Self acting PressFIT module

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Abstract

Customers of power electronics require more and more new, easy connection and mounting technologies. The PressFIT technology offers the possibility of solderless mounting combined with an improved reliability in comparison to soldering.

To continue this approach, a new module platform based on PressFIT technology has been developed which furthermore offers an extremely fast and robust mounting concept to improve the manufacturing, reliability and design of the inverters. Special focus has been put on mechanical robustness. Avoiding the risk of DCB cracks resulting from controllable forces originating from the module design, was one of the main approaches. To demonstrate the robustness, some mechanical tests have been done.

1. Mounting & connection of power modules

1.1. State of the art

If a power semiconductor module has two be mounted within a common inverter design, it is mostly fixed by screws. Screwing is a well known fastening process and due to this preferred by most customers of modules.

Unfortunately, a screw has two parameters, which can vary in the application and mounting procedure and which have important impact on the resulting pretensioning force. These are the friction within the thread and screw head, as well as the fastening torque itself. For dimensioning a bolted connection, is has to be evaluated, what the boundaries are and how they vary. The Fastening torque can be estimated then with the following approximation formula:

$$\mathbf{Fv=M/(0.159*P+\mu*0.577*d2+Dkm*\mu/2)}$$

Fv:=Pretension (Force); M:=Torque P:=Thread pitch; μ:=Friction coefficient; d2:=Screw thread diameter; Dkm:=Effective diameter

Fig. 1. Pretension approximation formula.

As an Example, the variation is calculated in figure 1 with a torque of 8.5Nm and a friction range of 0.11 to 0.17. Actually, the friction for an aluminium heatsink combined with a zinc coated screw is around 0.14. It shows the wide variation due to the interrelations between torque, friction and pretension: The resulting force varies roughly from 4.7KN up to 6.9KN.

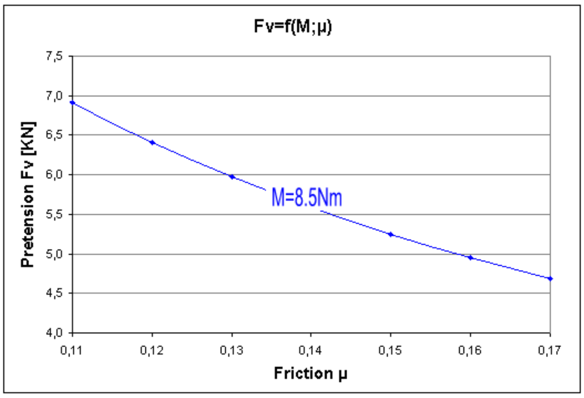

Fig. 2. Interrelation example between torque, friction and pretension.

1.2. Common subjects

Due to the variation possibilities of a screw fastening, there are some common subjects, which have to be covered by the power module suppliers and their customers as well.

1.2.1 Mounting effort

A typical power module up to the power range of 55KW is designed with several screw fixing points to the heatsink and to the PCB. The fastening to the heatsink is mandatory to get a good thermal interface to it. Adding the number of screws, it becomes obviously, that there is some room for improvement by reducing the number of bolted connections.

1.2.2 Ceramic crack issue

A trend in the marked of power semiconductor modules is to built the modules without the classic baseplate, because for a lot of applications it is sufficient to pass on the thermal capacity and the heat spreading effect of such a massive, mostly of copper made plate. This means, the module base is designed as the ceramic substrate, where the high power dies are bonded on. A plastic housing with two flanges is directly set on the substrate, where the fastening screws are located (Fig.3).

The high pretensioning force is necessary for a save connection. Due to the fast application of this load, there is a common risk of ceramic cracks by using existing designs. This results from the fact, that the force is applied directly onto edges, of weak ceramic substrate. A ceramic crack leads to a safety relevant isolation failure, what means that the module has to be scrapped.

The thermal grease, which is the best available thermal interface between power module and heatsink, increases the risk of cracks due to its viscosity and velocity proportional absorbability.

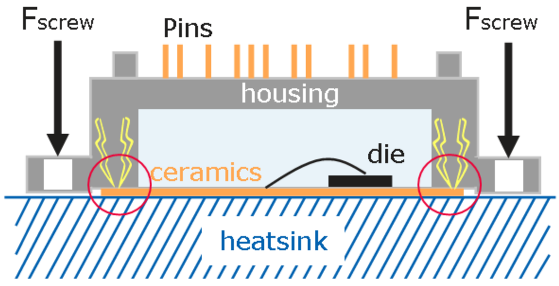

Fig. 3. Schematic drawing of the load transfer from screw to ceramics – stress concentration at the edges of ceramics.

1.2.3 Electrical contacts to PCB, PressFIT as the preferred solution

The electrical connection for power semiconductor modules to the PCB is usually done by the following three connection technologies: Soldering, spring contacts or PressFIT contacts.

To reduce production costs and maintain flexibility in the process flow and inverter design, there is an ongoing trend to use less solder connections.

The reliability of a PressFIT contact is based on the gas tight contact zone, which is very robust against climatic influences and corrosive environments. This results from the particular plastic deformation in the local contact point which generates a cold welded connection (Fig.4). Due to this, there is also a very low and stable contact resistance, which makes the technology suitable for high currents as well as for sensitive low level signals. So PressFIT should be the connection method with the highest potential for the future.

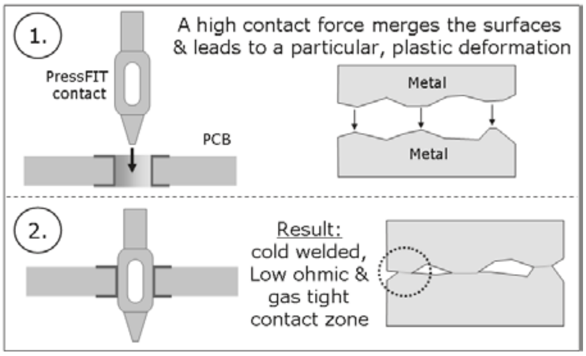

Fig. 4. Schematic drawing of a PressFIT connection

Common subjects for connectors are covered with a PressFIT connection, because: The high contact force destroys overlays, the fretting risk is very low and fritting is not necessary for the reliable function of the contact. This leads to very low FIT rates, which are approximately one tenth below that of solder connections.
The reliability is proven with substantial qualifications according to the well known standards IEC 60352-5 for the contact as well as IEC 60749 and 60068 for PressFIT equipped modules.

2. Self acting PressFIT

2.1. Requirements for future module designs

Regarding current module designs, there are three main improvement areas, which have to be combined in one solution: The approach is, to get a module which is suitable for a single step mounting process with a high mechanical robustness, in combination with a robust & solderless contact system.

2.2. The Smart principle

The Smart module is suitable for a single step mounting procedure by using PressFIT contacts. So it is called “self acting PressFIT” (Fig.5). This means that the fixation at the heatsink, the electrical contact and the fixation with the PCB is done in only one and very fast process step, simply by tightening a screw.

A counterholder transfers the force from the screw to the PCB and pushes the contact pins into the dedicated holes. At the end, this pressure part rests onto the module and presses this to heatsink for a good thermal contact. Because the PCB is fixed between the module and the counterholder after the mounting process, there are no additional fixing points for the board necessary around the module.

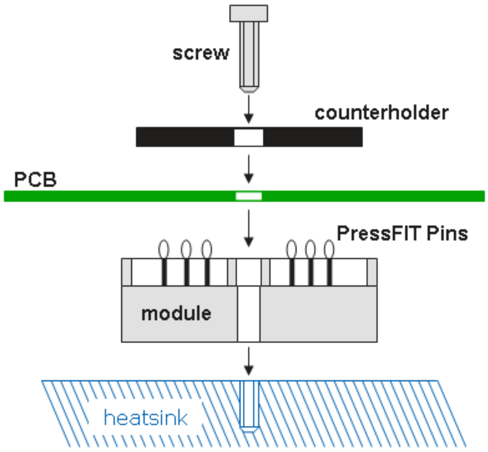

Fig. 5. Principle of “self acting PressFIT”.

Regarding mechanical issues, the Smart design is very robust. This is realized by a duplex frame, which protects the ceramic substrate from all screw forces and also from other external loads. It consists out of an inner module core with the ceramic substrate and two decoupled parts: A rivet and an outer frame (Fig.7). The screw force is only applied on the outer frame and inner part, which have a vertical degree of freedom. They are connected with the core over elastic elements, which push this to the heatsink. Also the PressFIT pins, which are directly distributed on the substrate, have big share to push the substrate.

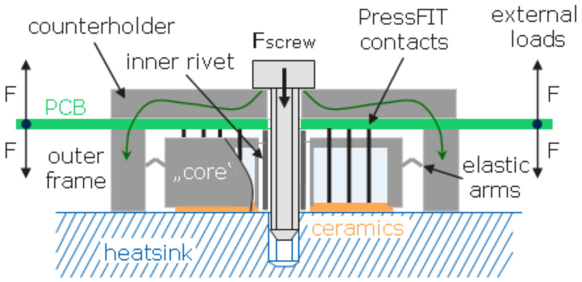

Fig. 6. Schematic drawing of a Smart module: The forces of the screw are transferred to the outer part – the inner, decoupled core part is protected.

To enable the single step mounting process, a solderless connection technology is required. Within the Smart modules, the well proven PressFIT contacts are used.

Fig. 7. Smart 1 module and dedicated counterholder.

The Smart family consists out of three packages, dedicated to the different power ranges. The following tests are done with the Smart1 module (Fig.7), but can be roughly also assigned for the Smart2 and Smart3, because of the similar mechanical concept.

3. Tests respective to common subjects

To evaluate the robustness of the Smart module, suitable test equipment with a dedicated setup has to be used. For the presented tests, the following main equipment has been used:
A Torque and angle controlled fastening unit, a pull-push machine for the force deflexion measurements and the camera measuring system with a climatic chamber to capture deformations and displacements also under different temperatures and loads.

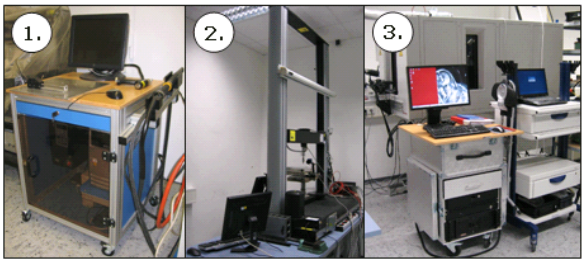

Fig. 8. Test Equipment: Atlas Copco Tensor 3-7 (1.), pull-push machine Instron 5567 (2.), camera measuring system GOM Aramis with a climatic chamber (3.).

3.1. Standard mounting procedure

One of the first mechanical characterisation points is the evaluation of the corrosponding fastening torque (Fig.9).

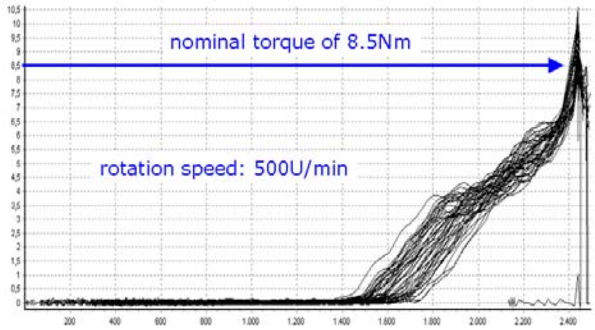

Fig. 9. Torque rotation-angle diagram of a Smart1 module

The specification for the lower torque limit must guarantee the mounting procedure has been completed. The upper torque limit must be low enough to ensure, that nothing is damaged.

In the first step, the torque was calculated approximately with the formula shown in Fig.1. For the selected M6 counter-sunk screw and under consideration of the required PressFIT forces, a torque of 8.5Nm ± 0.5 was evaluated for the Smart1 module.

3.2. Mechanical robustness

Torque and speed of rotation

The request of a modern manufacturing is to tighten screws as fast as possible. For a bolted connection with as zinc coated screw and a thread into an aluminium alloy, as typical for inverter designs, a meaningful speed of rotation is around 500 U/min. As can be seen in Fig.9, a fastening machine is not able to stop exactly at a torque limit at that speed. It has an overshooting effect due to the inertia of the rotating masses. A common corrective action is to use a two step procedure, where the speed is reduced in the second one to values of 100 U/min and below. A Smart module is suitable for a real one-step-mounting procedure with a rotation speed of 500 U/min, due to his robust and force absorbing design.

A second problem is the variation in the friction. Values, usual for the combination of a zinced screw and an aluminium heatsink, are around 0.14. As this can vary, this has to be taken into account. This is quite challenging, because it is nearly impossible, to vary the friction within a given setup. Due to this, some tests have been performed, where the torques have been increased or decreased, according to lower or higher friction values. The most interesting thing is here the overload situation, because this can lead to damages and to ceramic cracks in current designs – which cause an isolation failure of the module.

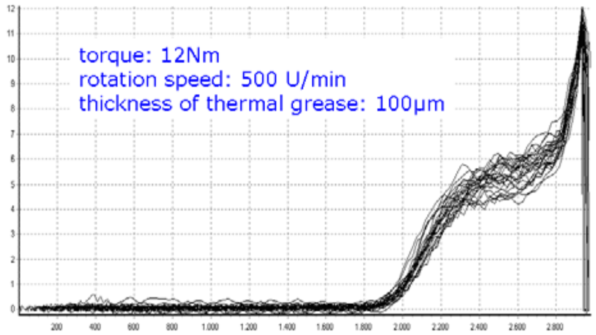

Fig. 10. Torque rotation-angle diagram with torque overload

Within the torque overload tests, also thermal grease with a thickness of 100µm was applied. It was chosen the Electrolube HTC material, because it has a very high viscosity, which is more critical for the crack sensitive ceramics. The overload torque was adjusted to a maximum of 12 Nm, which is corrosponding to a torque of 9 Nm at a friction value of 0.10. All modules have been inspected and measured due to their isolation capability before and after the test:

They passed the isolation test of 4,2KV for 1 second (acc. to 2,5KV for 10 sec.). That means there is no DCB crack occurred and also the rest of the device was without any damages.

Thermal grease

In every case, there is a small gap between module substrate and heatsink, which is annoying for the heat transfer and leads to a high thermal resistance, if it is not filled with an adequate interface. A common interface for power modules is thermal grease.

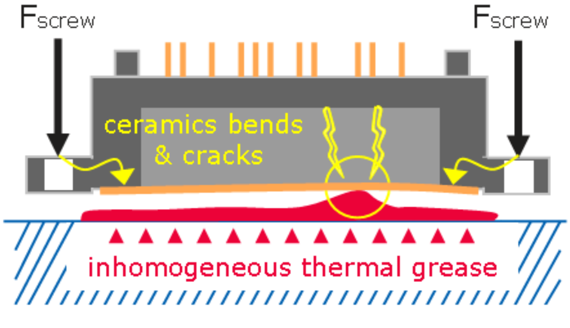

Fig. 11. Schematic: Crack risk of ceramics in standard module due to direct loads on inhomogeneous thermal grease support.

Unfortunately and especially if the thermal grease is applied by hand, there are some unavoidable fluctuations regarding the thickness of the grease. For the thermal behaviour of the module later on, these fluctuations are not a real problem, but due to the viscosity and velocity related damping of the grease material, they could be fatal for the ceramics and the isolation capability of the module. This comes from the inhomogeneous mechanical support and the resulting high, local bending stress which can lead to a crack (Fig.11). This risk is the higher, the higher the mounting speed, according to the speed of rotation of the screw is.

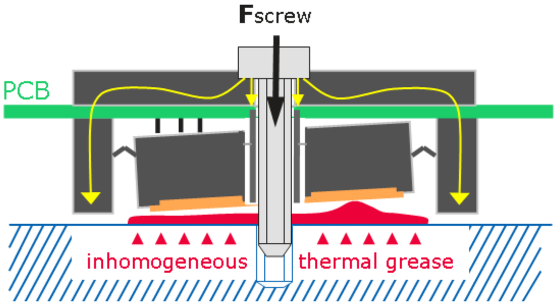

Fig. 12. Schematic: No ceramics cracks with the protecting Smart principle.

Compared to a standard module design, the Smart principle has the decoupled module core. That means first, that it is protected from the high screw loads and second, that the thermal grease has time to distribute and to spread out of the gaps, if the amount is too high (Fig.12).

In a present production line, like for frequency inverters, where power devices are assembled, the thermal grease is usually applied in semi or full automatic processes with module specific stencils. This process is very stable and the thickness has a good reproducibility.

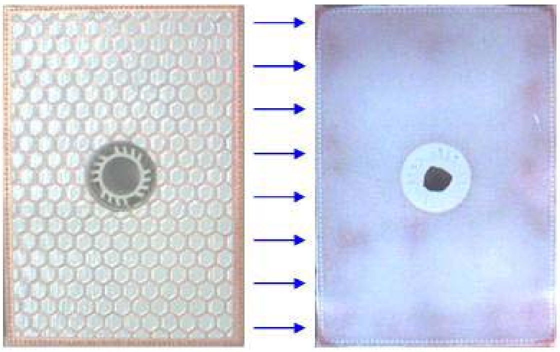

Fig. 13. Image of stencil printed thermal grease (left) and distribution of the grease after mounting the module (right).

Unfortunately, some printers have a less stable process capability or it is not economical to automate the grease application in every case.
Also the velocity proportional absorbability of the material has an influence and can lead to ceramic cracks.
To ensure the functionality of the Smart principle, some simple tests have been done, where the application of the thermal grease has been done in a wrong way intentionally.

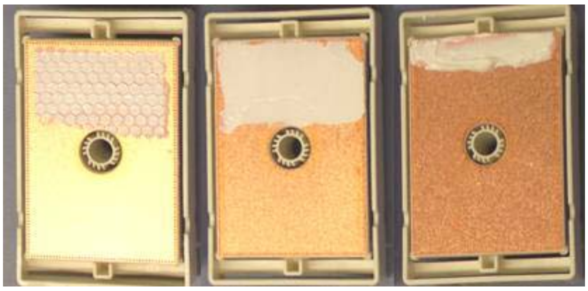

Fig. 14. Although with inhomogeneous, wrong applied thermal grease: No damage of ceramics.

The wrong application, exemplary shown in Fig.14, could not crack or damage the DCB or the module in anyway. It has been done with nominal torque and a speed of rotation of 500 U/min in one step.

3.3. Thermal resistance & cavity

Thermal Resistance

The most important parameter for the thermal performance and therefore the real useable power of the module is the thermal resistance.
As usual, the Rth junction to heatsink from a Smart1 module was measured with parallel operating IGBT’s, to cover the proximity effect and get really resilient values.
The resulting R_{thjh} for a FP35R12U1T4, which is a PIM (inverter, rectifier and brake chopper) module with 35A nominal current and 1200V blocking voltage, has a value of 1.05 K/W, which is very good, even more so with parallel operating devices.
Regarding the correlation between the mechanical measurable value of the cavity between module and heatsink and the thermal performance of a module, it is very difficult to detect a strong dependency. That is the reason, why suppliers can only give Rth parameters for their products and not corrosponding cavities. Changes of some micrometres are not noticeable in the thermal resistance. Furthermore, the measurement of the Rth itself is a quite extensive procedure and can not be done accurately under various boundaries like changing ambient temperatures

Cavity between module & heatsink

Compared to Rth, the cavity is observable also under different conditions. As mentioned before, these measurements are not directly transferrable to an Rth value. But if there is no relevant change in the cavity, there is also no change of the thermal resistance for sure.
The first question is, if the module is quite close to the heatsink after the assembly procedure. Due to this, the cavity was measured within a test setup, where it was observed as a function of the fasten-

ing torque. This was done with some sense devices, which detect the distance between heatsink surface level and module substrate with a resolution of 1µm.

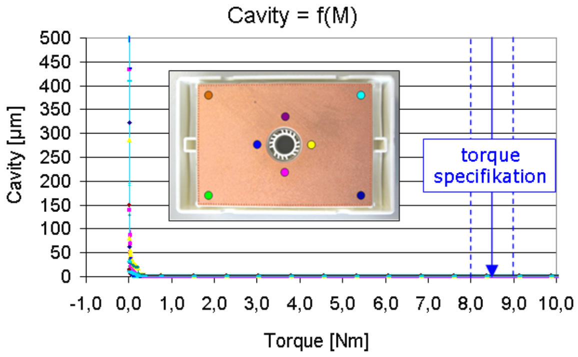

Fig. 15. Cavity as a function of the torque on 8 measuring points between module and heatsink: Module become close to the heatsink as soon as the screw is started to tighten.

Well below the nominal torque of 8,5 Newton meters, actually under 0,5 Newton meters, the module gets as close to the heatsink as possible and reaches its steady state (Fig.15). This shows also, that the necessary force for a good thermal contact is well below the high screw pretension.

The next question is what happens through some thermal loads. To answer this, a related test was performed. As shown in Fig.16 on the left picture, a Smart1 module was mounted into a climatic chamber on a glass plate, where the topology of the ceramic and with this, the analogue cavity between module and heatsink, could be observed under thermal cycling at three measuring points.
An external measuring point was used as the reference, which represents the zero level of the glass surface, analogue to the surface of a heatsink.

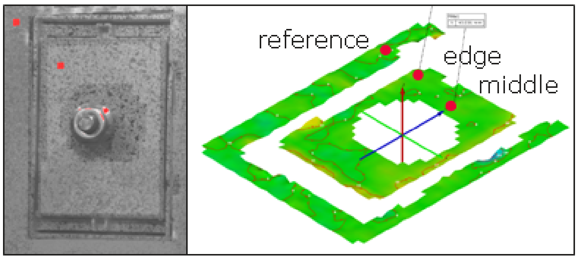

Fig. 16. Left: Measurement setup in climatic chamber. Right: Rear topology. Measurement points marked as red dots.

As shown in Fig.17, the cavity does not vary under thermal cycling from -40 to +125 degree Celsius. That means the module was kept as close as possible to the heatsink and the thermal performance will not be changed.

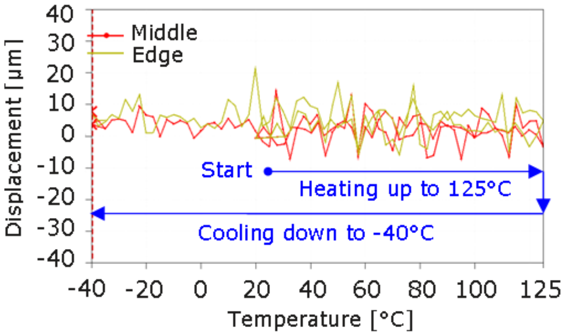

Fig. 17. Cavity measurement points during thermal cycling – no relevant changes.

4. Conclusion

A lot of tests regarding the mechanical robustness and behaviour of the Smart1 module have been performed.

All of them show that the Smart principle is a realized approach to cover all today's main improvement areas in one power module: A solderless, robust single step mounting concept, combined with a reliable and universal contact system.

Certainly, the Smart family will be extended to higher power ranges, with the same features and the same robustness.

Acknowledgement
I would like to thank R.Böttcher for accurately performing a big share of measurements.

Literature:
[1] M.Buschkuehle, T.Stolze, “SmartPIM and SmartPACK – self acting PressFIT assembly”, Bodos Power 2009.
[2] T.Stolze, M.Thoben, M.Koch, R.Severin, „Reliability of PressFIT connections“, PCIM 2008.
[3] P.Kanschat, T.Stolze, D.Kreuzer, R. Cordes, “The Thermal Heat Sink Interface of IGBT Modules w/o Base Plate - A Comprehensive Experimental and Simulation Study”, PCIM 2006.
[4] A .E. Schön, “Kontakttechnologie und Qualitätssicherung bei Kontaktbauteilen“, Seminarunterlagen, Starnberg, 2005