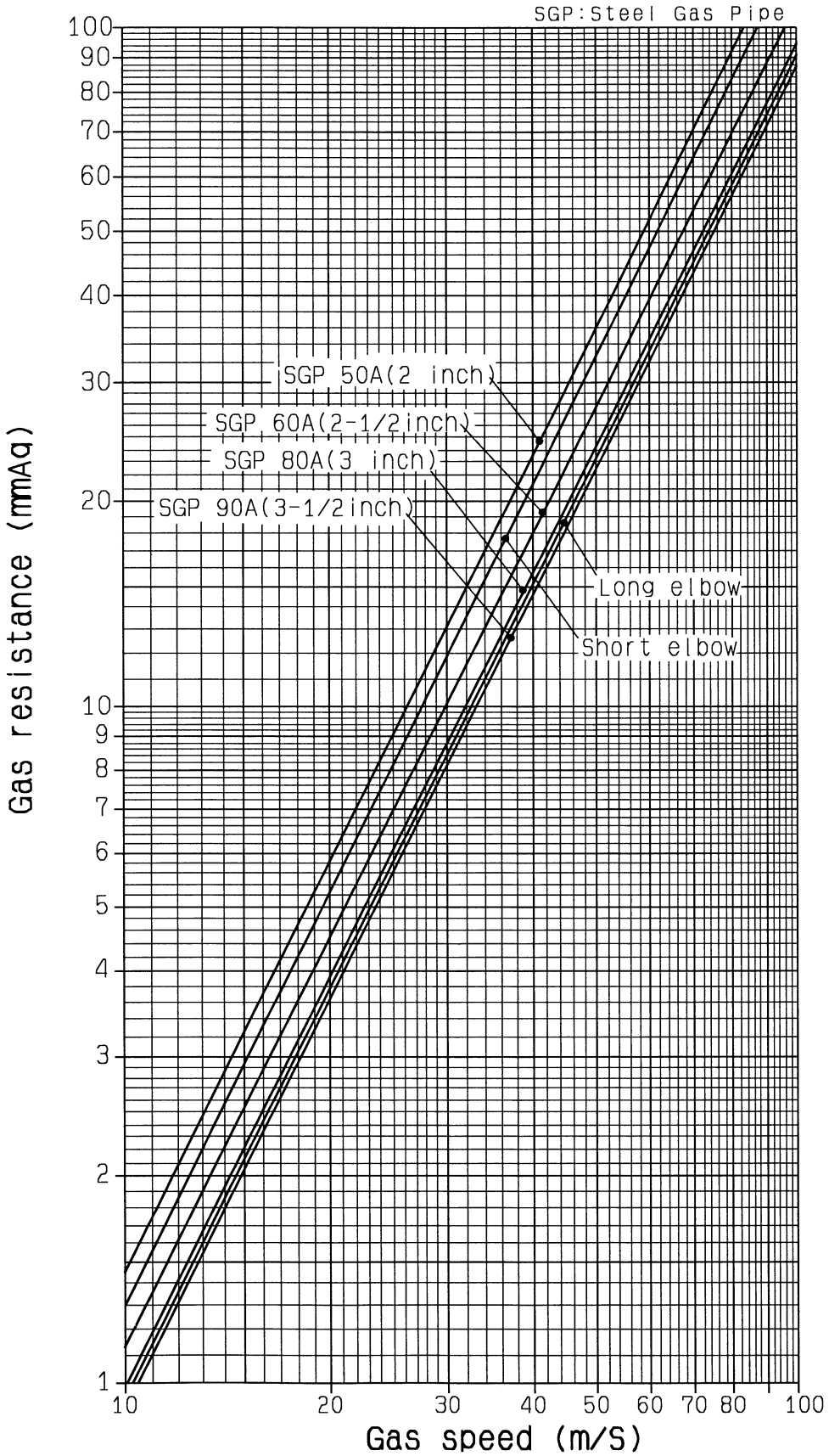
● Expansion type
Exhaust gas is discharged into an expansion chamber from the exhaust pipe to diffuse the noise.
This type comes with either a single or multiple expansion chambers.



● Dispersion type
Noise is muffled by changing the direction of the gas flow.



Rough estimate chart of exhaust gas resistance on straight pipe and elbow



Elbow dimensions

(mm)

	Short elbow		Long elbow	
	φD	A	φD	A
2 inch	52.9	50.8	52.9	76.2
2-1/2 inch	67.9	63.5	67.9	95.3
3 inch	80.7	76.2	80.7	114.3
3-1/2 inch	93.2	88.9	93.2	133.4

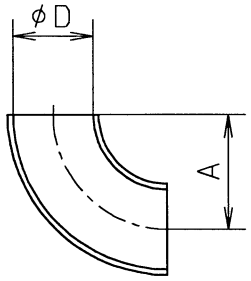


Fig. 7-2

There are many cases when combinations of these three kinds are used. The size of a muffler should generally be four or six times more than engine total displacement. This will vary according to length of exhaust pipe, type of muffler and purpose. Tests are required to determine the optimum arrangement.
When designing an exhaust system, exhaust direction and the high temperature of the pipes must be carefully considered for safety avoiding key engine parts, such as fuel piping and wiring are necessary when enclosing a muffler in an engine room or soundproof case. Air flow must be taken into consideration to keep the temperature inside as low as possible.

Other precautions

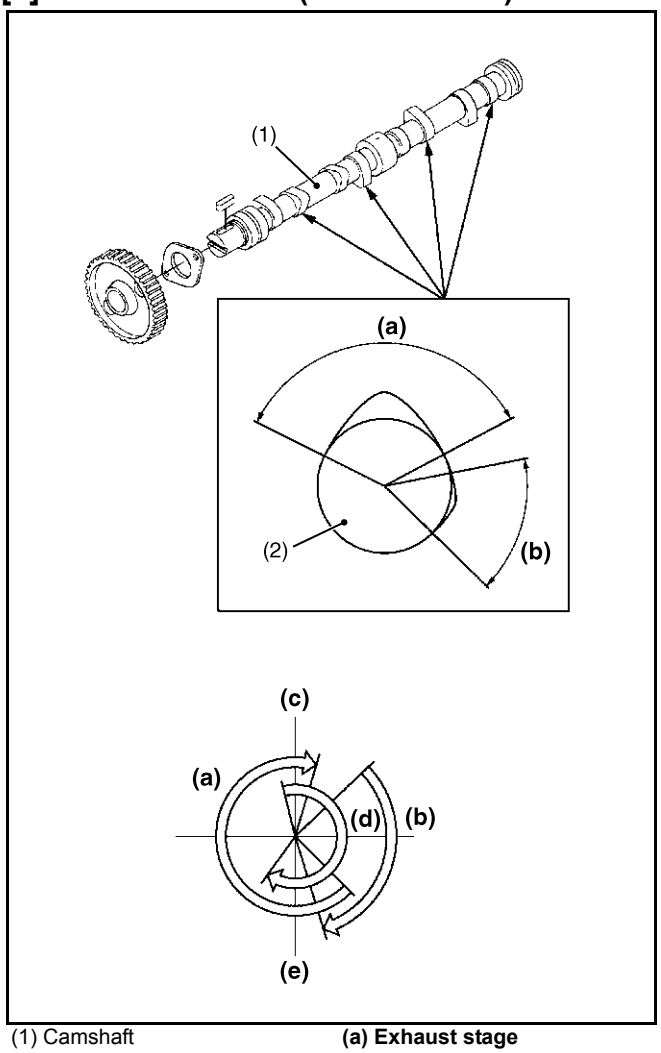
1) When directing the exhaust port upwards, rain will enter. Therefore, a snap-open cap at the top or a small drainage hole on the bottom of manifold must be provided.
2) If the muffler and exhaust piping are mounted on the machine body itself, a heatproof flexible pipe must be installed between the engine and the muffler. External piping must be isolated from vibration.
   Muffler must be held by additional stay from the engine in order to prevent a crack or break in the exhaust manifold or muffler itself.
3) Refer to the list of optional parts to arrange exhaust manifold outlets and directions of discharge.

5. EXHAUST GAS RECIRCULATION (EGR) SYSTEM

[1] GENERAL

In order to meet with the strict emission regulations, Kubota has adopted the EGR on the V3-E3B series and 07-E3B series. The nitrogen oxide (NOx) which is a hazardous component in exhaust gas is generated by oxidation of nitrogen in the air, due to rise of the combustion temperature in cylinders. The EGR is a system in which the exhaust gas with lean oxygen is cooled and returned to cylinders again in order to lower the combustion temperature. As a result, NOx can be decreased.
And EGR has 2 types. One is an internal EGR, the other is an external EGR.

[2] INTERNAL EGR (V3600-T-E3B)



(1) Camshaft
(2) 2 Stage exhaust cam

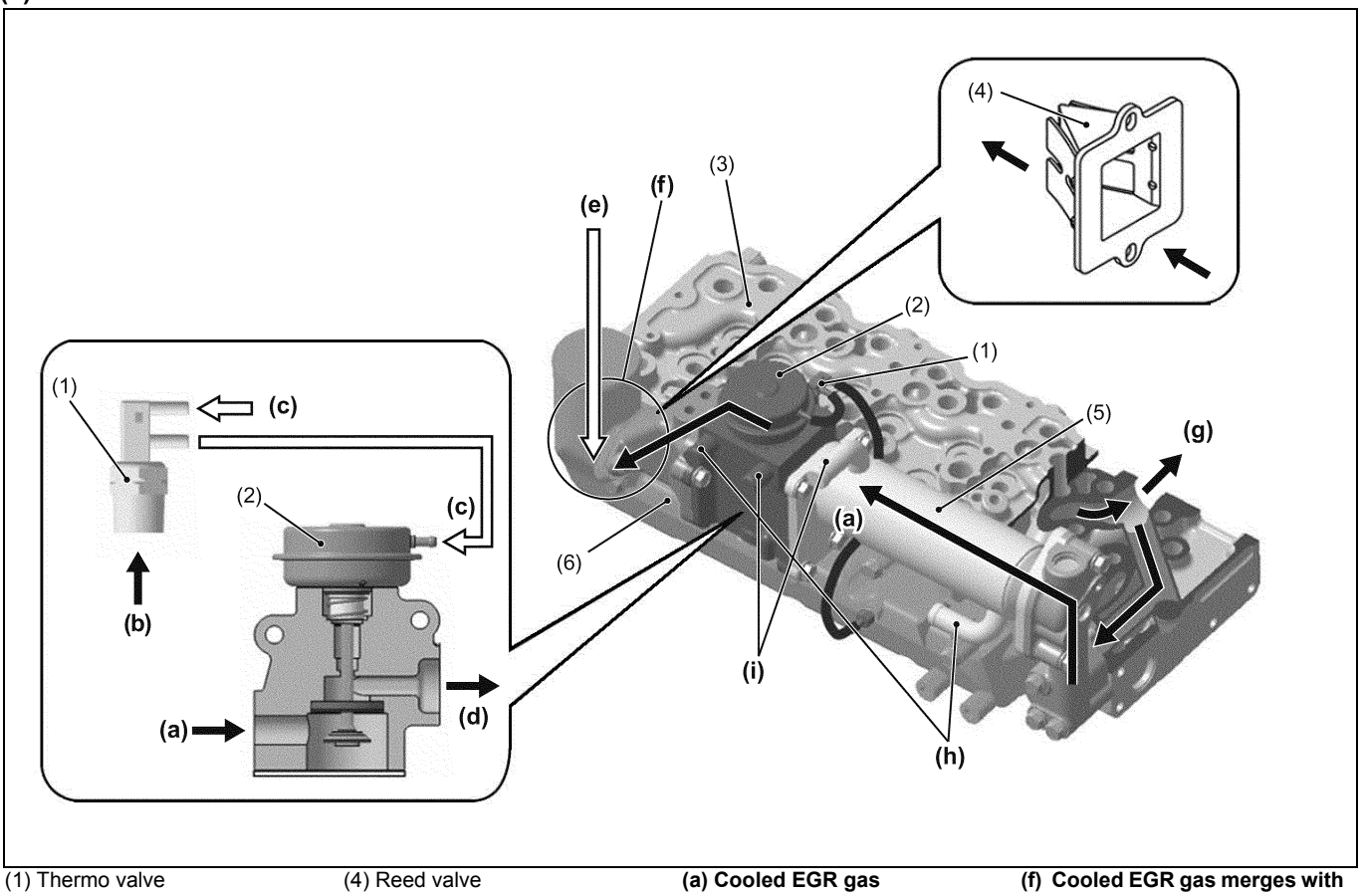
(a) Exhaust stage
(b) EGR Stage
(c) T.D.C. (Top dead center)
(d) Intake stage
(e) B.D.C. (Bottom dead center)

Fig. 7-3 Closed breather system

Internal EGR consists of 2 stage exhaust camshaft.
At the exhaust stroke, 1st stage exhaust cam opens the exhaust valve, and exhaust gas flows into the exhaust manifold. At the suction stroke, intake valve is open and fresh air flows into the cylinder, and also, 2nd stage exhaust cam opens the exhaust valve, and exhaust gas in the exhaust manifold is sucked back into the cylinder.

[3] EXTERNAL / MECHANICAL EGR

(1) V2607-DI-T-E3B / V3307-DI-T-E3B



(1) Thermo valve
(2) Mechanical EGR valve
(3) Cylinder head
(4) Reed valve
(5) EGR cooler
(6) Intake manifold

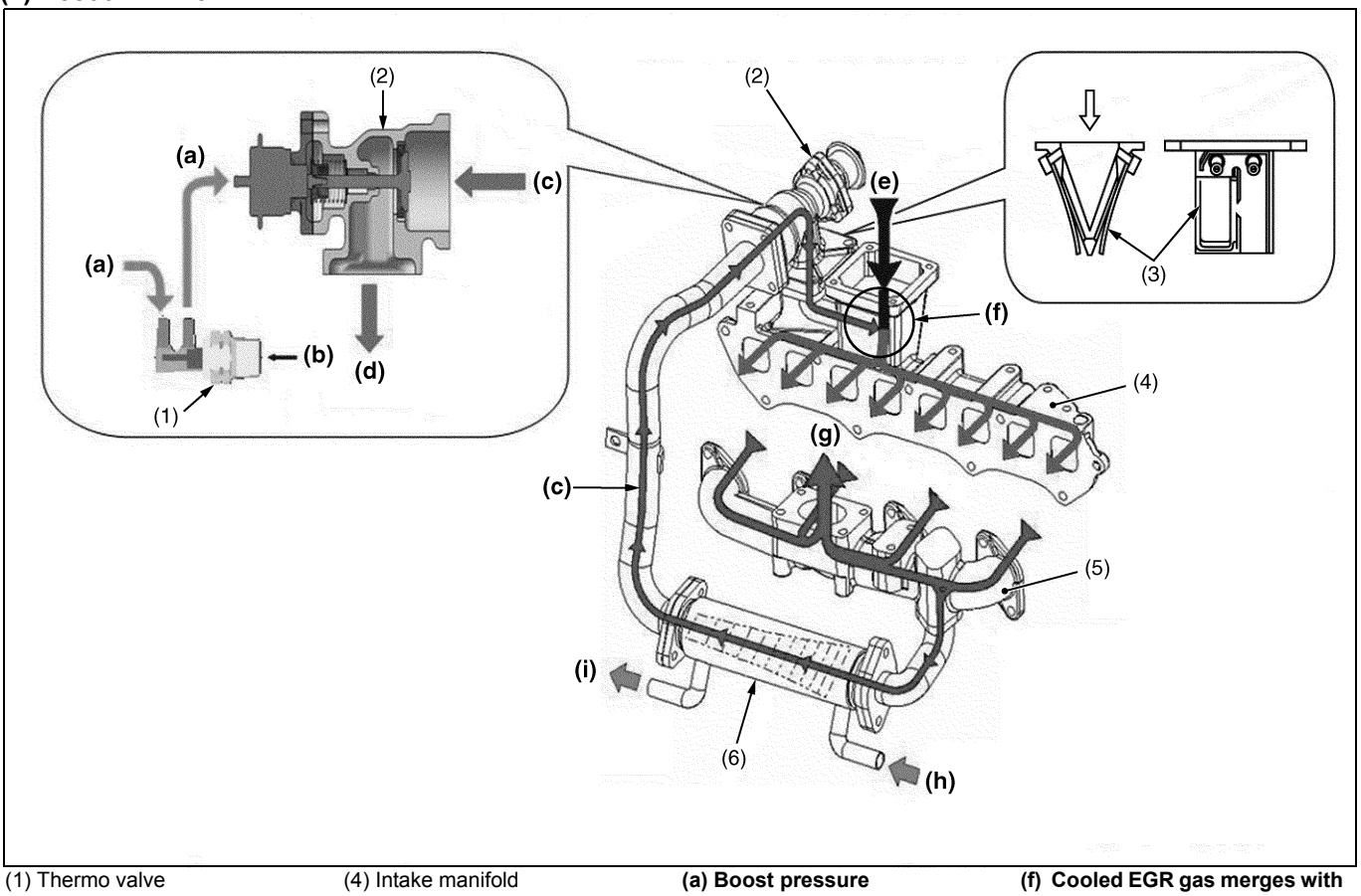
(a) Cooled EGR gas
(b) Coolant temperature
(c) Boost pressure
(d) To the intake manifold
(e) Fresh air
(f) Cooled EGR gas merges with fresh air
(g) Exhaust gas
(h) Coolant inlet
(i) Coolant outlet

Fig. 7-4

External mechanical EGR consists of water cooled EGR cooler (5), mechanical EGR valve (2), reed valve (4) and thermo valve (1).
When the coolant temperature **(b)** is getting higher, thermo valve (1) is open and the boost pressure of intake manifold (6) gets to reach the diaphragm of mechanical EGR valve (2).

If the coolant temperature **(b)** is high, but the boost pressure is low, the EGR valve (2) does not open. If coolant temperature **(b)** is high, boost pressure is also high, EGR valve (2) is open and cooled EGR gas **(a)** through the water cooled EGR cooler (5) flows into the intake manifold (6). And the reed valve (4) between EGR valve (2) and intake manifold (6) prevents the fresh air flowing into EGR system.

(2) V3800DI-T-E3B



(1) Thermo valve
(2) Mechanical EGR valve
(3) Reed valve
(4) Intake manifold
(5) Exhaust manifold
(6) EGR cooler

(a) Boost pressure
(b) Coolant temperature
(c) Cooled EGR gas
(d) To the intake manifold
(e) Fresh air
(f) Cooled EGR gas merges with fresh air
(g) Exhaust gas
(h) Coolant inlet
(i) Coolant outlet

Fig. 7-5

External / Mechanical EGR consists of water cooled EGR cooler, mechanical EGR valve, reed valve and thermo valve.
When the coolant temperature is getting higher, thermo valve is open and the boost pressure of intake manifold gets to reach the diaphragm of mechanical EGR valve.
If the coolant temperature is high, but the boost pressure is low, the EGR valve does not open. If coolant temperature is high, boost pressure is also high, EGR valve is open and cooled EGR gas through the water cooled EGR cooler flows into the intake manifold. And the reed valve between EGR valve and intake manifold prevents the fresh air flowing into EGR system.