Method of avoiding plastic IGBT module's torque loss in harsh application environment

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Abstract

This paper carried out environmental experiments that simulate the practical application of plastic housing modules, such as high-temperature storage, temperature cycling, vibration, etc. These experiments show the loss of torque after installation of the plastic housing IGBT module. Using the Norris-Landzberg model simultaneously, it can be inferred that the installation will fail after 52,560 cycles. To solve this issue, the plastic modules with drop-resistant screws or add thread glue can be well installed. Through the thermal resistance test, it is concluded that the torque loss of the drop-resistant screw affects the thermal resistance of the module by about 2%. Therefore, in order to simplify production, the use of drop-resistant screws allows the module to be used in harsh environments.

1 Introduction

Fig.1 shows an IGBT module in a plastic housing. The module is mounted on the heat sink via M4 screws. However, the elasticity of plastic is small, and screws in plastic holes will loosen in the application.

Fig.1 IGBT module of MACMIC plastic housing

2 The phenomenon of torque loss

The authors carried out environmental experiments that simulate the practical application of MACMIC plastic enclosure modules. These experiments show the loss of torque after installation of the MACMIC plastic housing IGBT module. The specific torque change is shown in **Fig.2**.

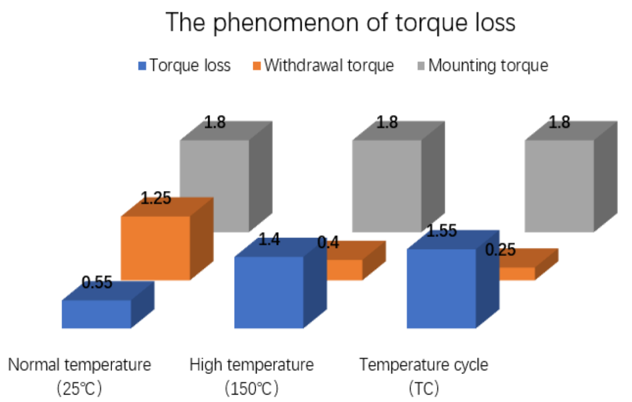

Fig. 2 The torque loss of standard M4 screws in the plastic hole of the module

As shown in the figure above, the IGBT module with plastic shell will lose some of the torque in the direct test after installation, but the remaining torque can ensure that the module is stably installed on the radiator. However, when the IGBT module is used, the temperature of the module shell also increases with the heating of the device. The plastic shell will deform after high temperature, causing the screws to loosen. What is more serious is the intermittent use of the module, then the plastic shell is in a cold and hot cycle environment, at this time the screw torque of the installation module is almost all lost, which has a huge impact on the long-term stable use of the module.

3 Analysis of torque loss

The installation of plastic holes can cause fatigue failure due to temperature cycling. The Norris-Landzberg model is suitable for fatigue failure caused by temperature cycling. The accelerated life data is analyzed by the General log-linear (GLL) model, and the parameters of the Norris-Landzberg model can be obtained by parameter transformation.

Norris-Landzberg model expression:

$$N_f = C(f)^{-m}(\Delta T)^{-n}e^{\frac{E_a}{k}(\frac{1}{T_{max}})}$$

Nf: the number of cycles at failure,C: coefficient,f: cycle frequency (cycles/day);

ΔT: Temperature range in one cycle (K) ;

Tmax: Maximum temperature value per cycle (K);

Ea :activation Energy (eV);

K: Bozeman's constant (8.617 x 10-5 eV/K);

m,n: model parameters.

The acceleration factor (AF), the ratio of the lifetime under actual stress (Nf,use) to the life under accelerated stress (Nf,acc), can be expressed as:

$$AF = \frac{N_{f,use}}{N_{f,acc}} = \left(\frac{f_{use}}{f_{acc}}\right)^{-m} \left(\frac{\Delta T_{use}}{\Delta T_{acc}}\right)^{-n} e^{\frac{E_a}{k}\left(\frac{1}{T_{max,use}}-\frac{1}{T_{max,acc}}\right)}$$

In the general log-linear (GLL) model, the characteristic life L is related to stress as follows:

$$L(\bar{X}) = e^{\alpha_0+\alpha_1 X1+\alpha_2 \mathrm{X2}+\alpha_3 X3}$$

Corresponding to the Norris-Landzberg model, the logarithmic transformation of f and ΔT is performed, and the reciprocal of Tmax is taken: X1=ln(f), X2=ln(ΔT), X3=1/Tmax, yielding:

$$L(\bar{X}) = e^{\alpha_0+\alpha_1 \ln(f)+\alpha_2 \ln(\Delta T)+\alpha_3\left(\frac{1}{T_{max}}\right)}$$
$$= e^{\alpha_0} f^{\alpha_1} \Delta T^{\alpha_2} e^{\alpha_3\left(\frac{1}{T_{max}}\right)}$$

Comparing the above equation with the equation of the Norris-Landzberg model, the correspondence of each parameter can be derived:

C = eα0,m = -α1,n = -α2,Ea/K =α3.

The following test is an accelerated life test that uses three stresses and satisfies the GLL life-stress relationship for the torque change of a plastic housing installation.

Table 1 shows the results of the temperature cycle test and the Settings for different stress levels. For three stress models, the test requires at least four different stress combinations. Assume that 10 samples are tested for each stress combination. Check the sample every hundred temperature cycles.

f(cyc/day)	ΔT(k)	Tmax(k)
6	165	398.15
12	165	408.15
24	175	408.15
24	175	418.15

The experimental results are shown in **Table 2.**

Table 2. Experimental result

Number	Rusult	Cycle	Number	Rusult	Cycle
1	S	100	1	F	100
1	F	200	1	F	200
2	F	300	2	F	300
3	F	400	3	F	400
3	F	500	3	F	500
2	F	100	2	F	100
3	F	200	3	F	200
3	F	300	3	F	300
2	F	400	2	F	400

Assuming that the life distribution follows lognormal distribution, AF=52.56 is calculated by modeling SPSS.

Combined with the experimental data, the average life expectancy under actual stress is：

$$F = 100 \times 52.56\ cyc$$

This number of cycles is not enough to support the product life cycle.

4 Improvement mounting solution

After the standard M4 screws are locked in the plastic hole housing, the screw installation torque will be lost. According to the acceleration factor AF=52.56, if the customer needs to meet the stable operation of the whole machine for 15 years, then the reliability acceleration test needs to be carried out 2500 cycles without sample failure.

In order to make the module with plastic shell pass the accelerated reliability test of torque loss after installation, the method of avoiding torque loss is studied. Common methods are: adding elastic gaskets, using self-tapping screws, adding thread glue, using falling screws and so on.

It is obviously not practical to install the plastic module to the radiator using self-tapping screws. Therefore, three methods of increasing elastic gasket, adding thread glue and using falling screws are studied to reduce torque loss.

4.1 Adding elastic gasket

Fig 3 Elastic gasket

Fig. 3 shows the elastic gasket.When the elastic gasket is used with the screw, the screw presses the washer. When the screw is gradually tightened, the spiral gasket is slowly flattened. There is always a counter-spring inside the flattened spring washer. When the external pressure is less than the internal recoil of the spring, the spring washer tends to change toward restoring original shape. Due to the existence of internal spring rebound force.When the bolt is slightly loose, the spring washer can compensate for the loss of bolt pre-tightening force to a certain extent.

Fig.4 shows the torque change of the plastic module after 50 temperature cycles with the addition of elastic gaskets.

According to the experimental results, the installation of plastic modules with elastic gaskets has no effect on reducing the loss of torque. Therefore, this method is not recommended.

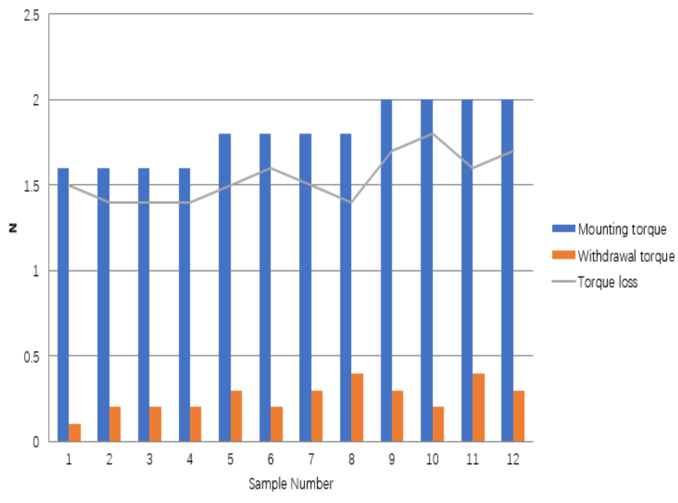

Fig.4 Torque change after adding elastic gaskets to plastic mounting holes and performing 50 temperature cycles

4.2 Adding thread glue

Fig.5 shows the torque change in the plastic mounting hole after 50 temperature cycles with thread glue added. From the experimental results, the thread glue avoids torque loss very well.

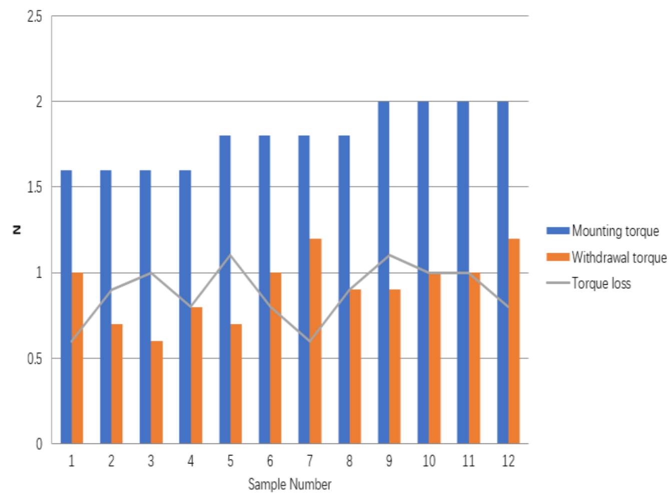

Fig.5 Torque change after 50 temperature cycles are added to the plastic mounting hole

To verify that modules mounted with thread glue can pass a prolonged accelerated reliability test, 30 modules are mounted on metal radiators and the results are verified through no less than 2500 temperature cycles. The results of the final acceleration reliability of thread glue are shown in **Table 3.** Where "Pass" means that the residual torque is greater than 0.3N.m, "Fail" means that the residual torque is lower than or equal to 0.3N.m.

Table 3. Results of temperature cycle test of modules installed with thread glue

NO.	Temperature cycle number			
	2500	2500~3000	3000~3500	3500~4000
#1~#10	pass	#3 Fail	#1,#4,#6~#7 Fail	#2,#8,#10 Fail
#11~#20	pass	#11,#19 Fail	#13,#17 Fail	#14,#16,#20 Fail
#21~#30	pass	#23 Fail	#24~#27 Fail	#21,#29,#30 Fail

According to the experimental results, the modules installed with thread glue have passed the minimum temperature cycle requirements, which can meet the application requirements. However, because the production of the product needs to add a process and the module has aesthetic problems.This scheme is recommended as an alternative.

4.3 Using drop-resistant screws

Drop-resistant screws are permanently adhered to the threads of the screws using special engineering resins. This allows the screws and nuts to be squeezed during locking to prevent the screws from loosening.

Fig.6 shows the torque change of the plastic mounting hole using drop-resistant screws and 50 temperature cycles. From the experimental results, the drop-resistant screw has a good effect of improving torque loss without thread glue. However, it is convenient for the production line to carry out mass production.

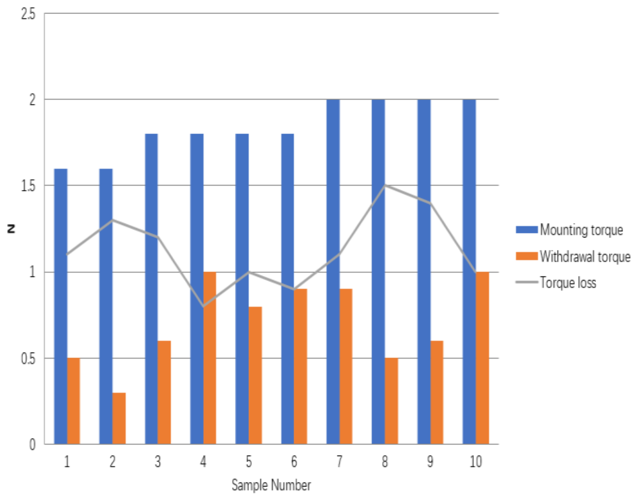

Fig.6 Torque change of 50 temperature cycles by using drop-resistant screws

In order to verify that the installation with fall screws can meet the application, 30 modules were selected to be mounted on metal radiators and temperature cycling experiments were carried out. The experimental results are shown in **Table 4.**

Table 4. Temperature cycle test results of fasteners mounting module

NO.	Temperature cycle number		
	2500	2500~3000	3000~3500
#1~#10	pass	#2~#7 Fail	#1,#8~#10 Fail
#11~#20	pass	#11~#19 Fail	#20 Fail
#21~#30	pass	#23~#26,#29 Fail	#21,#22,#27,#28 Fail

According to the experimental results of accelerated aging of the bolts, the bolts can basically meet the application needs of customers. However, the torque loss of the falling screw installation is more serious than that of the thread glue installation. But the screw can easily replace the ordinary screw, it is convenient to produce. Therefore, the fasteners are worth the practical application.

The above two available installation methods, torque in the end will not be much.The customer will be concerned that the module installation torque is large at the beginning, the module will conduct heat better, and the thermal resistance will be small. However, if the torque is lost, the remaining small torque will not increase the thermal resistance. Through the thermal resistance test before and after the torque loss, the author found that the torque loss would not affect the thermal resistance of the product.

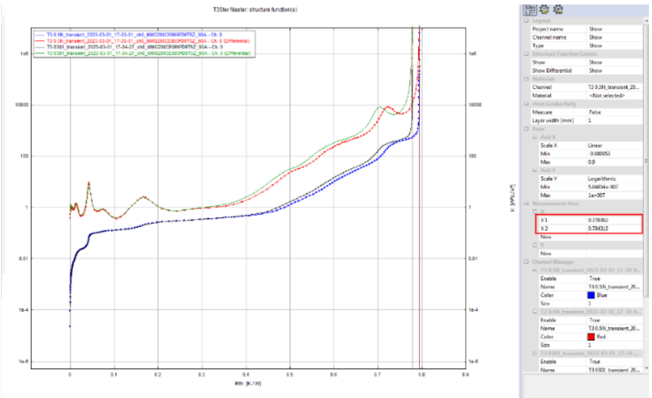

Fig.7 Thermal resistance of the module installed at forces of 0.3N.m and 2.0N.m

Fig.7 shows the thermal resistance values installed under the force of 0.3N.m and 2.0N.m, and the thermal resistance is 0.7943K/W and 0.7784K/W. The difference between the two is 2.04%.

The thermal resistance test is first to test the thermal resistance of the plastic module when 2.0N.m is used. After the test is completed, loosen the screw torque to 0.3N.m and test the thermal resistance again. T3ster was used to analyze the two thermal resistance and integrate them together to compare the results.

5 Conclusion

If the IGBT module of plastic shell is installed with ordinary screws, torque loss will occur in a long-term harsh application environment. The loss of torque does not guarantee that the module can work stably throughout the life of the machine. Therefore, torque loss can be reduced by adding thread glue and using falling screws.

The use of thread glue avoids torque loss.But this method adds an additional step to the production process. Even if the glue filling technology is not qualified, the appearance of the product will also have an impact. Production steps can be simplified if plastic modules are mounted with the drop-resistant screw. At the same time, it can ensure the stable operation of plastic modules in harsh environments.

6 References

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