IGBT

IGBT Module Assembly manual

Introduction

This application note describes IGBT module how to mount the module, and related notes.

Contents

1. Module Assembly

1.1 Recommended Procedure for Installing Module and Components in Inverter

When installing the IGBT module, gate drive board, and cooling component (part of the inverter housing may serve as a cooling component) into the inverter, improper assembly order and method can cause issues such as module deformation or unsuitable stress on the gate drive board. This can result in reduced product lifespan or serious issues such as cooling water leakage. We recommend following the assembly order below.

(1) Fit the module onto the gate drive board (using the guide pins).

(2) Press in the gate drive board (use of press jig is recommended).

(3) Prepare a cooling component equipped with an O-ring or other sealing component (this can be part of the inverter housing).

(4) Attach the module that includes the gate drive board to the prepared cooling system.

(5) Screw the module base plate to the cooling component.

(6) Fix the gate drive board to the inverter housing.

(7) Connect the module's power terminals to the busbars, capacitors, etc.

When mounting the module and gate drive board, always ensure connection reliability and avoid damage to components by tightening the screws according to the torque specified in the corresponding datasheet and this application note.

1.2 Module Mounting

1.2.1 Pin-fin Copper Base Module Mounting

1.2.1.1 Cooling Water Channel Design

Figure 1-1 shows the cross-sectional schematic of the pin-fin module equipped with a water channel (the cooling water would flow perpendicular to this figure). To cool the module efficiently, make sure the flow velocity of the cooling water (ex. 50% LLC solution) through the pin fin area is as high as possible. To do so, the cooling water flow must be limited to the pin-fin area as much as possible. In other words, the gaps between the pin-fin top and the water channel cover (Gap a in Area A) and the gap between the pin-fin side areas and the water channel cover (Gaps b in Areas B) must be as small as possible. If Gaps a and b are large, the amount of cooling water flowing in these spaces (called “bypass flow”) increases, and the amount of cooling water flowing in the pin-fin area decreases (the velocity of cooling water flowing in the pin-fin area is reduced).

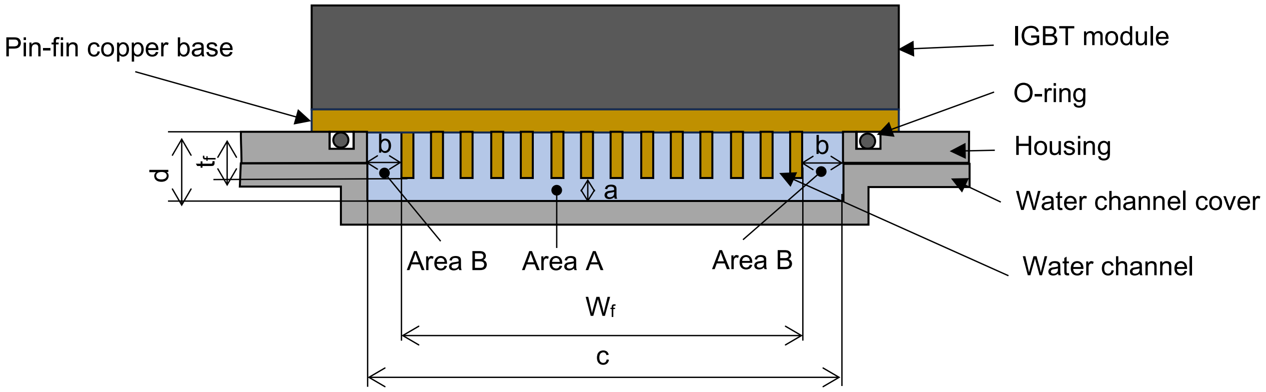


Figure 1-1 Cross-sectional Schematic of Cooling Water Channel and Pin-Fin Module

Assuming that the module is designed so that fin height is t_f and fin tolerance is Δt_f, and the depth of the channel cover is d and cover tolerance is Δd, depending on the design of d and Δd, the pin-fin tips may contact the inner surface of the channel cover, and it may be impossible to firmly fix the back surface of the pin-finned copper base plate to the housing. This means that the O-rings required to achieve a watertight seal cannot be properly compressed, leading to potential cooling water leakage.

To avoid this situation, design water channel cover depth d as follows:

$$d-\Delta d \geqq t_f+\Delta t_f \quad \Rightarrow \quad d \geqq t_f+\Delta t_f+\Delta d \text{ ——— } (1)$$

To ensure efficient flow of cooling water in the fin area, design d to be as small as possible, as follows:

$$d=t_f+\Delta t_f+\Delta d \text{ ——— } (2)$$

On the other hand, a is at maximum when the pin height is low and the water channel is deep, so the maximum value is calculated as follows:

$$a=d+\Delta d-(t_f-\Delta t_f)=d-t_f+\Delta d+\Delta t_f \text{ ——— } (3)$$

Based on equations (2) and (3), a is calculated as follows:

$$a= t_f+\Delta t_f+\Delta d-t_f+\Delta d+\Delta t_f=2\times(\Delta t_f+\Delta d) \text{ ——— } (4)$$

Naturally, to keep a small, the manufacturing tolerance Δd of the channel cover must be as small as possible.

The same argument applies to distance b in Area B. If the tolerance of channel cover width c is Δc and the tolerance of pin-fin area width W_f is ΔW_f, the maximum value of b is as follows:

$$b=\Delta c+\Delta W_f \text{ ——— } (5)$$

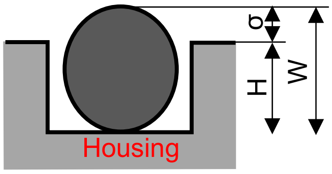
And, to make b smaller, the manufacturing tolerance of water channel cover width c must also be small.

When determining junction temperature for a design, always assume worst-case cooling performance conditions for IGBTs and FRDs and implement a heat transfer coefficient that can be achieved using cooling water flow by taking into account Gap a and Gap b as calculated in equations (4) and (5) above.

1.2.1.2 Designing the O-ring Mounting Area

This section describes how to design the O-ring insertion groove as protection against cooling water leakage. Figure 1-2 shows a cross-sectional schematic of the O-ring and groove in the housing where the O-ring is attached. For the O-ring to function properly and create a watertight seal, the O-ring compression rate (E) must be set appropriately. The lower limit of E is determined by the value at which zero tolerance (a watertight seal) can be achieved. If E is too small, the O-ring's reaction force will be too small to cut off the cooling water. On the other hand, if E is excessive, the O-ring will deform due to retaining strain (called "permanent compressive strain"); the reaction force will not be generated, and the O-ring will not create a watertight seal. In general, the optimal value of E is between 8% and 30%. Tolerances for groove depth H must be designed within this range. To ensure correct usage of O-rings, groove width and inner surface roughness must also be accurate. For details, refer to the O-ring manufacturer's catalog and usage manual.

Furthermore, O-ring materials must be selected based on the liquid to be sealed. For example, ethylene propylene rubber is a good material for O-rings that must be resistant to aqueous LLC solutions at temperatures near 100°C. Refer to the O-ring manufacturer's catalog for the appropriate O-ring materials.



$$E = \sigma / W \times 100$$

E (%): Compression ratio
σ (mm): Compression margin (=W-H)
W (mm): O-ring thickness
H (mm): Groove depth

Figure 1-2 Cross-Sectional Schematic of O-ring and Insertion Groove

The above explanation is based on a simple O-ring with a circular cross section. O-rings are available in a variety of cross-sectional shapes, so please determine the most appropriate product for your target design. Refer to the manufacturer's catalog and follow the above-mentioned compression ratio concept.

1.2.2 Usage Notes for Module Mounting

1.2.2.1 Ensuring Leakage Resistance (watertightness)

When using the flat copper base described in section 1.2.3, the module is usually attached to the back surface of the inverter housing with thermally conductive grease (refer to Fig. 1-3). Since the inside of the inverter housing is fundamentally a closed space, leakage is not a risk. However, with the pin-fin type, which is a direct cooling method, a section of the inverter housing must have an opening so that the module’s copper base comes into direct contact with the cooling water. Damage to the seal of the cooling water channel will allow cooling water to enter the inverter housing. If a leak occurs, any of the circuits in the housing could incur damage, and in the worst-case scenario, there is a risk of electric shock due to leakage current for inverters that have a voltage of 200V or more.

Accordingly, carrying out sufficient reliability testing of leakage resistance is imperative. We recommend that at least the following tests be performed to confirm satisfactory leakage resistance.

(1) The module copper base has a concave back surface with maximum tolerance which reduces the compression margin of O-rings or other sealing methods. Note that there is no need to carry out the test using the actual module. For example, you can test a flat base not equipped with pin fins. (In fact, we recommend testing the flat base, as it has less rigidity than the actual module, and will therefore be a more severe test.)

(2) Use the specified bolts to attach the above-mentioned copper base to a water-cooling jacket, which simulates the actual housing and water channel cover. The water-cooling jacket and copper base should form a sealed space except for the gas and liquid inlets. Set the tightening torque to the lower limit value specified in the module datasheet.

(3) Inject the LCC solution or other liquid, or air or other gas, from the inlet mentioned in (2) above at a significantly higher pressure than that of normal operations (e.g., 100 kPa) and ensure that there is no liquid or gas leakage for a specified period.

(4) Conduct a temperature cycling test on the test structure, for example, from -40°C to 125°C, and follow that with the test described in (3). Finally, confirm that there are no issues with watertightness or airtightness even after 1000 cycles.

1.2.2.2 Water Channel Corrosion Prevention

For indirect cooling, where the flat copper base shown in Figure 1-3 is fixed to the cooling water channel with thermally conductive grease, the cooling water channel is generally composed of the inverter housing and the water channel cover. In automotive inverters, since both the housing and the water channel cover are composed of aluminum diecast (such as ADC12), the cooling water contacts only the same material.

However, in the direct cooling structure shown in Fig. 1-1, the cooling water channel is composed of a nickel-plated copper base and an aluminum diecast, so the cooling water contacts two types of materials. In this case, unlike the conventional indirect cooling structure, galvanic corrosion, must be taken into consideration. When comparing copper or nickel (as a surface plating material) and aluminum, aluminum has a greater tendency to ionize. This means that the cooling water could act as an electrolyte, forming a battery with aluminum as the anode and nickel or copper as the cathode, resulting in severe aluminum corrosion.

The degree of galvanic corrosion mentioned above depends on the anti-rusting characteristics of the cooling water (such as a 50% LLC aqueous solution). Therefore, before using the module, conduct a galvanic corrosion test with the cooling water used in the actual module to ensure an acceptable degree of corrosion.

1.2.3 Flat Cooper Base Module Mounting

1.2.3.1 Mounting with Grease

Figure 1-3 shows the cross-sectional schematic of a flat copper base module attached in a cooling channel. The cooling water would flow perpendicular to this figure. This a general mounting configuration of the prevalent water-cooling method before the appearance of the direct water-cooling method described in section 1-2-1. The fins are installed on the bottom of the inverter housing to form a cooling water channel with the water channel cover. The module is attached directly above the fins with thermally conductive grease. With this mounting, the heat generated by the IGBT and FRD is dissipated through the flat copper base, grease, and fins into the cooling water. Without thermally conductive grease, the microscopic irregularities on the housing surface and on the back of the copper base create microscopic gaps where the two surfaces interface, effectively creating an adiabatic state, and the system cannot function as a heat-dissipating system. It is essential to fill all gaps caused by the unevenness with heat-conductive grease.

In this schematic, the bottleneck for heat dissipation is the grease, which has lower thermal conductivity than metals and ceramics. The key to achieving low thermal resistance is to use grease with the highest possible thermal conductivity while making sure the coating is thin and uniform. The grease must be applied uniformly using a stencil and squeegee. The higher the thermal conductivity of the grease, the greater the content of fillers, etc., and the more difficult it is to apply. Accordingly, when selecting the grease, always take application efficiency for mass production into consideration.

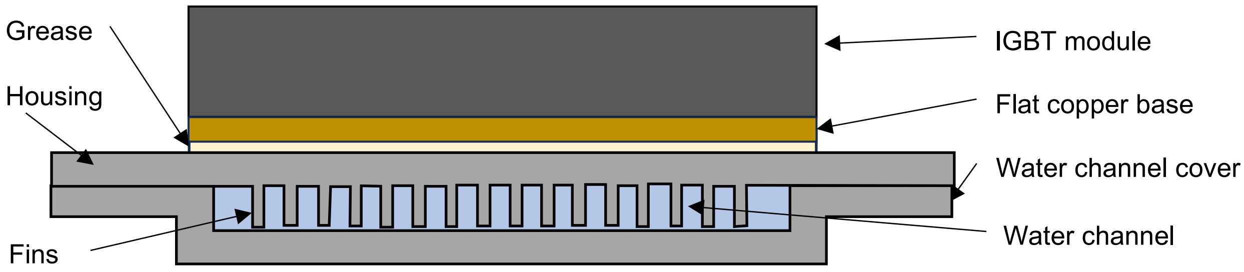


Figure 1-3. Cross-sectional Schematic of Cooling Water Channel and Flat Copper Base Module

1.2.3.2 Direct Water Cooling for Flat Copper Base

Although the superior level of heat dissipation like that of direct water cooling for the pin-finned copper base cannot be expected, a mounting configuration in which cooling water is directly applied to the back surface of the flat copper base is also a useful method. Figure 1-4 shows a cross-sectional schematic of a direct water-cooling system. (The cooling water would flow perpendicular to this figure.) To achieve low thermal resistance in this configuration, the flow velocity of the cooling water must be as high as possible to increase the heat transfer coefficient. To do so, the flow rate must be increased and/or channel depth D reduced. However, a high flow rate is constrained by two factors. First, the pressure loss, which is the differential pressure between the inlet and outlet of the cooling water, must be less than the performance of the flow-through pump used. Second, the inner surface of the channel must be protected from deterioration due to erosion, a phenomenon in which material is eroded away by mechanical action. Electric pumps are generally used for inverters installed in electric vehicles, and low-output pumps are used as they reduce electricity consumption. Therefore, the flow velocity (flow rate) is most often dictated by pressure loss.

One way to increase the heat transfer coefficient without relying solely on high flow velocity is to use a flow path that is shaped to facilitate turbulent flow in the cooling water. For example, as shown in Figure 1-4, consider intentionally disrupting the flow of cooling water by making the bottom of the channel bumpy. This method has a certain effect on achieving a high heat transfer coefficient, but at the same time increases pressure loss. In other words, the advantage of this structure is that it has a certain effect on improving the heat transfer coefficient-pressure loss tradeoff.

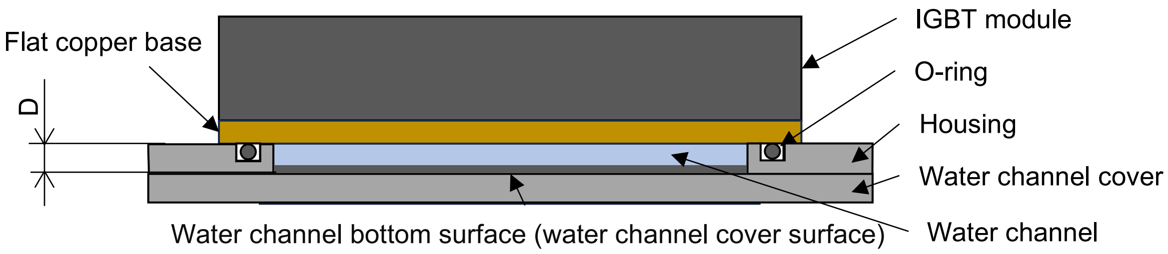


Figure 1-4 Cross-sectional Schematic of Cooling Water Channel and Flat Copper Base Module

1.3 Gate Drive Circuit Board Mounting

1.3.1 Print Circuit Board Specifications for Gate Drive Circuits

The module's control pins are intended to be connected to the through-holes of the gate circuit board (PCB) using press-fit technology. Therefore, the PCB must be a FR4 standard printed circuit board (with tin plating) compliant with IEC 60352-5. In addition, the PCB material must comply with IEC 60249-2-4 or IEC 60249-2-5 is using a double-sided printed circuit board and IEC 60249-2-11 or IEC 60249-2-12 if using a multi-layer printed circuit board. Further PCB specifications are listed below.

Table 1-1 lists the through-hole and other specifications required for the press fit. The specifications indicated here must be followed accurately to ensure the proper connection. Table 1-2 lists the through-hole specifications for PCB positioning guide pins (X-pin and Y-pin). Table 1-3 shows the recommended conditions for component placement and fixing screw holes on the PCB. Stress and strain are applied to the PCB around press-fit pins during press-fitting, so a certain distance is required between the periphery of through-holes for press-fit pins and the mounted components. We recommend two types of specifications for that distance, based on the importance of each component.

Table 1-1 PCB Specifications for Gate Circuits For Press-Fit

No	Item	Min.	Typ.	Max.	Unit
1	Drill tool diameter	1.13	-	1.17	mm
2	Copper thickness in hole	25	-	50	µm
3	Metallization in hole	-	-	15	µm
4	End hole diameter	1.03	1.07	1.11	mm
5	Copper thickness of conductors	35	70-105	400	µm
6	Recommended PCB thickness	-	1.6	-	mm
7	Metallization of circuit board	Tin (chemically)			
8	Metallization of pin	Tin (galvanic)			

Table 1-2 Through-hole Specifications for Gate Circuit PCB X/Y Pins

No	Item	Min.	Typ.	Max.	Unit
1	End hole diameter for X-pin (5.5 mm)	5.82	5.90	-	mm
2	End hole diameter for Y-pin (4.5 mm)	4.82	4.90	-	mm

Table 1-3 Recommended PCB Conditions for Gate Circuits

No	Item	Recommended Conditoins
1	Protective press-fit pin area	・Uncritical or not safety relevant components: ≥ 3 mm radius from hole center ・Other: ≥ 4 mm radius from hole center
2	PCB fixing screw holes	End hole diameter : 3.60 mm Top layer copper diameter: ≥ 7.00 mm Mid layer copper diameter: ≥ 6.50 mm Bottom layer copper diameter: ≥ 6.60 mm

1.3.2 Press-fit Process

The following describes the press jig and press-fit process. We recommend using use the most appropriate jig to achieve stable mass production and highly reliable connections.

Figure 2-1 shows the press jig structure. The side view of the IGBT module is shown along with the jig. The jig structure comprises two components: the top tool and bottom tool. The cylinders formed on the top tool press down on the gate circuit PCB, pressing the PCB onto the module's control pins.

This figure shows the state before the cylinders contact the PCB. During the press process, the top tool and bottom tool must remain parallel to each other, and the PCB must be fixed in place and moved mechanically in the vertical direction only.

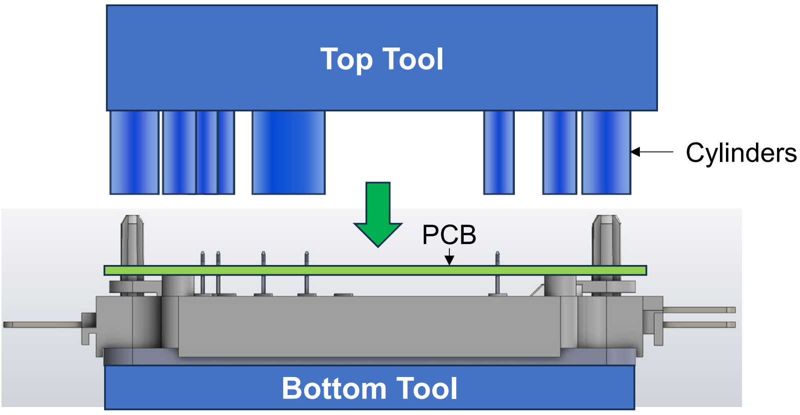


Figure 2-1 Press Jig Structural Schematic

Although not shown in the figure, we also recommend adding two guide pillars on the bottom tool for aligning the top and bottom tools, and creating corresponding cavities in the top tool as receptors for the guide pillars. This ensures the alignment of the top and bottom tools, potentially reducing takt time for mass production.

The top tool must be made of steel or a similar material to withstand the pressing force. The cylinders should be designed in an appropriate number and shape on the PCB so that the pressing force is applied as uniformly as possible. Cylinders placed at control pin positions are essential, and holes should be formed in the cylinders to avoid hitting the pins. Additionally, cylinder height should be adjusted according to the height of the components mounted on the PCB.

When using a pin-finned module, the cavities on the bottom tool must be created in the pin-fin region to avoid applying pressing force on fins. Make sure the pin-fin tips and the bottom tool do not come into contact with the cylinders. In other words, the bottom tool must look like the format shown in Figure 2-2 The area of the bottom tool that contacts the bottom surface of the module is also used by the O-ring or other form of sealing. To ensure watertight reliability, the bottom surface of the module cannot be scratched or damaged. Therefore, the material of the bottom tool must withstand the pressing force while not causing scratches or damage to the module's seal area.

Table 1-4 shows the press-fit process conditions that meet requirements for mass production and high reliability.

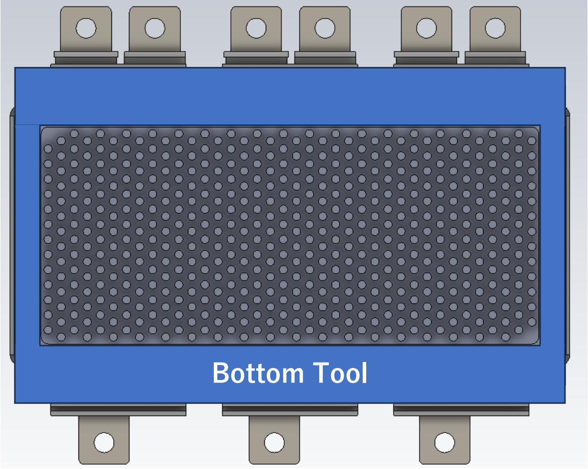


Figure 2-2 Bottom Tool Area Diagram

Table 1-4 Press-fit Process Specifications

No	Item	Min.	Typ.	Max.	Unit
1	Press-in speed	0.4	2 - 4	8	mm/s
2	Recommended press-in stop force Using press-tool with distance keeper	-	-	3.5	kN
3	Recommended effective press-in length	0.9	-	-	mm

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	2024.09.19	-	First edition

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(Rev.5.0-1 October 2020)

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