## Chapter 7 Typical Troubles and Troubleshooting

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This chapter describes typical troubles and how to deal with them.

1. Troubleshooting

When abnormalities such as device failure occurs, it is necessary to clarify the situation and determine the cause before taking countermeasures. Referring to Table 7-1, please investigate the failure mode and analyze the causes of abnormalities by observing the irregularities outside of the device. If the cause cannot be determined by using Table 7-1, use the detailed diagram shown in Fig.7-1(a-f) to help your investigation.

<table>
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<th>Table.7-1 Device destruction mode and cause estimation</th>
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<td><strong>External abnormalities</strong></td>
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<tr>
<td>Arm short circuit</td>
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<tr>
<td>Insufficient dead time</td>
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<td>dv/dt shoot through and causes short circuit failure</td>
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<td>Short circuit failure due to noise etc.</td>
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<td>Wiring mistake, abnormal wire contact, load short circuit</td>
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<td>Short circuit</td>
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<tr>
<td>Matching of turn-on-withstand voltage while use</td>
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<td>Check to failure using the vibration of other mounting as taking help cannot be done</td>
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<td>Overheat</td>
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<tr>
<td>Overcurrent protection setting error</td>
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<tr>
<td>Overvoltage exceeding the device withstand voltage is applied to C-E</td>
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<tr>
<td>Overvoltage protection setting error</td>
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<tr>
<td>Overvoltage at turn-off exceeds RBSOA</td>
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<tr>
<td>Overvoltage during FWD reverse recovery exceeds device withstand voltage</td>
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<tr>
<td>Electromagnetic induction from the main circuit to the gate signal line</td>
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<tr>
<td>( V_{GDr} ) drops below the design value, ( V_{GDr} ) increases, heat generation (loss) increases, causing destruction</td>
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<tr>
<td>Drive supply voltage rise is too slow</td>
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<tr>
<td>Gate signal wiring disconnected</td>
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<tr>
<td>Static electricity is applied to G-E</td>
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<tr>
<td>The gate wiring is too long, resulting in overvoltage exceeding G-E withstand voltage</td>
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<tr>
<td>Destruction by applying C-E voltage (on voltage / withstand voltage measurement, etc.) while the gate is open</td>
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<tr>
<td>Insufficient heat dissipation capacity</td>
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<tr>
<td>Insufficient heat dissipation capacity causes the device to overheat beyond ( T_{Cmax} ).</td>
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<tr>
<td>Insufficient heat dissipation capacity</td>
</tr>
<tr>
<td>Thermal runaway</td>
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<tr>
<td>Stress</td>
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<td>Vibration</td>
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<td>Reliability</td>
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Fig.7-1 IGBT failure analysis diagram (A-E symbols are connected to the following figures)

Fig.7-1(a) Mode A: RBSOA deviation

Fig.7-1(b) Mode B: Gate overvoltage
Fig. 7-1(c)  Mode C: Junction overheating

- **On-state loss increase**
  - $V_{CE(sat)}$ increase
  - $I_e$ increase
  - Over current
  - Over current protection circuit malfunction
  - Series arm short circuit
  - Gate drive circuit malfunction
  - Insufficient dead time
  - Output short circuit
  - Ground fault
  - Overload

- **Switching loss increase**
  - Number of switching increase
  - Carrier frequency increase
  - $d/dt$ malfunction
  - Gate drive circuit malfunction
  - $E_{on}$ increase
  - Turn-on time increase
  - $+V_{GE}$ decrease
  - $R_s$ value increase
  - Excessive turn-on current
  - Excessive snubber discharge current
  - Series arm short circuit
  - Insufficient dead time
  - $E_{off}$ increase
  - Turn-off time increase
  - $V_{GE}$ decrease
  - $R_s$ value increase
  - Series arm short circuit
  - Insufficient dead time
  - Contact thermal resistance increase
  - Insufficient tightening force during mounting
  - Excessive heat sink warpage
  - Insufficient volume of thermal grease

- **Case temperature rise**
  - Decreased cooling capacity
  - Heat sink clogging
  - Cooling fan speed decrease or stop
  - Abnormal rise in ambient temperature
  - Partial overheating of the stack
  - Temperature protection device malfunction

**Origin of failure**
- Abnormal gate drive circuit
- Abnormal control power circuit
- Abnormal control PCB
- Abnormal gate drive circuit
- Abnormal control PCB
- Abnormal load
- Abnormal load
- Abnormal control PCB
- Abnormal load
- Abnormal control PCB
- Abnormal snubber circuit
- Abnormal gate drive circuit
- Abnormal control PCB
- Abnormal gate drive circuit
- Abnormal control PCB
- Abnormal control PCB
- Abnormal control PCB
- Abnormal control PCB
- Abnormal control PCB
- Heat sink warpage failure
- Insufficient adjustment of thermal grease volume
- Insufficient dustproof measures
- Abnormal cooling fan
- Abnormal cooling system
- Abnormal temperature protection device
Fig. 7-1(d) Mode D: Destruction of FWD
Mode E: Reliability

- **Destruction caused by handling**
  - Insufficient screw tightening torque
  - Vibration
  - Shock

- **Loading during product storage**
  - Stress applied on terminals during mounting
  - Excessive contact resistance
  - Excessive vibration during transportation (products, equipment)
  - Loose fixing during product mounting

- **Storage in abnormal condition**
  - Storage in corrosive gas atmosphere
  - Storage in environment prone to condensation
  - Storage in dusty environment

- **Destruction in parallel connection**
  - Poor uniformity of the main circuit, causing transient current concentration and current oscillation

- **Reliability (lifetime)**
  - Long-term storage at high temperature (High temperature storage)
  - Long-term storage in low temperature (Low temperature storage)
  - Long-term storage in hot and humid conditions (Temperature humidity storage)

- **Thermal stress fatigue caused by repeated gradual rise and fall of product temperature** (Temperature cycle, $\Delta T$ power cycle)

- **Thermal stress failure caused by a sudden rise or fall of product temperature** (Thermal shock)

- **Thermal stress failure of internal wiring of products caused by changes in semiconductor chip temperature due to sudden changes in load, etc.** ($\Delta T_{j}$ power cycle)

- **Long-term voltage application in high temperature** (High temperature bias for C-E and G-E)

- **Long-term use at high temperature**

- **Long-term voltage application in hot and humid conditions** (Temperature humidity bias (THB))

- **Long-term use in hot and humid conditions**

※For the results of the reliability test conducted by Fuji Electric, please refer to the specifications or the reliability test result report.

Mode F: Dielectric breakdown

- **Improper insulation sheet installation**

- **Insulation sheet**

Fig.7-1(e) Mode E: Reliability

Fig.7-1(f) Mode F: Dielectric breakdown
2. IGBT Test Procedures

The following items can be determined by using a transistor curve tracer (hereinafter as CT) to check the faulty IGBT.

1. G-E leakage current
2. C-E leakage current (G-E must be shorted)

Other test equipment, such as a Volt-ohm multi-meter that is capable of measuring voltage/resistance and so forth to determine failures, can be used to help diagnose the fault.

**<G-E check>**

As shown in Fig.7-2, measure the G-E leakage current or resistance, with C-E shorted. If the product is normal, the leakage current should be several hundreds nA and the resistance should be several tens of MΩ to infinity. If the leakage current is more than a few nA or the resistance value is less than a few MΩ, the device may be defective.

Do not apply G-E voltage in excess of 20V. When using a Volt-ohm multi-meter, make sure the internal battery voltage is below 20V.

**<C-E check>**

As shown in Fig.7-3, measure the C-E leakage current or resistance, with G-E shorted. If the IGBT is normal, the leakage current should be below $I_{CES \text{ max}}$ specified in the datasheet. Please note the following items.

1. Be sure to connect C to (+) and E to (-). Reverse connections will conduct the FWD thus making measurement impossible.
2. Do not apply voltage higher than the rated value. Applying voltage higher than the rated value may destroy the device.
3. Typical Troubles and Troubleshooting

<How to avoid dv/dt shoot through during FWD reverse recovery>
This section describes how to avoid dv/dt shoot through of the IGBT during FWD reverse recovery. Fig.7-4 shows the causes of dv/dt shoot through. In this fig., IGBT2 is reverse biased. If IGBT1 changes from off to on, FWD2 on the opposite arm goes in to reverse recovery mode. At the same time, the voltage potentials of IGBT2 and FWD2 in the off-state rise, and dv/dt is generated according to the switching time of IGBT1. Since IGBT1 and IGBT2 have C_res, current I = C_res · dv/dt is generated through C_res. This current flow through RG, resulting in rise of VGE. If this VGE exceeds the sum of the reverse bias voltage of IGBT2 and the threshold voltage VGE(th), IGBT2 will be turned-on, resulting in short circuit of IGBT1 and IGBT2.

![Fig.7-4 Principle of dv/dt shoot through](image-url)
Fig.7-5 shows the method to avoid the shoot through.

There are three methods, which are $C_{GE}$ addition, increase of $-V_{GE}$ and increase of $R_G$. Check the effects of these measures as they differ depending on the gate drive circuit. Also, check the effect of these measures on switching loss.

The method to add $C_{GE}$ is the way to decrease the current flowing through $R_G$ by passing through $C_{GE}$. However, in order to charge/discharge the additional $C_{GE}$, switching speed becomes slower. Thus, just adding $C_{GE}$ results in increase switching loss. However, by reducing $R_G$ and adding $C_{GE}$, it is possible to avoid the shoot through without increasing switching loss.

Recommended $C_{GE}$ is about two times the value of $C_{ins}$ described in the specification sheet, and recommended $R_G$ is about half the value before adding $C_{GE}$.
<Energizing main circuit voltage when G-E is open>

When checking the characteristics of a single device, if voltage is applied to C-E when G-E is open, current \( i \) will flow through \( C_{\text{res}} \) of the IGBT as shown in Fig.7-6. As a result, G-E capacitance is charged and the gate potential rises, causing the IGBT to turn-on. Thus, \( I_C \) flows and heat is generated, which may cause destruction. When driving the IGBT, be sure to drive it with a G-E signal. Also, be sure to discharge the main circuit voltage (C-E) to 0V before switching the gate signal.

Fig.7-7 shows an example of on-voltage measurement circuit. The measurement sequence is described with reference to this measurement circuit. First, turn-off the gate drive unit (GDU) \((V_{GE}=0V)\). Then turn-on SW1 to apply C-E voltage. Next, apply predefined forward bias voltage from the GDU to energize the IGBT, and measures the on-voltage. Lastly, turn-off the gate circuit and turn-off SW1. This sequencing will allow for the safe measurement of device characteristics without risking destruction.

Fig.7-6 IGBT behavior when G-E is open

Fig.7-7 On-voltage measurement circuit

DUT: IGBT under test, GDU: Gate drive circuit, G: Variable AC power supply, CRO: Oscilloscope, \( R_1, R_2 \): Protective resistance, \( R_3 \): Current measurement non-inductive resistance, \( D_1, D_2 \): Diode, SW1: Switch
<Diode reverse recovery from transient on-state (short off pulse reverse recovery)>

If very short off pulses are generated when gate signal interruption happens due to noise while driving the IGBT, excessive reverse recovery overvoltage will occur. This phenomenon is called the short off pulse reverse recovery. Fig.7-8 shows the timing chart of this phenomenon.

In Fig.7-9, when an off signal $T_w$ is generated at $V_{GE}$ during period $T_{on}$ in which IGBT2 is on, IGBT2 is turned off while FWD1 on the opposite arm side is turned on, and IGBT2 is immediately turned on again while FWD1 goes into reverse recovery. Normally, reverse recovery started after sufficient carriers are accumulated in the FWD. On the other hand, in the short off pulse reverse recovery, FWD goes into reverse recovery without sufficient carrier accumulation. As a result, the depletion layer spreads rapidly in the FWD, causing steep $\text{d}i/\text{d}t$ and $\text{d}v/\text{d}t$, and very large C-E (A-K) overvoltage as shown in the dotted line in Fig.7-8. If the overvoltage exceeds the device voltage rating, the device may be destroyed. When designing the equipment, be careful not to design a circuit that will generate such short gate signal off pulse.

![Fig.7-8 Waveforms during short off pulse reverse recovery](image1)

![Fig.7-9 Circuit diagram](image2)
<Precautions in parallel connection>

When using IGBT to control large current, IGBTs may be connected in parallel. If the current is not balanced among the IGBTs, current may concentrate on one device and destroy it. The electrical characteristics of the IGBT as well as the wiring design, affect the current balance between parallel connected IGBT. In order to maintain current balance it is necessary to match the $V_{CE(sat)}$ values of all devices. When connecting in parallel, we recommend to use products from the same product lot.

When the main circuit wiring is uneven, uneven voltage is generated in the inductance of each wiring due to $di/dt$ during switching, and oscillating current flows through the control side wiring loop of the emitter connected in parallel, causing the gate voltage to oscillate. This oscillation may cause the IGBT to malfunction.

Balanced current sharing can be achieved by using symmetrical wiring to prevent the above-mentioned IGBT malfunction (see Fig. 7-10).

![Equivalent circuit of parallel connection](image)
Fig.7-11(1) shows the oscillation phenomenon when the wiring inductance of the emitter is made extremely unbalanced.

A common mode coil can be inserted in each gate emitter wiring to eliminate the loop current in the emitter. Fig.7-11 (2) shows the waveforms with the common mode coil. Compared with Fig.7-11(1), oscillation is suppressed.

Fig.7-12 Parallel circuit with common mode coil inserted