Fuji Electric

Innovating Energy Technology

Automotive IGBT Module Application Note

Fuji Electric Co., Ltd.

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Automotive IGBT Module Application Note – Chapter 1 – Basic Concept and Features

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Introduction

This chapter describes the basic concept and features of the automotive IGBT module.

1. Basic concept of the automotive IGBT module

From the viewpoint of protecting the global environment, the reduction of Carbon dioxide (CO_2) emissions has recently been required in the world. In the automotive field, use of hybrid electric vehicles (HEV) and electric vehicles (HV) has been increasing to reduce CO_2 emissions. HEV and EV drive a running motor A driving motor in HEV and EV is driven by converting DC power stored in a high-voltage battery into AC power using a power conversion system. IGBT modules are mainly used for such power conversion system. The IGBT module used for the power conversion system is required to be compact since a high-voltage battery, power conversion system, motor, etc. must be installed within a limited space.

In view of such circumstances, Fuji's automotive IGBT module has been developed based on the concept of "downsizing."

Figure 1-1 shows the basic needs in the market for IGBT modules, which include the improvement in performance and reliability and reduction in environmental impact. Since characteristics determining performance, reliability, and environmental load are related to one another, it is essential to improve them in good balance to downsize the IGBT module.

The newly developed automotive IGBT module achieves the basic concept "downsizing" by adopting (i) direct liquid-cooling structure, (ii) ceramic insulated substrate with low thermal impedance, (iii) 6th-generation V-series IGBT chip, and (iv) high-strength soldering material, thus optimizing the performance, reliability and environmental impact.

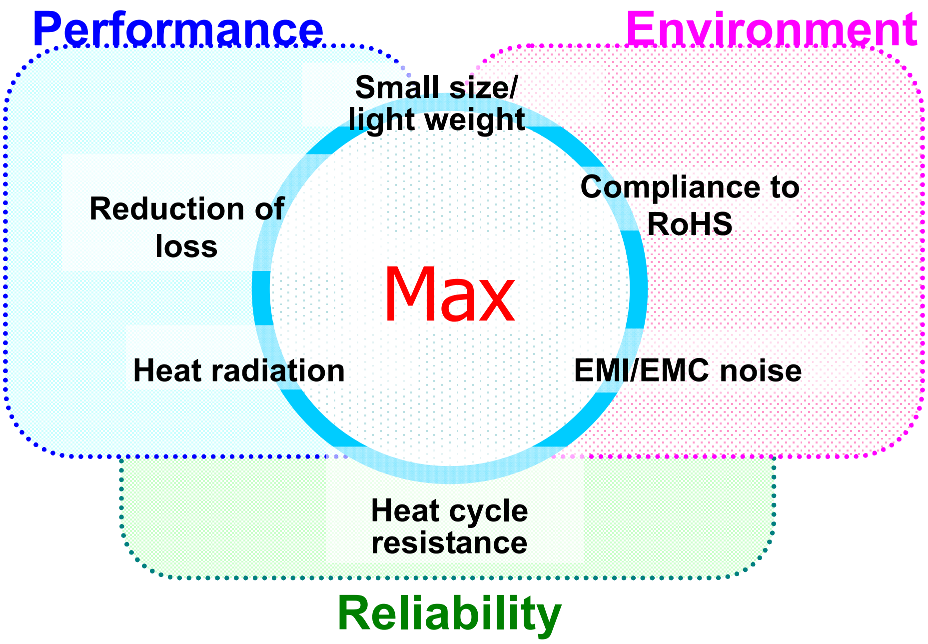


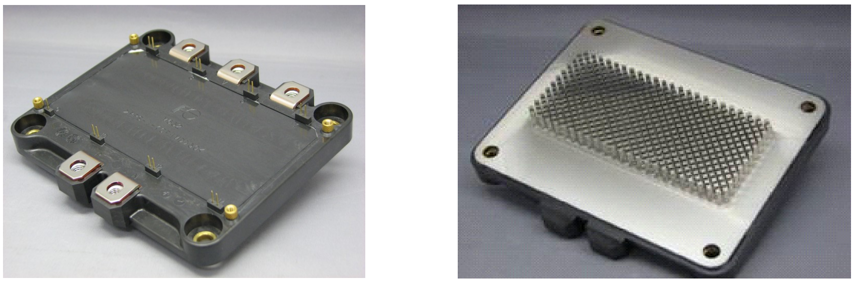
Fig. 1-1 IGBT module development concept targeted by Fuji Electric

2. Direct liquid-cooling structure

The newly developed automotive IGBT module has achieved the decreasing of thermal resistance significantly by adopting direct water-cooling structure. Thermal grease is used in the conventional IGBT module in order to decrease contact thermal resistance between a copper base and a heat sink. Since thermal grease has low thermal conductivity in general, the heat transferring performance is low. That is a problem have to be solved. In the direct liquid-cooling structure, the copper base and a fin are integrated into one and cooling liquid is made to contact the fin directly, thereby eliminating the need for thermal grease, which improves the heat transferring performance from the IGBT module to the heat sink significantly.

Figure 1-2 shows the appearance of the newly developed automotive IGBT module developed this time.

FIG. 1-3 is a comparison of steady-state thermal resistance between the conventional structure using thermal grease and the direct liquid-cooling structure. It is obvious from Fig. 1-3 that the direct liquid-cooling structure doesn’t have the thermal resistance of the thermal grease layer, the steady state thermal resistance is decreased by approximately 30% compared to the conventional cooling system.



(a) Top face (b) Bottom face

Fig. 1-2 Appearance of 6MBI600VW-065V

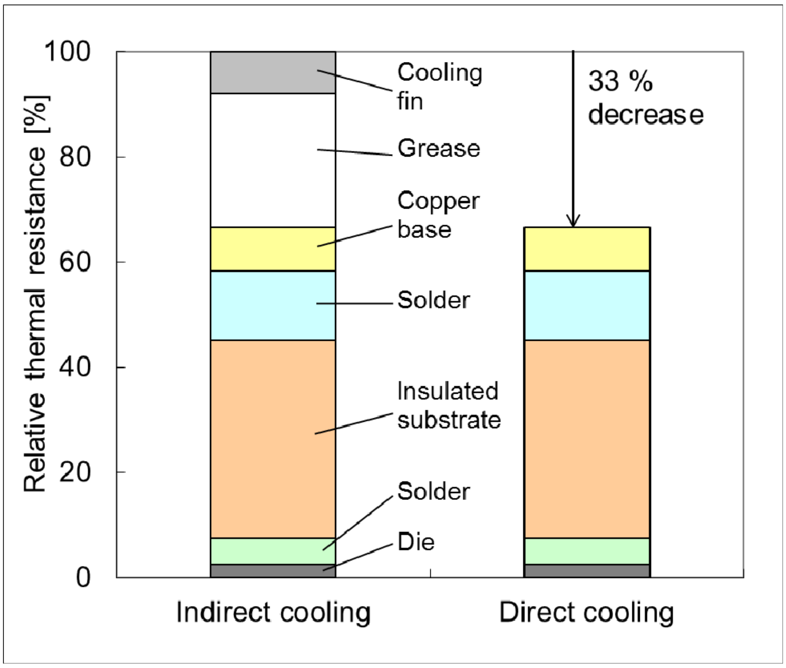


Fig. 1-3 Comparison in thermal resistance between conventional structure

and direct liquid-cooling structure

3. Application of high thermal conductivity ceramic insulated substrate and high-strength soldering material

3.1 Application of ceramic insulated substrate with high thermal conductivity

In addition to the direct liquid-cooling structure described previously, silicon nitride (Si_3N_4) ceramic, which has high thermal conductivity, is used as an insulated substrate for the module in order to decrease thermal resistance. Figure 1-4 shows comparison of the thermal resistance between the conventional structure which has a thermal grease and an aluminum oxide (Al_2O_3) insulated substrate are used and the direct liquid-cooling structure which uses a silicon nitride ceramic substrate. The significant reduction in thermal resistance has been achieved (reduction by 63% with respect to the conventional structure) by eliminating thermal grease layer and applying the insulated substrate with high thermal conductivity.

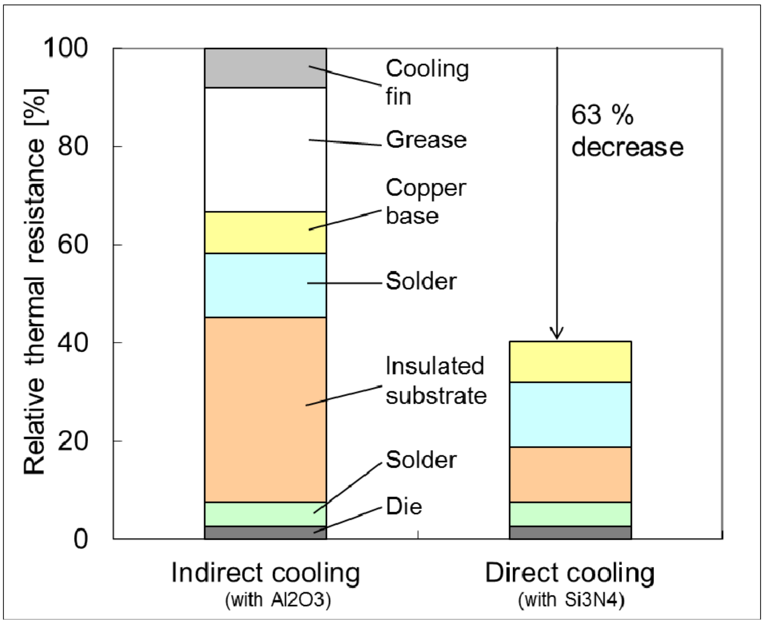
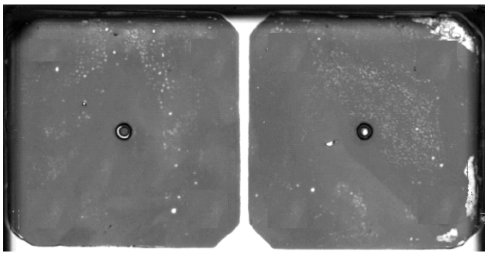


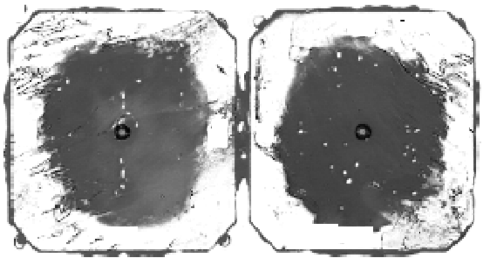
Fig. 1-4 Comparison in thermal resistance between conventional structure and direct water-cooling structure

3.2 High-strength solder

Since automotive semiconductors are often used in a severe condition compared to industrial or consumer use, higher reliability is required. In particular, if a crack is generated in a solder layer between the insulated substrate and the baseplate due to mechanical stress by temperature cycles, the thermal resistance is increased then abnormal chip heating might be occurred, and it cause a failure of the IGBT module. Fuji's automotive IGBT module suppresses generation of cracks significantly by changing solder material to newly developed SnSb series solder from conventional SnAg-series solder (Fig. 1-5).



(a) SnSb-series solder



(b) SnAg-series solder

Fig. 1-5 Comparison in progress of cracks after temperature cycle test
between SnSb-series solder and SnAg-series solder
(Ultrasonic flow detection image after 2,000 temperature cycles)

4. Feature of V-series IGBT chips

The newly developed two models of automotive IGBT module (6MBI400VW-065V, 6MBI600VW-065V) are using 650 V “V-series” IGBTs and FWDs. The V-series IGBT has decreased on-state voltage and switching loss by optimizing field-stop (FS) structure. Furthermore, switching-speed controllability has also been improved by optimizing trench gate structure.

See the application manual of the 6th-generation V-series IGBT modules for more details.

5. Numbering system

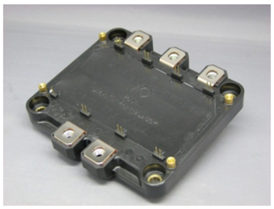
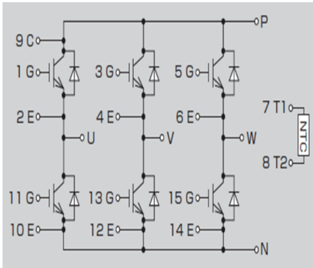
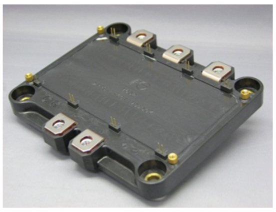
The numbering system of the automotive IGBT module for 6MBI400VW-065V is shown in list below as an example.

	Symbol	Description
① Number of switch elements	6	6 arms
② Model group	MB	IGBT model
③ Insulation type	I	Insulated type
④ Maximum current	400	400 A
⑤ Chip generation	V	V series
⑥ In-house identification No.	W	Identification No.
⑦ Element rating	065	Withstand voltage: 650 V
⑧ Automotive product	V	Automotive product

6. Circuit configuration

Table 1-1 shows the circuit configuration of the automotive IGBT modules.

Table 1-1 Circuit configuration

Name	Model name	Model name	Equivalent circuit	Features
6in1	6MBI400VW-065V			**Six each of IGBT and FWD are embedded in the product along with a thermistor for temperature detection.**
	6MBI600VW-065V			

– Chapter 2 –

Terms and Characteristics

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This chapter describes the terms related to the automotive IGBT module and its characteristics.

1. Description of terms

Various terms used in the specification, etc. are described below.

Table 2-1 Maximum ratings

Term	Symbol	Definition explanation (See specifications for test conditions)
Collector-emitter voltage	V_{CES}	Maximum collector-emitter voltage with gate-emitter shorted
Gate-emitter voltage	V_{GES}	Maximum gate-emitter voltage with collector-emitter shorted
Collector current	I_C	Maximum DC collector current
	I_C pulse	Maximum pulse collector current
	-Ic	Maximum forward DC current of internal diode
	$-I_C$ pulse	Maximum forward pulse current of internal diode
Maximum power dissipation	P_C	Maximum power dissipation per element
Junction temperature	T_j	Maximum chip temperature, at which normal operation is possible. You must not exceed this temperature in the worst condition.
Operation junction temperature	$T_{j(op)}$	Maximum chip temperature during continuous operation
Water temperature	T_{win}	Temperature of the coolant (Temperature of the coolant at the inlet of the flow path of the coolant. See Chapter 3 for details.)
Storage temperature	T_{stg}	Temperature range for storage or transportation, when there is no electrical load on the terminals
FWD I^2t	I^2t	Value of joule energy (value of integration of overcurrent) that can be allowed within the range which device does not destroy. The overcurrent is defined by a line frequency sine half wave (50, 60Hz) and one cycle.
FWD surge current	I_{FSM}	The maximum value of overcurrent that can be allowed in which the device is not destroyed. The overcurrent is defined by a line frequency sine half wave (50, 60Hz).
Isolation voltage	V_{iso}	Maximum effective value of the sine-wave voltage between the terminals and the heat sink, when all terminals are shorted simultaneously
Screw torque	Mounting	Maximum and recommended torque for specified screws when mounting the IGBT on a heat sink
	Terminal	Maximum and recommended torque for terminal screws when connecting external wires/bus bars to the main terminals

Caution: The maximum ratings must not be exceeded under any circumstances.

Table 2-2 Electrical characteristics

Term		Symbol	Definition explanation (See specifications for test conditions)
Static characteristics	Zero gate voltage collector current	I_{CES}	Collector leakage current when a specific voltage is applied between the collector and emitter with gate-emitter shorted
	Gate-emitter leakage current	I_{GES}	Gate leakage current when a specific voltage is applied between the gate and emitter with collector-emitter shorted
	Gate-emitter threshold voltage	$V_{GE(th)}$	Gate-emitter voltage at a specified collector current and collector-emitter voltage (gate-emitter voltage which start to flow a low collector current)
	Collector-emitter saturation voltage	$V_{CE(sat)}$	Collector-emitter voltage at a specified collector current and gate-emitter voltage (Usually V_{GE}=15V)
	Input capacitance	C_{ies}	Gate-emitter capacitance, when a specified voltage is applied between the gate and emitter as well as between the collector and emitter, with the collector and emitter shorted in AC
	Output capacitance	C_{oes}	Gate-emitter capacitance, when a specified voltage is applied between the gate and emitter as well as between the collector and emitter, with gate-emitter shorted in AC
	Reverse transfer capacitance	C_{res}	Collector-gate capacitance, when a specified voltage is applied between the gate and emitter, while the emitter is grounded
	Diode forward on voltage	V_F	Forward voltage when the specified forward current is applied to the internal diode
Dynamic characteristics	Turn-on time	t_{on}	The time interval between when the gate-emitter voltage rises to 0V and when the collector-emitter voltage drops to 10% of the maximum value during IGBT turn on
	Rise time	t_r	The time interval between when the collector current rises to 10% of the maximum value and when collector-emitter voltage drops to 10% of the maximum value during IGBT turn on
		$t_{r(i)}$	The time interval between when the collector current rises to 10% and when the collector current rises to 90% of the maximum value at IGBT turn-on
	Turn-off time	t_{off}	The time interval between when the gate-emitter voltage drops to 90% of the maximum value and when the collector current drops to 10% of the maximum value during IGBT turn off
	Fall time	t_f	Time required for collector current to drop from 90% to 10% of the maximum value
	Reverse recovery time	t_{rr}	Time required for reverse recovery current in the internal diode to decay
	Reverse recovery current	$I_{rr}(I_{rp})$	Peak reverse current during reverse recovery
Reverse bias safe operating area		RBSOA	Current and voltage area when IGBT can be turned off under specified conditions
Gate resistance		R_G	Series gate resistance (See switching time test conditions for standard values)
Gate charge capacity		Q_g	Turn on gate charge between gate and emitter

Table 2-3 Thermal resistance characteristics

Term	Symbol	Definition explanation (See specifications for test conditions)
Thermal resistance	$R_{th(j-f)}$	Thermal resistance between the fin base and the chip or internal diode
	$R_{th(f-win)}$	Thermal resistance between the fin base and the cooling liquid allowable in a state where cooling water is fed to the water jacket
Case temperature	T_c	IGBT case temperature

Table 2-4 Thermistor characteristics

Term	Symbol	Definition explanation (See specifications for test conditions)
Thermistor resistance	Resistance	Thermistor resistance at the specified temperature
B value	B	Temperature coefficient of the resistance

2. Cooling performance of the automotive IGBT module

2.1 Cooler (liquid-cooling jacket)

The automotive IGBT module has a direct liquid-cooling structure which has a copper base plate with cooling pin-fins, and the cooling efficiency is enhanced by eliminating a thermal grease layer. The direct cooling structure requires a cooler (liquid-cooling jacket) which has a flow path of coolant. Design of the liquid-cooling jacket is very important because its cooling performance depends on the state of the flow path in the liquid-cooling jacket and the clearance between the cooling fin on the module and the cooling jacket.

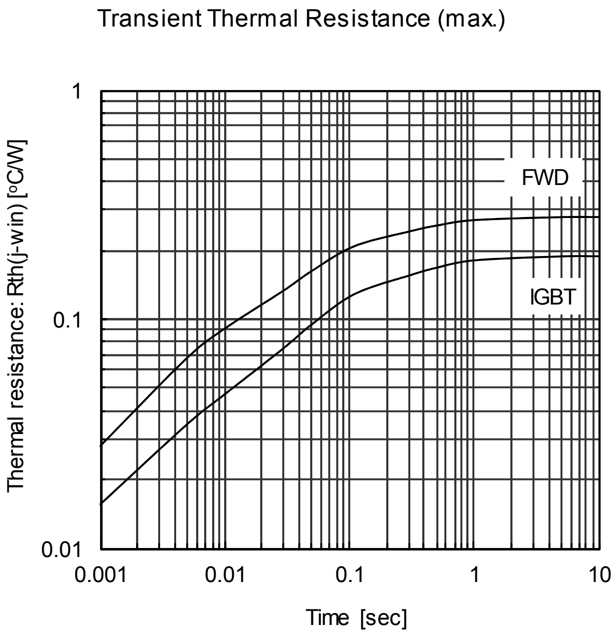
See Chapter 3 Heat dissipation design method for more details of liquid cooling jacket design.

2.2 Transient thermal resistance characteristics

Figure 2-1 shows the transient thermal resistance characteristics which is used to calculate temperature increase and design a liquid cooling jacket. (This characteristics curve represents the value of one element of IGBT or FWD)

The thermal resistance characteristics are often used for thermal analysis, and defined by a formula similar to the one representing the Ohm's law for electrical resistance.

Temperature difference ΔT[°C] = Thermal resistance Rth [°C/W] × Energy (loss) [W]



The thermal resistance is used for calculation of Tj of IGBT and FWD in the automotive IGBT module.

(See Chapter 3 Heat dissipation design method for details.)

Fig. 2-1 Transient thermal resistance characteristics

2.3 Cooling performance dependence of cooling liquid temperature

The temperature of the cooling liquid (coolant) which is used to cool the automotive IGBT module does not affect the thermal resistance. Meanwhile, the higher the cooling water temperature, the lower the pressure loss, but higher the junction temperature. Due attention should therefore be paid to the above when designing the module. As a typical example, Fig. 2-2 shows the dependency of the thermal resistance to coolant temperature when a 50% water solution of long-life coolant (LLC) is used as the coolant.

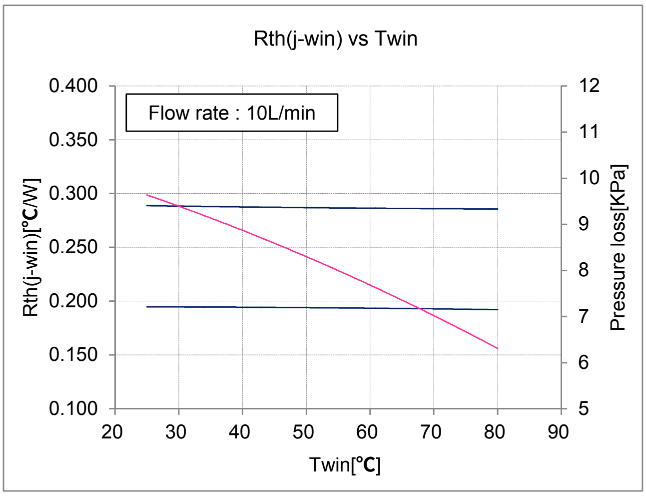


Fig. 2-2 Dependency of thermal resistance on coolant temperature

2.4 Cooling performance and pressure loss dependence of flow rate of cooling liquid

As well as the cooling liquid temperature, the flow rate of the cooling liquid also affects the cooling performance. The cooling performance increases with an increase of flow rate, but the pressure loss between the inlet and outlet of the flow path also increases. If the pressure loss increases, the variation of chip temperature in the module becomes wide. Therefore it is necessary to optimize the performance of the pump in the system and flow path design.

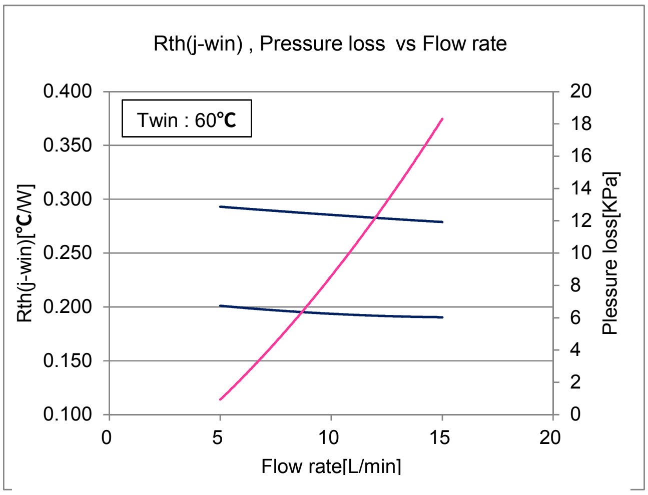


Fig. 2-3 Dependency of thermal resistance and pressure loss on flow rate

As a typical example, Fig. 2-3 shows the dependency of thermal resistance and pressure loss on the flow rate of coolant. Refer to this figure when designing a module.

– Chapter 3 –

Heat Dissipation Design Method

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This chapter describes heat dissipation design.

To operate the IGBT safely, it is necessary not to allow the junction temperature (Tj) to exceed Tjmax. Perform thermal design with sufficient allowance in order not for Tjmax. to be exceeded not only in the operation under the rated load but also in abnormal situations such as overload operation.

1. Power dissipation loss calculation

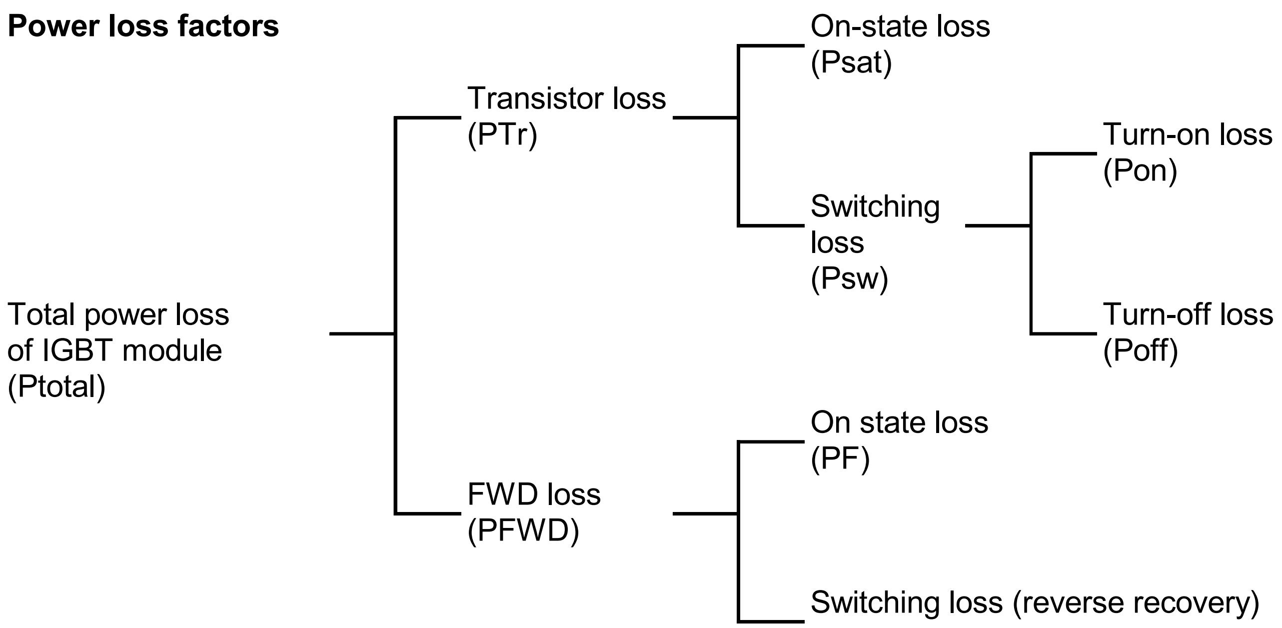
In this section, the simplified method of calculating power dissipation for IGBT modules is explained.

In addition, an IGBT loss simulator is available on the Fuji Electric WEB site (http://www.fujielectric.co.jp/xxxxx/). It helps to calculate the power dissipation and thermal design for various working condition with various Fuji IGBT modules.

1.1 Types of power loss

The IGBT module consists of several IGBT dies and FWD dies. The sum of the power losses from these dies equals the total power loss for the module. Power loss can be classified as either on-state loss or switching loss. A diagram of the power loss factors is shown as follows.

Power loss factors



The on-state power loss from the IGBT and FWD elements can be calculated using the output characteristics, and the switching losses can be calculated from the switching loss vs. collector current characteristics on the datasheet. Use these power loss calculations in order to design a suitable cooling system to keep the junction temperature Tj below the maximum rated value.

The on-state voltage and switching loss values at standard junction temperature (T_j=150°C) is recommended for the calculation.

Please refer to the module specification sheet for these characteristics data.

1.2 Power dissipation loss calculation for sinusoidal VVVF inverter application

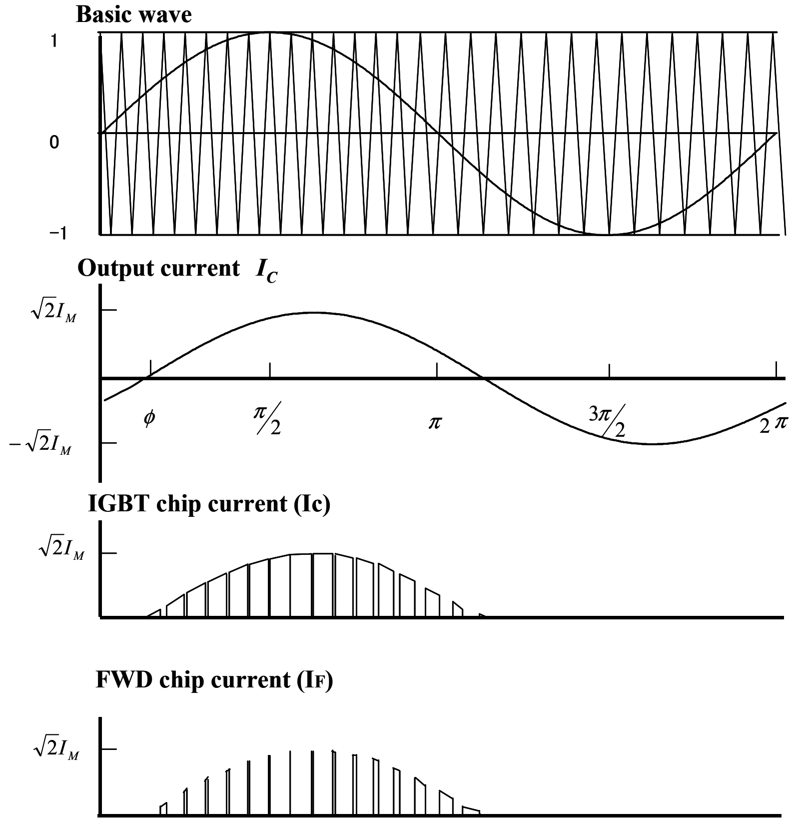


Fig.3-1 PWM inverter output current

In case of a VVVF inverter with PWM control, the output current and the operation pattern are kept changing as shown in Fig.3-1. Therefore, it is helpful to use a computer calculation for detailed power loss calculation. However, since a computer simulation is very complicated, a simplified loss calculation method using approximate equations is explained in this section.

Prerequisites

For approximate power loss calculations, the following prerequisites are necessary:

- Three-phase PWM-control VVVF inverter for with ideal sinusoidal current output
- PWM control based on the comparison of sinusoidal wave and saw tooth waves

On-state power loss calculation (Psat, PF)

As displayed in Fig.3-2, the output characteristics of the IGBT and FWD have been approximated based on the data contained in the module specification sheets.

On-state power loss in IGBT chip (P_{sat}) and FWD chip (P_F) can be calculated by following equations:

$$(P_{sat}) = DT\int_0^x I_C V_{CE(sat)} d\theta$$
$$= \frac{1}{2} DT\left[\frac{2\sqrt{2}}{\pi} I_M V_O + I_{M^2} R\right]$$

$$(P_F) = \frac{1}{2} DF\left[\frac{2\sqrt{2}}{\pi} I_M V_O + I_{M^2} R\right]$$

DT, DF: Average on-state ratio of the IGBT and FWD at a half-cycle of the output current. (Refer to Fig.3-3)

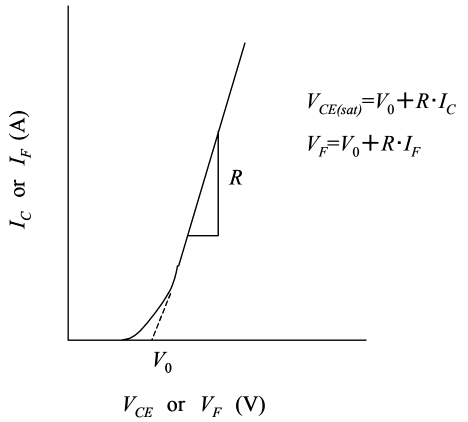


Fig. 2-2 Approximate output characteristics

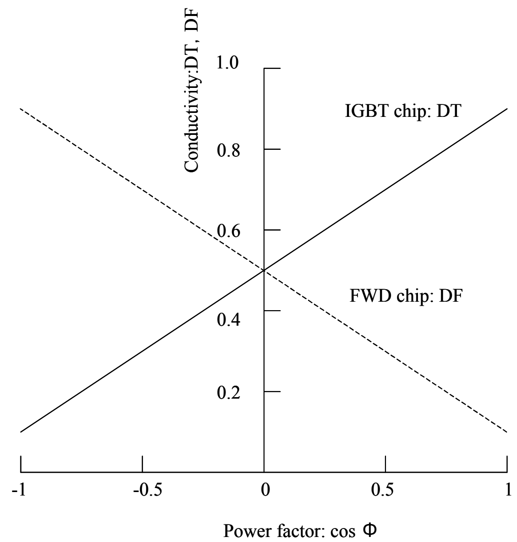


Fig.3-3 Relationship between power factor sine-wave PWM inverter and conductivity

Switching loss calculation

The characteristics of switching loss vs. I_C as shown in Fig.3-4 are generally approximated by using following equations.

$$E_{on} = E_{on'}(I_C / ratedI_C)^a$$

$$E_{off} = E_{off'}(I_C / ratedI_C)^b$$

$$E_{rr} = E_{rr'}(I_C / ratedI_C)^c$$

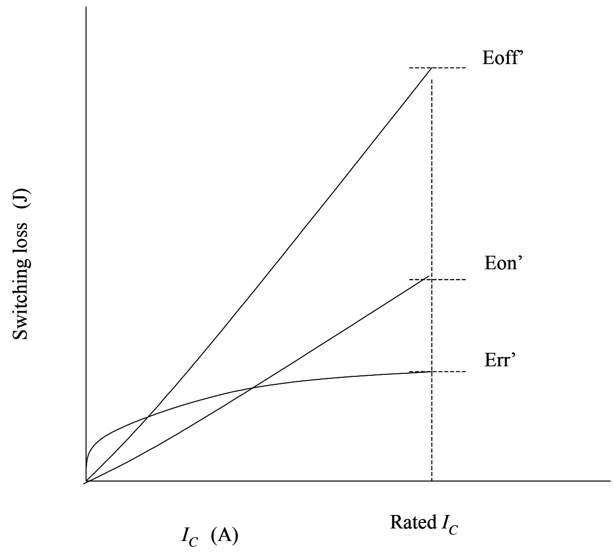


Fig.3-4 Approximate switching losses

a, b, c: Multiplier

E_{on}', E_{off}', E_{rr}': E_{on}, E_{off} and E_{rr} at rated IC

The switching losses can be represented as follows:

· **Turn-on loss (Pon)**

$$P_{on} = fo\sum_{K=1}^{n}(E_{on})k \qquad \left(n : Half-cycle\ switching\ count = \frac{fc}{2fo}\right)$$

$$= foE_{on}'\frac{1}{rated\ I_{C^a}}\sum_{k=1}^{n}(I_{C^a})k$$

$$= foE_{on}'\frac{n}{rated\ I_{C^a}\times\pi}\int_0^{\pi}\sqrt{2}I_{M^a}\sin\theta d\theta$$

$$= foE_{on}'\frac{1}{rated\ I_{C^a}}nI_{M^a}$$

$$= \frac{1}{2}fcE_{on}'\left[\frac{I_M}{rated\ I_C}\right]^a$$

$$= \frac{1}{2}fcE_{on}(I_M)$$

Eon(IM):Ic= Eon at IM

· **Turn-off loss (Poff)**

$$P_{off} = \frac{1}{2}fcE_{off}(I_M)$$

Eoff(IM):Ic= Eoff at IM

· **FWD reverse recovery loss (Prr)**

$$P_{off} \approx \frac{1}{2} fcE_{rr}(I_M)$$

E_{rr} when $E_{rr}(I_M)$:$I_C = I_M$

Total power loss

Using the results obtained in section 1.2.

IGBT chip power loss: $P_{Tr} = P_{sat} + P_{on} + P_{off}$

FWD chip power loss: $P_{FWD} = P_F + P_{rr}$

The DC supply voltage, gate resistance, and other circuit parameters will differ from the standard values listed in the module specification sheets.

Nevertheless, by applying the instructions of this section, the actual values can easily be calculated.

2. Method of selecting a liquid cooling jacket

The electrode terminals and the mounting base of the automotive IGBT power modules (6MBI400VW-065V/6MBI600VW-065V) are insulated, it is easy for mounting and compact wiring. It is important to select an appropriate liquid-cooling jacket because it is necessary to dissipate the heat generated at each device during operation for safety operation of the module. The basic concept in selecting a liquid cooling jacket is described in this section.

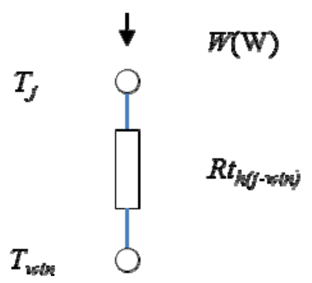
2.1 Thermal equation in steady state

Thermal conduction of IGBT module can be represented by an electrical circuit. In this section, in the case only one IGBT module mounted to a heat sink is considered. This case can be represented by an equivalent circuit as shown in Fig. 3-5 thermally.

From the equivalent circuit shown in Fig. 3-5, the junction temperature (Tj) can be calculated using the following thermal equation:

$$Tj = W \times \{Rth(j-win)\} + Twin$$

where, the inlet coolant temperature T_{win} is represents the temperature at the position shown in Fig. 3-6. As shown in Fig. 3-6, the temperature at points other than the relevant point is measured low in actual state, and it depends on the heat dissipation performance of the water jacket. Please be designed to be aware of these.



W : Module power loss

T_j : Junction temperature if IGBT chip

T_{win} : Cooling water temperature

$Rth_{h(j-win)}$: Thermal resistance between junction and cooling water

Fig. 3-3 Thermal resistance equivalent circuit

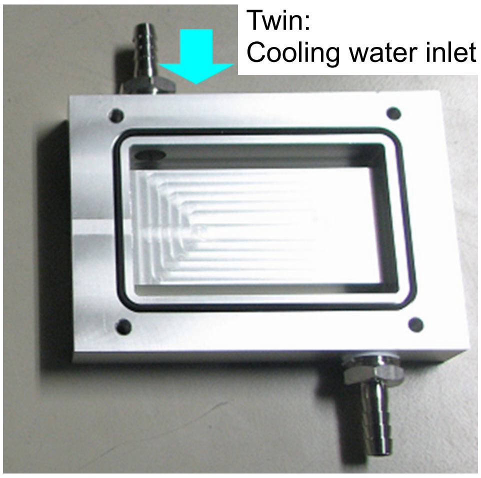


Fig. 3-4 Cooling water inlet temperature

2.2 Thermal equations for transient power loss calculations

Generally, it is enough to calculate Tj in steady state from the average loss calculated as described previous section. In actual situations, however, actual operation has temperature ripples as shown in Fig. 3-7 because repetitive switching produce pulse wave power dissipation and heat generation. In this case, considering the generated loss as a continuous rectangular-wave pulse having a certain cycle and a peak value, the temperature ripple peak value (Tjp) can be calculated approximately using a transit thermal resistance curve shown in the specification (Fig. 3-8).

$$Tjp - Twin = P \times \left[R(\infty) \times \frac{t1}{t2} + \left(1 - \frac{t1}{t2}\right) \times R(t1 + t2) - R(t2) + R(t1) \right]$$

Select a water jacket by checking that this Tjp does not exceed Tjmax.

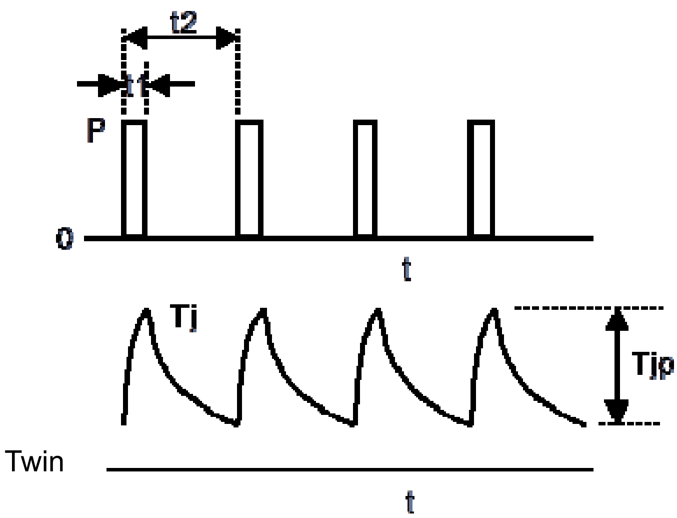


Fig. 3-5 Temperature ripple

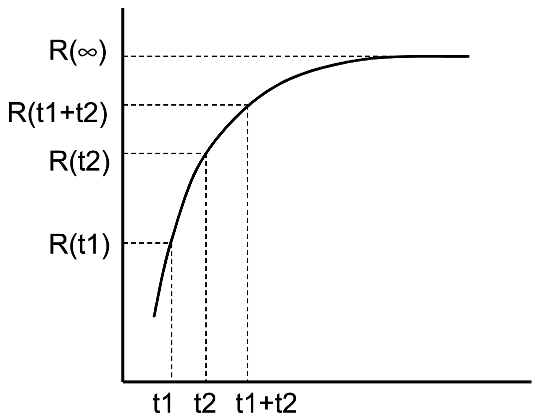


Fig. 3-6 Transit thermal resistance curve

3. Method of mounting the IGBT module

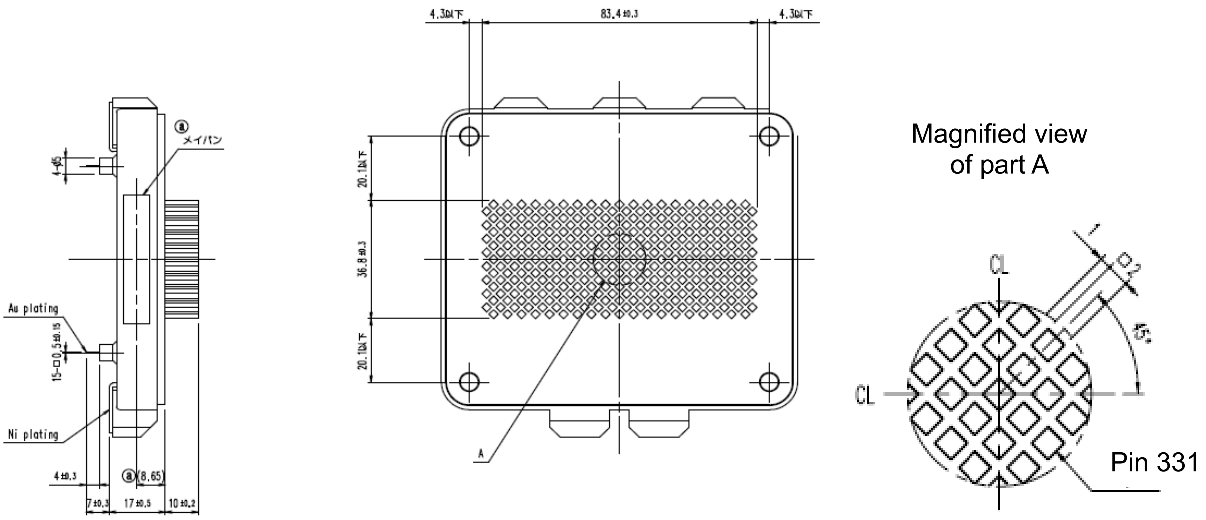
3.1 Method of mounting the module to the liquid-cooling jacket

By mounting the automotive IGBT module to a liquid-cooling jacket and directly cooling it with cooling water, the thermal resistance can be suppressed to lower than the conventional structure which IGBT module is mounted to a heat sink and cooled by air.

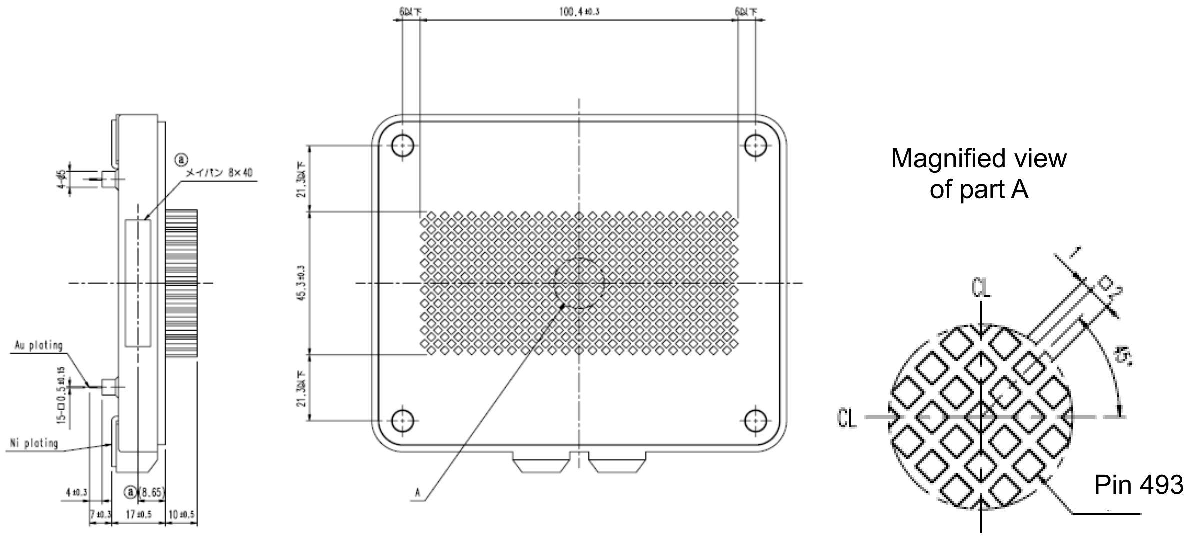
Figure 3-9 is the outline drawing of the module with pin-fin baseplate. The fin base is made of a nickel (Ni)-plated copper (Cu) material. Please make sure not to damage the nickel plating, pin-fins and surface of the base plate when mounting the module. Especially scratches on the base surface might cause a liquid leakage.

Please note following points when you design a liquid-cooling jacket:

- Flow path and pressure loss
- Selection of cooling liquid
- Clearance between the pin-fin and the cooling jacket
- Selection of O-ring



6MBI400VW-065V



6MBI600VW-065V

Fig. 3-7 Outline drawing of the fin

3.1.1 Flow path and pressure loss

The liquid-cooling jacket should be designed with attention to the flow path of coolant because the pressure loss and chip temperature are varied by the state of flow path. As shown in Fig. 3-10, if the coolant flows in a major (long) axis of the pin-fin area (Direction 1), the pressure loss is higher. Meanwhile, if the coolant flows in a minor (short) axis of the pin-fin area (Direction 2), the pressure loss is lower. Regarding chip temperature, the variation of chip temperature can be suppressed if the coolant is fed in Direction 2 rather than Direction 1.

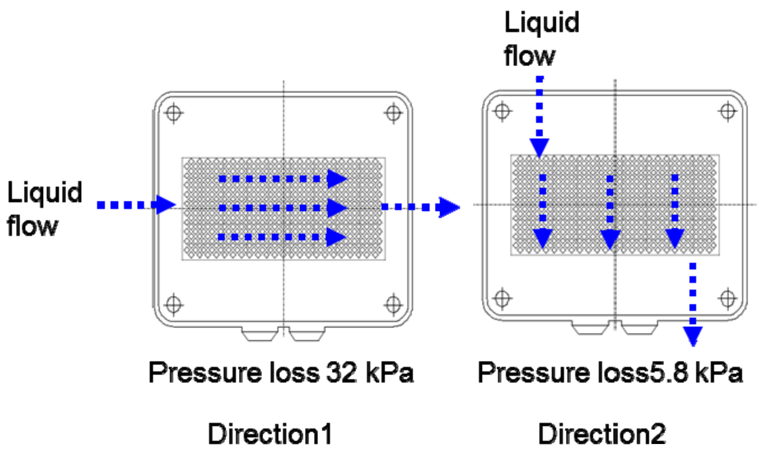
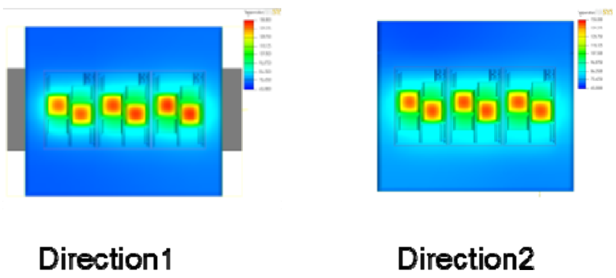


Fig. 3-8 Dependency of pressure loss on flow path



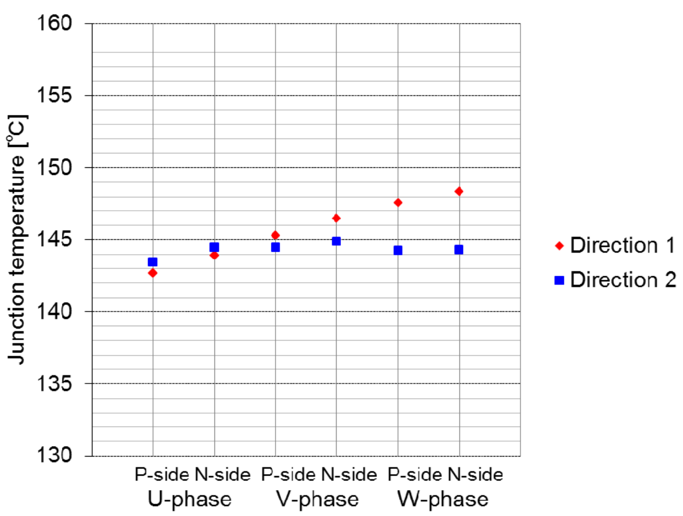


Fig. 3-9 Dependency of chip temperature on flow path

3.1.2 Selection of cooling liquid

A mixed liquid of water and ethylene glycol is a suitable coolant for the direct liquid-cooling system. As cooling liquid, 50% of long life coolant (LLC) aqueous solution is recommended. Impurities contained in the coolant cause a clogging of flow path, and increasing pressure loss and decreasing cooling performance. Please eliminate impurities as much as possible. In addition, if the pH value of the coolant is low, the nickel plating may be corroded. To prevent the corrosion of fin base of the IGBT module, it is recommended to monitor the pH buffer solution and the corrosion inhibitor in the coolant periodically to keep these concentrations over the value which recommended by the LLC manufacturer. Replenish or replace the pH buffer agent and the corrosion inhibitor before their concentration decreases to the recommended reference value or lower.

3.1.3 Clearance between the pin fin and the cooling jacket

Figure 3-12 shows the thermal resistance and pressure loss dependences on the gap between the tip of the pin-fin and the bottom of liquid-cooling jacket. If the gap becomes larger, the pressure loss is smaller. However, the thermal resistance becomes higher because the coolant flows through the gap unnecessarily. The recommended gap length is 0.5 mm.

If the gap between the side of the pin fin and the side wall of the cooling jacket is too large, the coolant flows unnecessarily flow path, thus decreasing cooling performance. Perform design so that the gap becomes as small as possible.

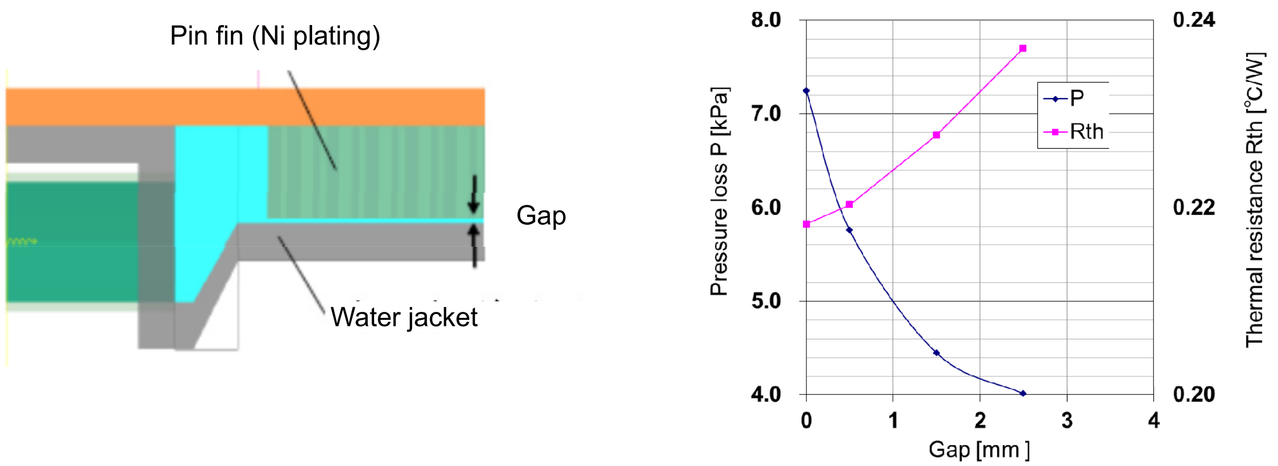


Fig. 3-10 Relation between the gap and pressure loss/thermal resistance

Figure 3-13 shows the relation between the pipe diameter of the inlet and outlet of coolant and the pressure loss when 50% LLC is fed at the flow rate of 10 L/min. If the pipe diameter is too small, the pressure loss increases. The recommended pipe diameter is ϕ12 mm.

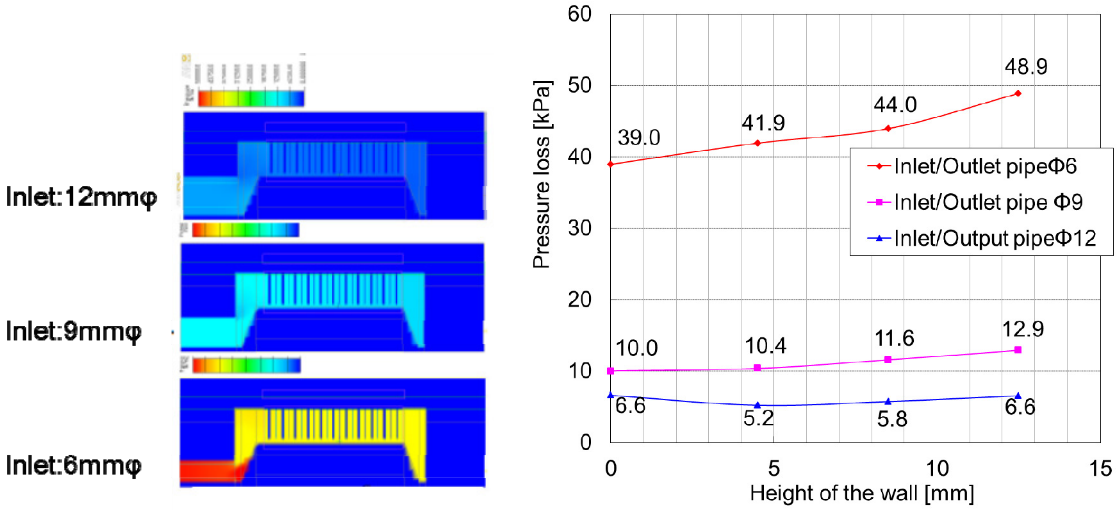


Fig. 3-11 Pipe diameter and pressure loss

3.1.4 Selection of O-ring

Since the IGBT module is mounted to the liquid-cooling jacket via a sealing material, sealing technique for preventing coolant leakage even if temperature and water pressure change is essential. As a sealing material, an O-ring that is mounted by grooving the liquid-cooling jacket is recommended. As the material of the sealing material, ethylene propylene rubber (E116, NOK Corporation) is recommended.

Figure 3-14 shows a typical sealing part. As the diameter of the sealing material, ϕ2.5 mm or larger is recommended. The groove of the water jacket to which the sealing material is to be mounted should be as deep as approximately 0.7 to 0.8 times the diameter of the sealing material. Ensure that the average surface roughness of the sealing surface of the water jacket falls within the following range: Ra<1.6 μm, Rz<6.3 μm.

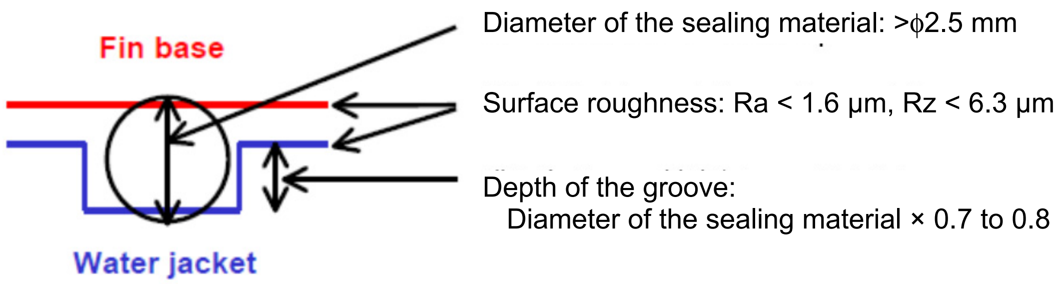


Fig. 3-12 Detailed drawing of the sealing part

3.1.5 Typical water jacket

Refer to figure 3-15(a) and (b) for an example of liquid-cooling jacket for 6MBI400VW-065V/ 6MBI600VW-065V.

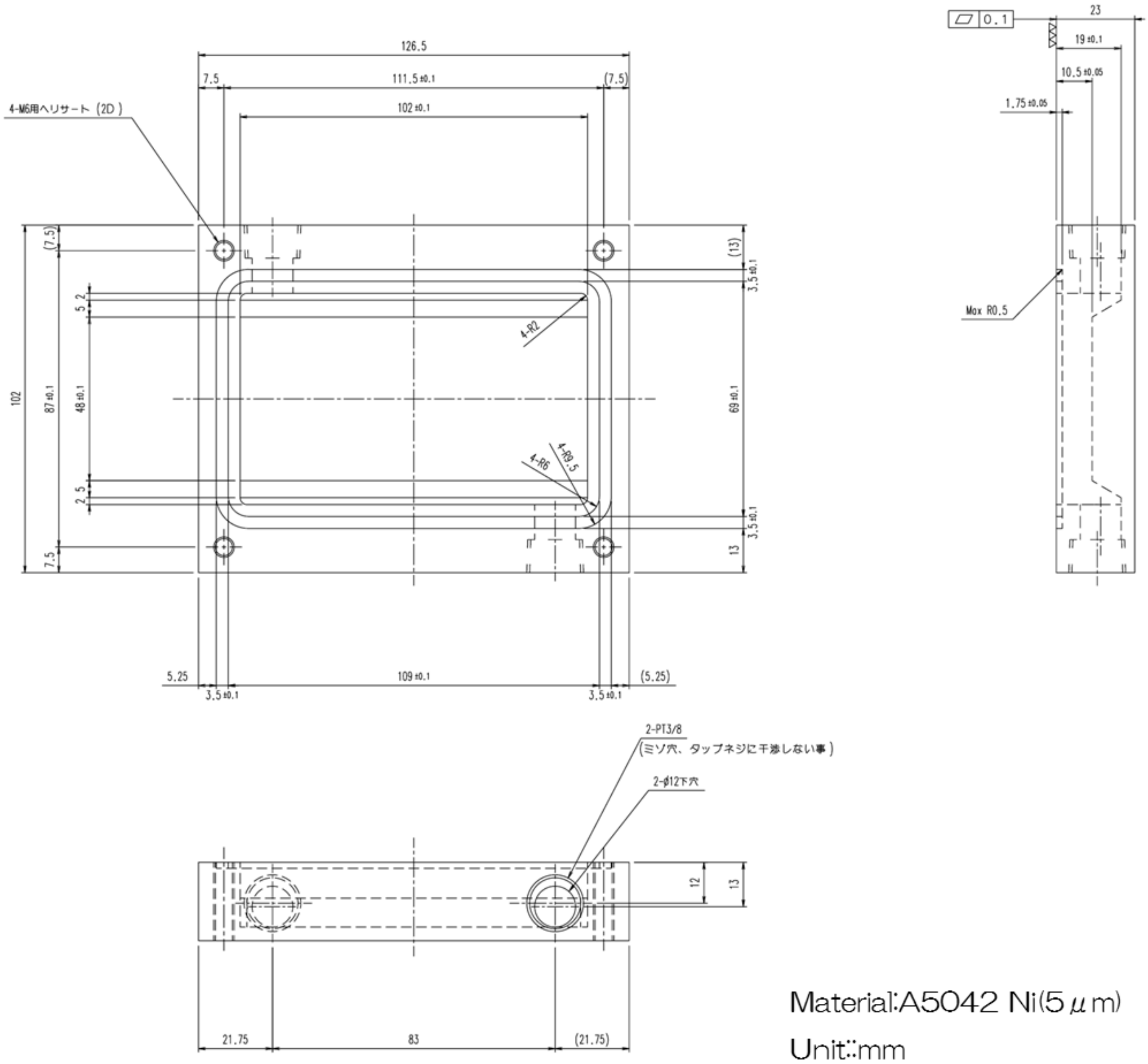


Fig. 3-15(a) liquid-cooling jacket for 6MB400VW-065V

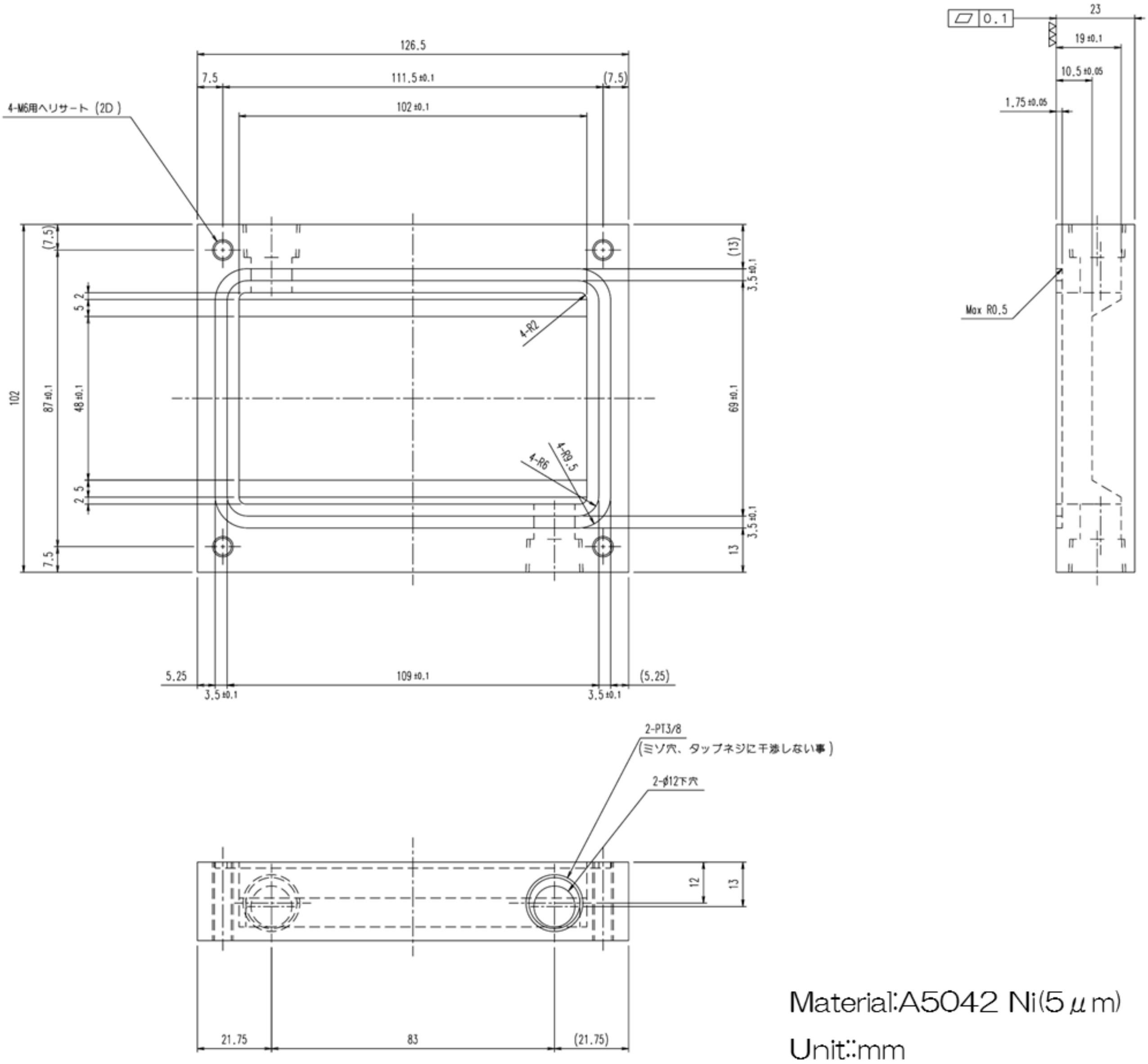
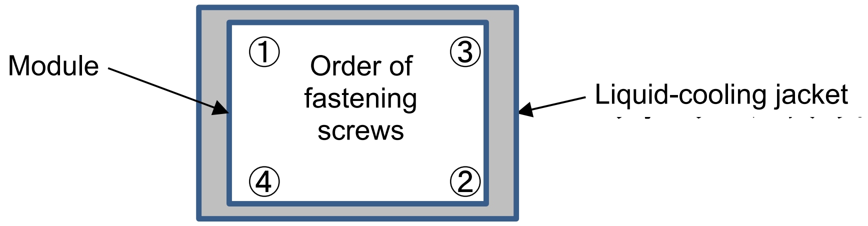


Fig. 3-15(b) liquid-cooling jacket for 6MB600VW-065V

3.2 Mounting procedure

Figure 3-16 shows the procedure of fastening screws when mounting the IGBT module on cooling jacket. The screws should be fastened by specified torque which is shown in the specification. If this torque is insufficient, it would cause a coolant leakage from the jacket or loosening of screws during operation. If excessive torque is applied, the case might be damaged.



	Torque	Sequence
Initial	1/3 specified torque	①→②→③→④
Final	Full specified torque	④→③→②→①

Fig. 3-16 Screw sequence for IGBT module

3.3 Temperature check

After selecting a liquid-cooling jacket and determining the mounting position of the IGBT module, the temperature of each part should be measured to make sure that the junction temperature (Tj) of the IGBT module does not exceed the rating or the designed value.

– Chapter 4 –

Troubleshooting

Contents **Page**

This chapter describes how to deal with troubles that may occur while the automotive IGBT module is handled.

1. Troubleshooting

When the IGBT module is installed in an inverter circuit, etc. a failure of the IGBT module might be occurred due to improper wiring or mounting. Once a failure is occurred, it is important to identify the root cause of the failure. Table 4-1 illustrates how to determine a failure mode as well as the original causes of the failure by observing irregularities outside of the device. First of all, estimate a failure mode of the module by using the table when a failure is happened. If the root cause cannot be identified by using Table 4-1, see Fig. 4-1 as detailed analysis chart for helping your further investigation.

Table 4-1 causes of device failure modes

External abnormalities		Cause		Device failure mode	Further checkpoints
Short circuit	Arm short circuit	Short circuit destruction of one element		Outside SCSOA	Confirm waveform (locus) and device ruggedness match during an arm short circuit.
	Series arm short circuit	Gate or logic Circuit malfunction	Noise, etc.	Outside SCSOA	Check for circuit malfunction. Apply the above.
		dv/dt	Insufficient gate reverse bias. Gate wiring too long	Overheating	Check for accidental turn-on caused by dv/dt.
		Dead time too short	Insufficient gate reverse bias. Date time setting error	Overheating	Check that elements t_{off} and deadtime match.
	Output short circuit	Mis-wiring, abnormal wire contact, or load short circuit.		Outside SCSOA	Check conditions at time of failure. Check that device ruggedness and protection circuit match. Check wiring condition.
	Ground short	Mis-wiring, abnormal wire contact		Outside SCSOA	
Overload		Logic circuit malfunction Overcurrent protection circuit setting error		Overheating	Check logic circuit.
					Check that overload current and gate voltage match. If necessary, adjust overcurrent protection level.
Over Voltage	Excessive input voltage	Excessive input voltage Insufficient overvoltage protection		C-E Overvoltage	If necessary, adjust overvoltage protection level.
	Excessive spike voltage	Switching turn-off		Outside RBSOA	Check that turn-off operation (loci) and RBSOA match. If necessary, adjust overcurrent protection level.
		FWD commutation	High di/dt resulting	C-E Overvoltage	Check that spike voltage and device ruggedness match. If necessary, adjust snubber circuit.
			Transient on state (Short off pulse reverse recovery)		Check logic circuit.
					Gate signal interruptions resulting from noise interference.
Drive supply voltage drop		DC-Dc converter malfunction		Overheating	Check circuit.
		Drive voltage rise is too slow.		Overheating	
		Disconnected wire		Overheating	

External abnormalities		Cause		Device failure mode	Further checkpoints
Gate overvoltage		Static electricity Spike voltage due to excessive length of gate wiring		Avalanche Overvoltage	Check operating conditions (anti-static protection). Check gate voltage.
Overheating	Overheating	Improper flow path design Insufficient flow rate Defect in radiator		Overheating	Check cooling conditions. Check logic circuit. Logic circuit malfunction
	Thermal runaway	Logic circuit malfunction		Overheating	
Stress	Stress	The soldering part of the terminal is disconnected by the stress fatigue.	Stress from external wiring	Disconnection of circuit	Check the stress and mounting parts.
	Vibration		Vibration of mounting parts		
Reliability (Life time)		The application condition exceeds the reliability of the module.		Destruction is different in each case.	Refer to Fig.4-1 (a-f).

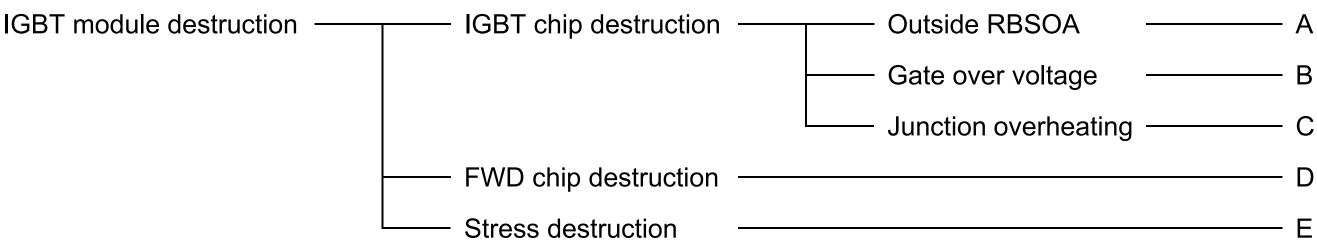


Fig.4-1 (a) IGBT module failure analysis

A. Outside RBSOA

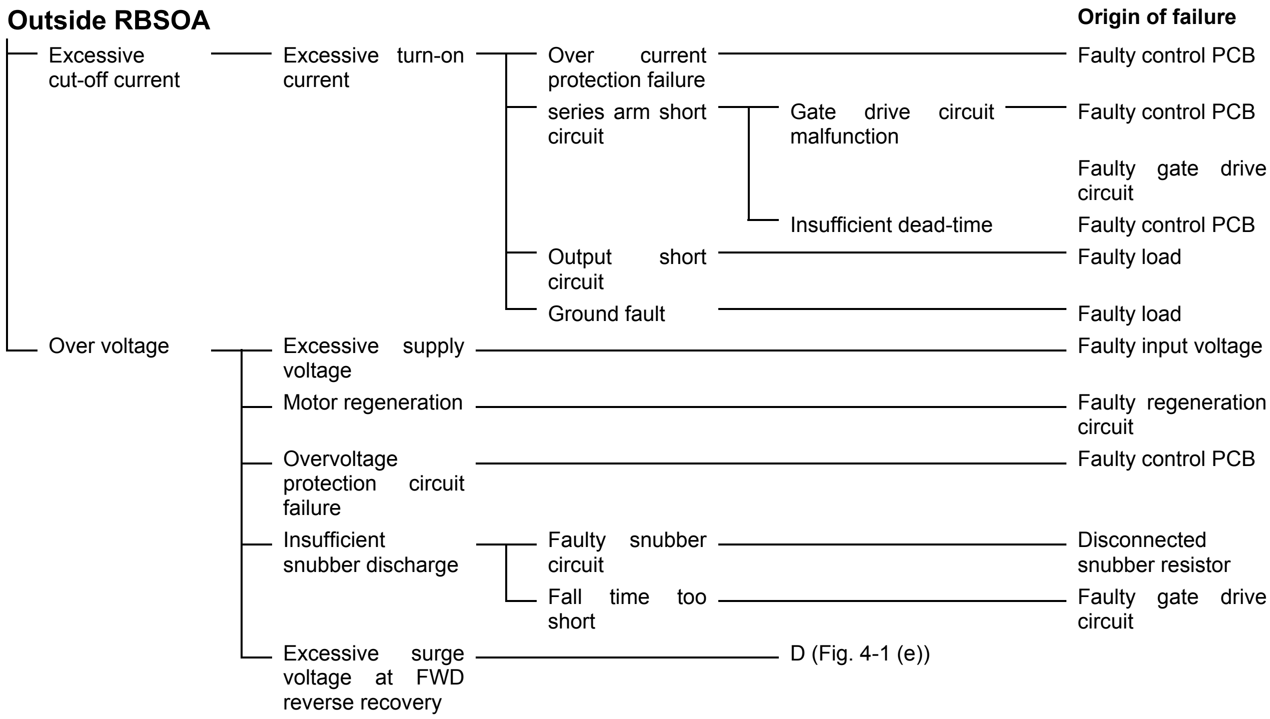


Fig.4-1 (b) Mode A: Outside RBSOA

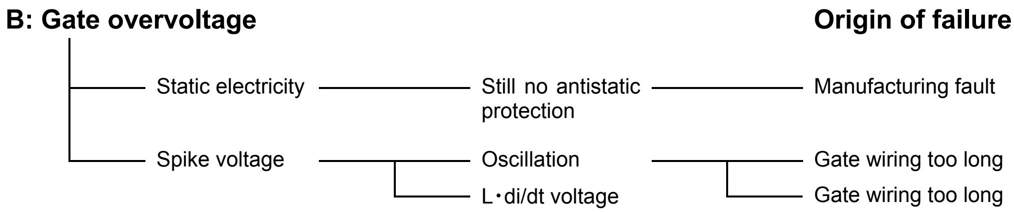


Fig.4-1 (c) Mode B: Gate overvoltage

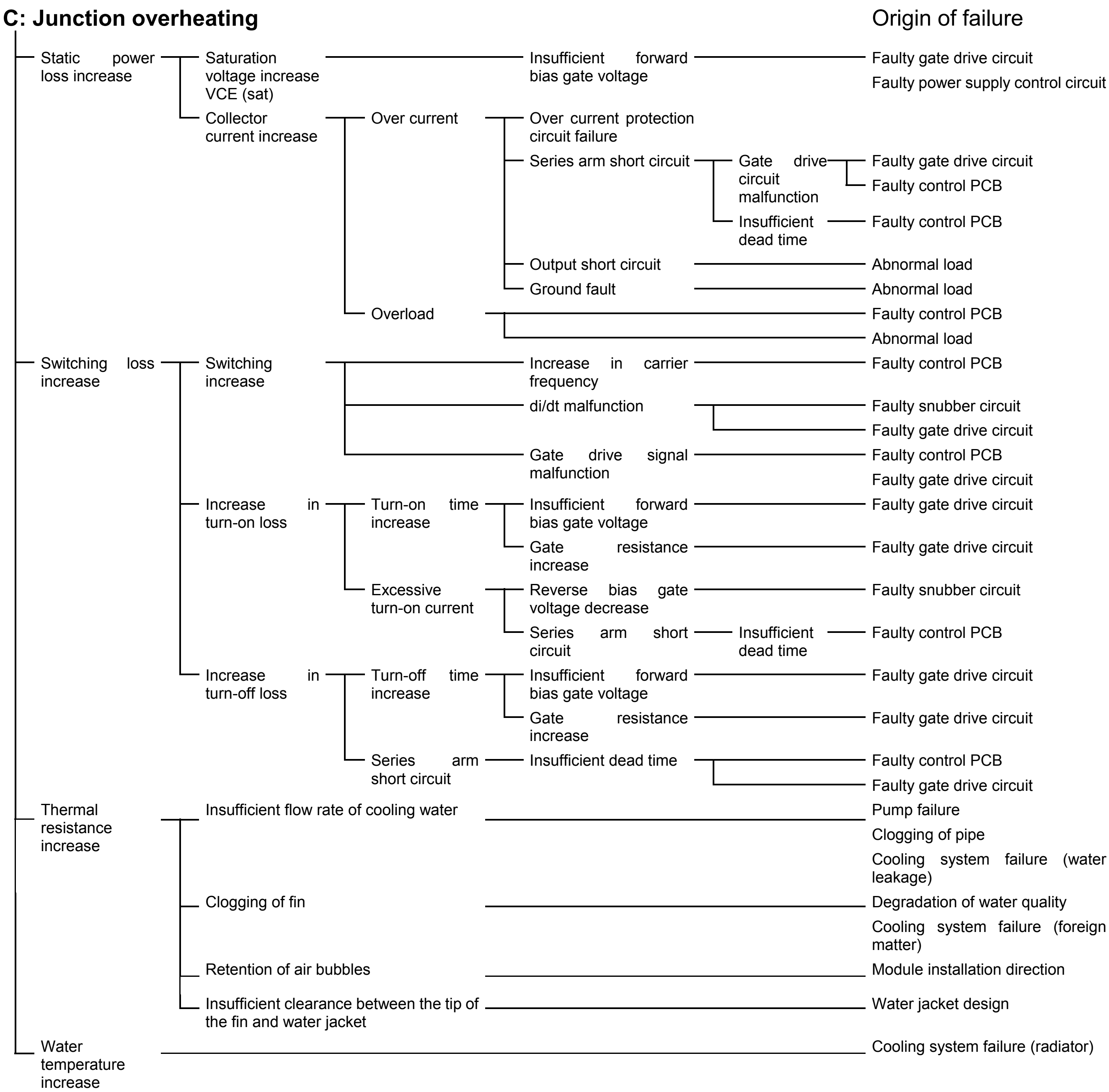


Fig.4-1 (d) Mode C: Junction overheating

D: FWD destruction

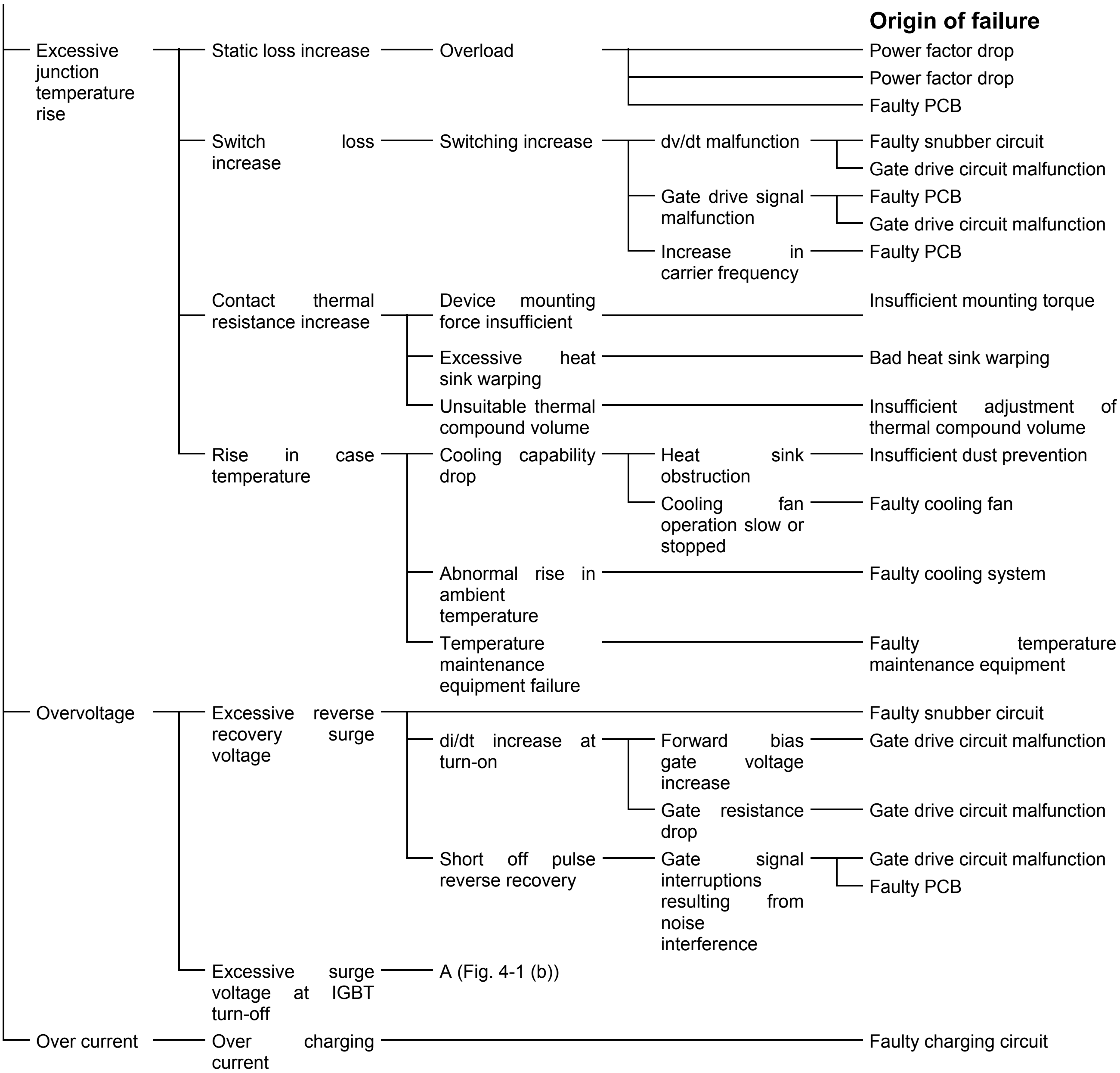


Fig.4-1 (e) Mode D: FWD destruction

E: Reliability issues or product mishandling destruction

Mode	Cause	Detail	Origin of failure
Destruction caused by handling	External force or load	Loading during product storage	Loading conditions
		Stress produced in the terminals when mounted	Stress in the terminal section
		Excessively long screws used in the main and control terminal	Screw length
	Excessive tightening torque		Clamped section
			Terminal section
	Insufficient tightening torque for main terminal screws	Increased contact resistance	Main terminal section
	Vibration	Excessive vibration during transport	Transport conditions
		Loose component clamping during product mounting	Product terminal section
	Impact	Dropping, collision during transport	Transport conditions
	Soldered terminal heat resistance	Excessive heat during terminal soldering	Assembly conditions during product mounting
	Storage in abnormal conditions	Environments where corrosive gases are present	Storage conditions
		Condensation-prone environments	Storage conditions
		Environments where dust is present	Storage conditions
	Destruction on parallel connection	Poor uniformity of main circuit wiring, causing transient current concentration or current oscillation	Uniformity of the main circuit wiring
Reliability (life time) destruction	High-temperature state	Stored at high temperatures for long periods of time	Storage conditions
	Low-temperature state	Stored at low temperatures for long periods of time	Storage conditions
	Hot and humid	Stored in hot and humid conditions for long periods of time	Storage conditions
	Temperature cycle, ΔTc power cycle		Matching between working conditions and product life time
	Thermal stress destruction caused by sharp rises or falls in product temperature		Matching between working conditions and product life time
	ΔTj power cycle		Matching between working conditions and product life time
	Voltage applied for long periods of time at high temperature (between C and E and between G and E)	Used for long periods of time at high temperature	Matching between working conditions and product life time
	Voltage applied for long periods of time in hot and humid conditions (THB)	Used for long periods of time in hot and humid conditions	Matching between working conditions and product life time

Fig.4-1 (f) Mode E: Reliability issues or mishandling destruction

– Chapter 5 –

Reliability

Contents	Page

This chapter describes the reliability of the module.

1. Reliability test

Fuji performs various reliability tests to verify the spec and ensure long term reliability. The following table shows some of the typical reliability tests of the automotive IGBT module. Please refer to the specification for more details.

Table 5-1 Reliability test (environmental test) of automotive IGBT module

5. Reliability test results

5-1. Reliability test item

Test categories		Test items	Test methods and conditions	Reference norms EIAJ ED-4701 (Aug.-2001 edition)	Number of sample	Acceptance number
Mechanical Tests	1	Mounting Strength	Screw torque : 5.8 N·m (M6) 4.5 N·m (M5) Test time : 10 ± 1 sec.	Test Method 402 method I	5	(0 : 1)
	2	Vibration	Range of frequency : 10 ~ 500 Hz Sweeping time : 15 min. Acceleration : 100 m/sec^2 Sweeping direction : Each X, Y, Z axis Test time : 10 hr. / one axis	Test Method 403 Reference 1 Condition code B	5	(0 : 1)
	3	Solderabitlity	Solder temp. : 245 ± 5 ℃ Immersion time : 5 ± 0.5 sec. Test time : 1 time Each terminal should be immersed in solder within 1~1.5mm the body.	Test Method 303 Condition code A	5	(0 : 1)
	4	Resistance to solderring heat	Solder temp. : 260 ± 5 ℃ Immersion time : 10 ± 1 sec. Test time : 1 time Each terminal should be immersed in solder within 1~1.5mm the body.	Test Method 302 Condition code A	5	(0 : 1)
Environment Tests	1	High Temperature Storage	Storage temp. : 125 ± 5 ℃ Test duration : 1000 hr.	Test Method 201	5	(0 : 1)
	2	Low Temperature Storage	Storage temp. : -40 ± 5 ℃ Test duration : 1000 hr.	Test Method 202	5	(0 : 1)
	3	Temperature Humidity Storage	Storage temp. : 85 ± 2 ℃ Relative humidity : 85 ± 5 % Test duration : 1000 hr.	Test Method 103 Test code C	5	(0 : 1)
	4	Temperature Cycle	Test temp. : low temp. -40±5 ℃ high temp. 125±5 ℃ Dwell time : High ~ Low 1 hr 1 hr Number of cycles : 1000 cycles	Test Method 105	5	(0 : 1)

Table 5-2 Reliability test (durability test) of V-series modules

Test categories		Test items	Test methods and conditions		Reference norms EIAJ ED-4701 (Aug.-2001 edition)	Number of sample	Acceptance number
Endurance Test	1	High temperature reverse bias	Test temp. Bias Voltage Bias Method Test duration	: Tj = 150 ℃(-0 ℃/+5 ℃) : VC = 0.8 × VCES : Applied DC voltage to C-E VGE = 0 V : 1000 hr.	Test Method 101	5	(0 : 1)
	2	High temperature bias (for gate)	Test temp. Bias Voltage Bias Method Test duration	: Tj = 150 ℃(-0 ℃/+5 ℃) : VC = VGE = +20 V or -20 V : Applied DC voltage to G-E VCE = 0 V : 1000 hr.	Test Method 101	5	(0 : 1)
	3	Temperature and humidity bias	Test temp. Relative humidit Bias Voltage Bias Method Test duration	: 85±2 ℃ : 85±5 % : VC = 0.8 × VCES : Applied DC voltage to C-E VGE = 0 V : 1000 hr.	Test Method 102 Condition code C	5	(0 : 1)
	4	Intermittent operating life (⊿Tj power cycle)	ON time OFF time Test temp. No. of cycles	: 2 sec. : 18 sec. : 100±5 ℃ Tj ≦ 150 ℃, Ta=25±5 ℃ : 30000 cycles	Test Method 106	5	(0 : 1)

– Chapter 6 –

Recommended mounting method

Contents	Page

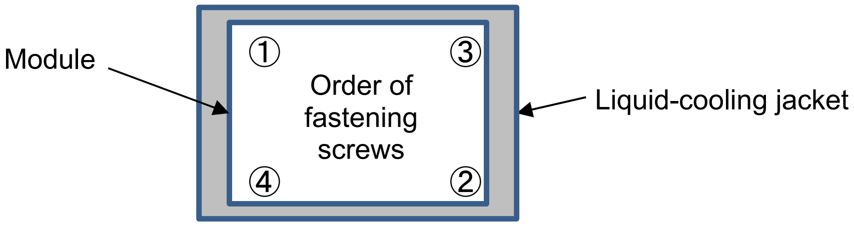
This chapter describes the recommended method of mounting the IGBT module and the PCB.

1. Instruction of mounting the IGBT module

1.1. Method of fastening the module to liquid-cooling jacket

Figure 6-1 shows the recommended procedure of tightening screws for mounting the IGBT module. The fastening screws should be tightened with the specified torque.

See the specification for the specified torque and screws size to be used. If the torque is insufficient, liquid leakage from the cooling jacket may occur, or the screws may be loosened during operation. Meanwhile, if the torque is excessive, the case may be damaged.



	Torque	Sequence
Initial	1/3 of specified torque	①→②→③→④
Final	Full specified torque	④→③→②→①

Fig. 6-1 Screw sequence for IGBT module

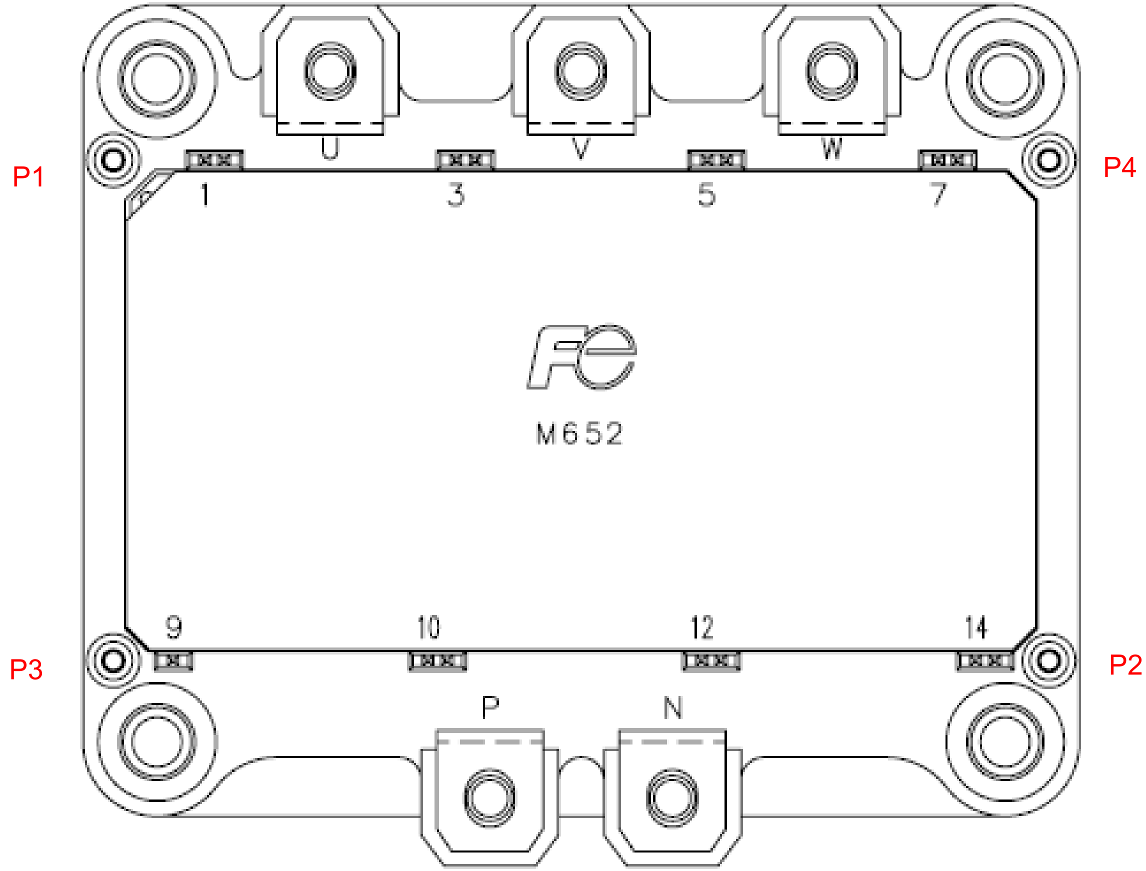
1.2. Method of mounting the PCB and cautions

(a) As screws to be used at positions P1 to P4, M3 cross-recessed head screw with spring lock washer is recommended.
The recommended length of the screw thread is the thicknesses of the PCB plus 5 to 8 mm.
Check the depth of screw holes on the outline drawing.
Adjust the length of the screws depending on the types of the screws used if necessary.

(b) See the specification for the maximum fastening torque of the screws.

(c) Fix the screws temporarily with 1/3 of the final fastening torque and in the sequence P1, P2, P3, and P4 in Fig. 6-2.

FR4 is a recommended material for PCB.



	Torque	Sequence
Initial	1/3 of specified torque	P1→P2→P3→P4
Final	Full specified torque	P4→P3→P2→P1

Fig. 6-2 Method of mounting the PCB

1.3. Electrostatic discharge protection

If excessive static electricity is applied to the control terminal, the module may be damaged. Please take measures against static electricity when handling the module.

2. Connection of the main terminal

2.1. Connection of the main circuit

(a) Recommended screw size: M6

(b) Maximum fastening torque: See the specification.

(c) Length of the screw: Bus bar +7 to 10 mm
Check the depth of screw holes on the outline drawing.
Adjust the length of the screws depending on the types of screws used if necessary.

2.2. Clearance and creepage distance

It is necessary to keep enough clearance distance and the creepage distance (defined as (a) in Fig. 6-3) from the main terminal to secure desirable insulation voltage. The clearance distance and the creepage distance must be longer than the minimum value shown below:

(a) Spatial distance: 10 mm

(b) Creepage distance: 10 mm

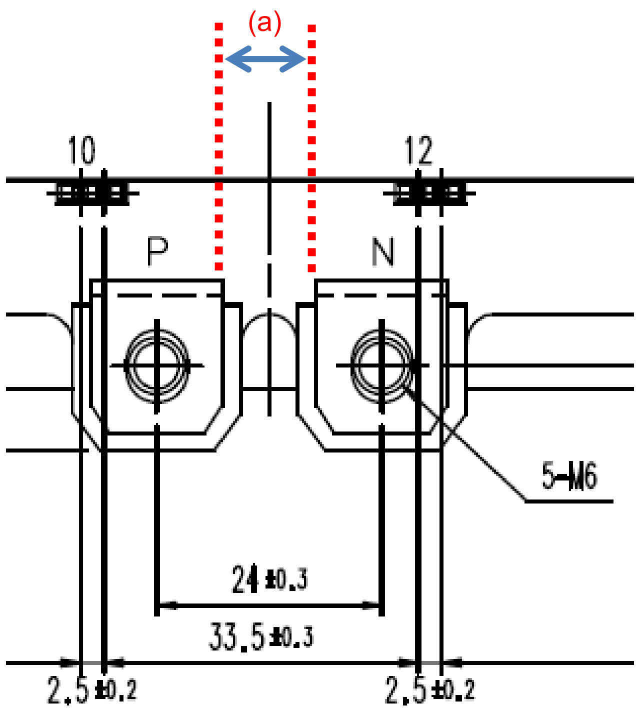


Fig. 6-3 Spatial distance and creepage distance from the main terminal of the IGBT module

3. Soldering of the control terminal

3.1. Plating of the control terminal

The plating of terminal: base coat is Ni plating, surface coat is Ag plating.

3.2. Recommended soldering condition

1) Flow soldering

(a) Maximum temperature: 245°C

(b) Maximum soldering duration: 5 sec.

2) Soldering using soldering iron

(a) Maximum temperature: 385°C

(b) Maximum soldering duration: 5 sec.

– Chapter 7 –

Gate Drive Circuit Board for Evaluation

Contents	Page

This chapter describes the gate drive circuit board for evaluation.

1. Gate drive evaluation for assessment

1.1 Gate drive circuit board exclusively for 6MBI400VW-065V/6MBI600VW-065V

The gate drive circuit board for evaluation designed exclusively by Avago Technology is available for 6MBI400VW-065V and 6MBI600VW-065V. Modules can be evaluated quickly by using this gate drive circuit board.

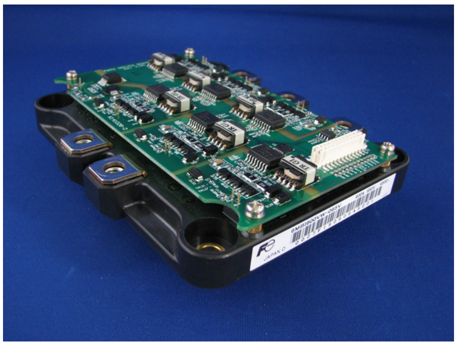


Fig. 7-1 6MBI600VW-065Vmounted with the dedicated gate drive circuit board

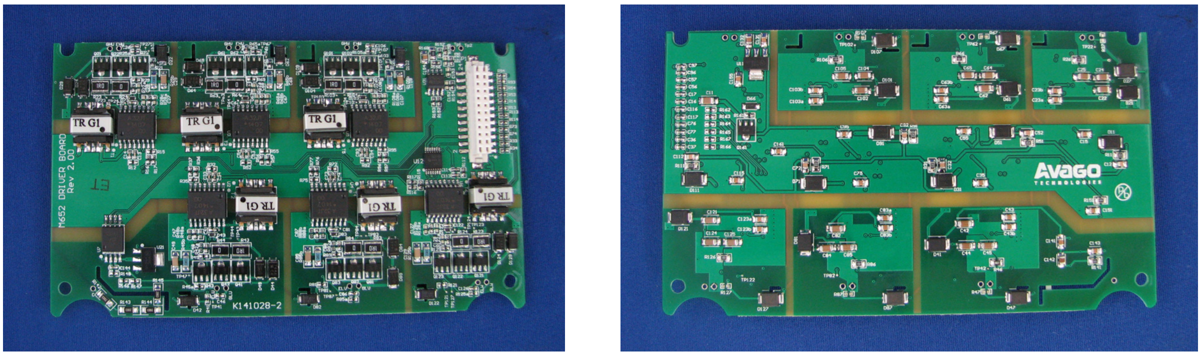


Fig. 7-2 Gate drive circuit board manufactured
by Avago Technologies for evaluation of 6MBI600VW-065

1.2 Gate drive circuit board for evaluation manufactured by Avago Technologies

For handling and precautions for the gate drive circuit board for evaluation, contact Avago Technologies.

Contact::

Japan:	Avago Technologies Japan, Ltd., Technical Response Center Tel: 0120-611-280 e-mail：support.japan@avagotech.com
Overseas:	Soon Aum Andy Poh (Andy Poh) Isolation Products Division, Automotive Marketing (Singapore) e-mail：andy-sa.poh@avagotech.com

1.3 How to mount

See Chapter 6 for soldering and screwing methods for the circuit board.

WARNING

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The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this Catalog, be sur to obtain the latest specifications.

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• Traffic-signal control equipment • Gas leakage detectors with an auto-shut-off feature
• Emergency equipment for responding to disasters and anti-burglary devices • Safety devices
• Medical equipment

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