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Power Conversion Solutions - Distribution - D.C. Power Supplies

IB 1154

Press-Pak High Power Semiconductors

Application note:

Recommendations regarding mechanical clamping of Press-Pak High Power Semiconductors

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1.0 Foreword

Press-Pak high power semiconductors are in many applications very powerful components in controlling electrical power. To utilize their full potential a proper mechanical design of the complete assembly, including Press-Pak high power semiconductors, heat-sink, bus bars and other components, is crucial. In this application note some important issues for the mechanical design and the assembly work for stacks using Press-Pak high power semiconductors are addressed. Figure 1 shows the internal construction on typical free-floating Press-Pak semiconductor.

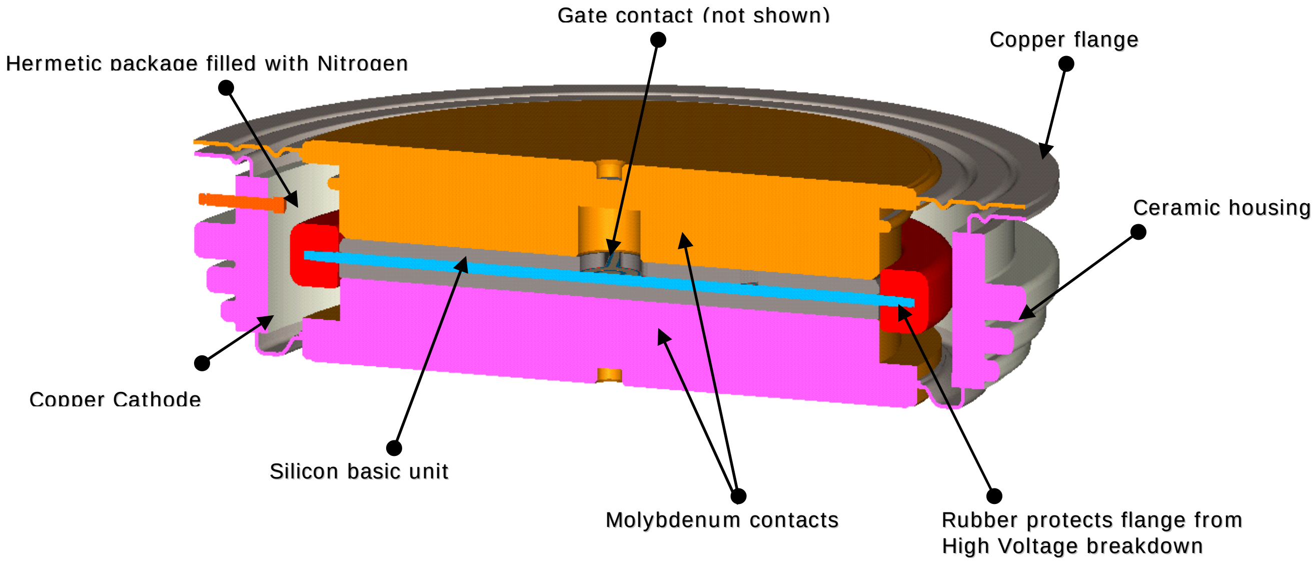

Figure 1. Internal Construction of typical Free-Floating Press-Pak Semiconductor

1.1 Introduction

The Forward Voltage Drop and Thermal Resistance of a Press-Pak semiconductor is affected by the clamping force that is applied to the device. This is due to the internal interfaces between the copper electrodes and the molybdenum discs and washers being free floating. These interfaces contribute an electrical and thermal resistance, which adds to the bulk resistance of the materials constituting the device.

Figure 2 shows the theoretical thermal resistance vs. load for the dry interfaces in a fully floating silicon Thyristor. The clamping force recommended by Semiconductor Mfg's in its data sheet has been established as being that force necessary to give good thermal and electrical contact between the internal and external interfaces of the device. To determine this, the Forward Voltage Drop and Thermal Resistance of the devices are measured at different clamping forces.

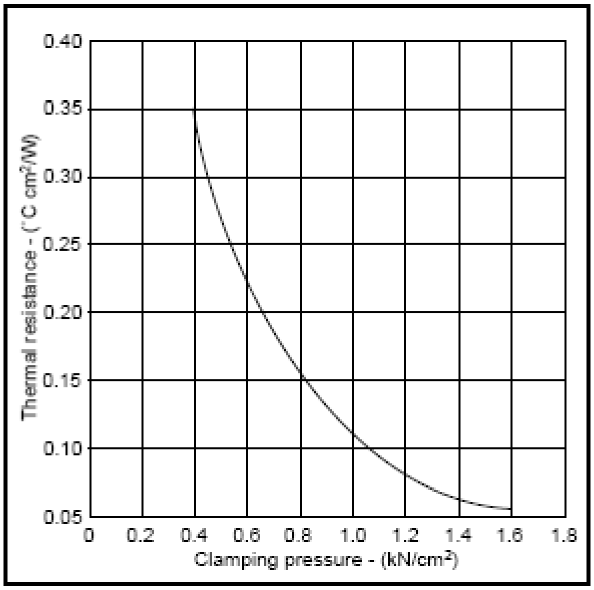

Fig.2 Additional thermal resistance for dry interfaces of a Free Floating Semiconductor Press-Pak

The minimum clamping force is determined as the force above which the Thermal Resistance and Forward voltage drop do not improve significantly. The maximum recommended clamping force is then taken to be 1.22 x the minimum value.

The published figure is a mean value +/- 10%. It is important, therefore, that the user takes due regard that the clamping force remains between these values under all conditions that arise from variations in tolerance of the clamps and any thermal expansion and contraction that may affect their settings. In this way the user will be sure that the thermal and electrical characteristics are within those specified on the data sheet and that the long term tolerance to thermal cycling has been verified. Of course, this clamping force must be evenly distributed over the entire surface of the semiconductor to ensure that the above conditions are obtained. Uneven clamping can result in high thermal resistance, high forward voltage drop, and mechanical damage to the device. Care, must therefore, be taken to ensure that the clamp applies force to the center of the pole face and that it is subsequently spread evenly over the whole contact area by suitably thick and stiff buffers.

2.0 <u>Recommendations for the interface properties</u>

The current and heat conducting interfaces should be designed to retain good conduction properties throughout the equipment lifetime. This is accomplished by creating a sufficient number of stable metal-to metal connections, referred to as a-spots in contact theory, which can efficiently conduct current from the semiconductor through the heat-sink to the bus bars. These a-spots must be maintained at hard stress conditions such as load cycling, environmental impact through vibration and chemical contamination as sulphur gases. To achieve this, care must be taken in choosing the right materials for the components. They must be coated properly and have the right surface finish. In this application note we concentrate on the interface between the Press-Pak high power semiconductor and the heat-sink.

2.1 Definitions

Roughness: The surface roughness is a measure of the microstructure of the surface. It is expressed as a Ra-value as per ISO 4287. The roughness is Ra ≤0.8 μm for most semiconductor Press-Pak devices.
Flatness: The flatness is ≤10 μm for most devices with pole piece diameter ≤50 mm and ≤15 μm for devices with pole piece diameter > 50 mm. This means that a specific pole piece surface is limited by two parallel planes at a maximum distance of 10 or 15 μm apart.
FM: The mounting force is the recommended force to be applied for optimal device performance. The data sheet limits are not guaranteed at a too low mounting force. The thermal impedance and the on-state voltage drop will increase, and the surge current rating will decrease when the force is reduced below the rated value. Too high a mounting force may reduce the load cycling capability by excessive deformations of the fine wafer structures or, at worst, by silicon wafer cracks.

2.2 Design of the utilized components

When using air-cooled or water-cooled heat-sinks the cooling should be as homogeneous as possible over the entire contact surface of the device.
For water-cooled a single water channel through the center of the heat-sink may not be sufficient for heavy-duty equipment and could lead to over heating of the device rim. It is advisable to use water channels that create turbulences rather than using simple straight paths (though this may be sufficient for light duty units). Darrah Electric supplies compact water-cooled heat-sinks for heavy-duty equipment see Figure 3. These heat-sinks use a stainless steel wire wound tube at both sides of the surface to optimize cooling.

Figure 3 Water-cooled heat-sinks supplied by Darrah Electric.

The heat-sinks must have adequate mechanical robustness to withstand compression with forces up to 135kN without deformation. Deformation could lead to inhomogeneous pressure distribution. Casted or extruded heat-sinks need in almost all cases to be machined properly through processes as milling or fine turning to get to the recommended surface finish.

For air-cooled heat-sinks it important to select a heat-sink with a sufficient surface area for cooling and a center web wide enough to accommodate the pole face of the Press-Pak being mounted. Refer to Darrah Gold for more details. Darrah Electric supplies compact air-cooled heat-sinks for any application see Figure 4. For air-cooled units, both convection and forced air, adequate airflow must be assured and pressure drops and additional heating in the cubicle must be considered in the thermal dimensioning of the unit.

Figure 4 Air-cooled heat-sinks supplied by Darrah Electric

2.3 Surface treatment

Surface finish and treatment are crucial for optimal heat and current conduction over the device and heat-sink interface. It is recommended that the heat-sink surfaces have the same flatness and roughness as the Press-Pak high power semiconductor measured on the surface where the device is to be mounted. Darrah Electric recommends the use of heat-sinks with a good quality plating of nickel or silver. For applications with hard component stress, Darrah Electric recommends chemical plating rather then electrolytic plating. Bare copper or aluminum is not recommended due to corrosion that rapidly deteriorates the contact surfaces. Nickel and Silver do corrode, however silver oxide does not have the harmful effects on the interface that aluminum oxide does. Press-Pak high power semiconductors have pole pieces of copper with a nickel-plating of approximately 5 μm. When using nickel-plating, it is recommended to use the same plating thickness on the heat-sink area that is in contact with the device. A thin film of a light grease or special silicone oil may be applied on the contact surfaces before the devices are assembled between the heat-sinks. The interface grease or silicone oil must be carefully chosen for its long-term chemical stability, corrosion inhibiting properties, temperature range, electrical properties and ease of use. Darrah Electric recommends No. 2 EJC (Electrical Joint Compound) Z22130. **Warning:** Too little jointing compound will lead to high thermal resistance. However, a more common error is to apply too much compound, which can give a high electrical contact resistance.

3.0 <u>Recommendations for the mechanical design and assembly</u>

The mechanical design and the assembly of the stack are also crucial for the performance and reliability of the Press-Pak high power semiconductor. Inhomogeneous pressure distribution caused by the mechanics is a common cause of device failure.

3.1 The mechanical design

The clamping must be carefully designed to ensure that the device is clamped with the correct, calibrated force and it must also allow homogeneous pressure distribution over the whole contact surface of the device. Uneven pressure will lead to deformation of the housing and internal stress between the different layers inside the device causing it to fail prematurely during load cycling. Designing for pressure uniformity is not always easy and the complexity should not be underestimated. Simple solutions, such as clamping the device between two rectangular plates by bolting down the corners will exhibit poor reliability. To verify that the pressure distribution is uniform, Darrah Electric recommends the use of calibrated clamps. Figures 5 and 6 show two samples from pressure distribution measurements on Press Pak Semiconductors. Figure 5 shows good pressure distribution and Figure 6 poor pressure distribution with a large area of the device having too low a pressure and some areas having too high a pressure.

Figure 2 Good pressure distribution

Figure 5: Good Pressure

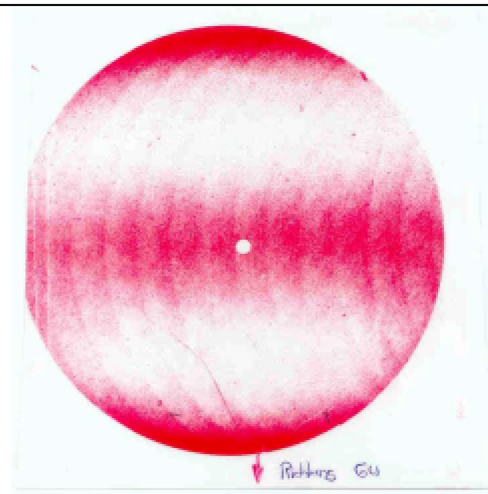

Figure 3 Poor pressure distribution

Figure 6: Poor or uneven pressure

Ideally, the mounting force should be applied from a single point above the center of the device. Our recommendation is that the center of the force is within 2 mm from the center of the device, and at a minimum distance equal to half the pole-piece diameter of the device from the device surface, as shown in Figure 7. This to achieve good pressure uniformity considering the “90 ° force cone”. A spherical cup between the mounting clamp and the pressure spreader above the heat-sink can act as this single point of force and ensures that the force from the mounting clamp is transferred symmetrically to the device. It also allows parts within the stack to adapt to inherently present non-parallelisms. There will always be inherent non-parallelisms in a stack since it is not possible to manufacture heat-sinks and Press-Pak high power semiconductors with perfectly parallel surfaces. It should though be striven to reduce the non-parallelisms as much as possible. The non-parallelism between the anode and cathode pole pieces is ≤100 µm for devices with pole piece diameter ≤50 mm and ≤150 µm for devices with pole piece diameter > 50 mm. Due to space restrictions in some applications, it may not always be practical to use the recommended half pole-piece diameter of distance, but reasonable results can also be obtained with smaller distances when stiff materials such as steel are used for the force spreader, possibly together with Belleville springs.

Center of device heat-sink force spreader preferably steel, 90° force cone heat-sink Press Pak semiconductor point of applied force. Max 2 mm misaligned towards center of device Minimum distance half a pole piece diameter.

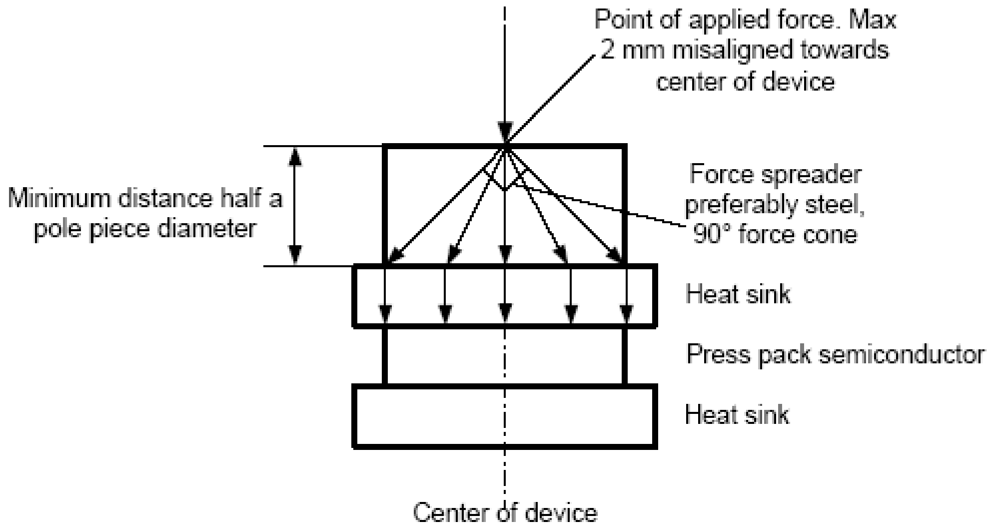

Figure 7 Recommended application of the mounting force.

Darrah Electric sells a series of mounting clamps for mounting forces 4 – 135 kN. An example of a 135 kN clamp can be seen in the left stack of Figure 8. The components and the clamp design must be chosen to withstand the temperature levels and the forces caused by mechanical expansions and contractions due to temperature changes that occur during working conditions without damage. This over the whole equipment lifetime. The design must also allow for temperature expansion and contraction without large changes in force and pressure distribution on the Press Pak high power semiconductor. In long stacks with more than 2 devices and their heat-sinks, it may be difficult to obtain good mechanical stability when using a design with 2 rods and a standard mounting clamp. Therefore Darrah Electric recommends the use of a 4-rod Belleville spring construction for long stacks as shown in Figure 9.

Figure 8-9. Two rods are enough for shorter stacks, but for longer stacks 4 rods are recommended.

Press-Pak high power semiconductors, whether parallel or anti-parallel connected, should always be separately clamped as shown in Figure 10 , unless they are stacked as shown in Figure8-9. Due to mechanical tolerances there will be differences in height and parallelism that in many cases will create mechanical forces large enough to significantly reduce the lifetime of or even destroy the devices if 2 or more devices are clamped together between two rigid bus bars or heat-sinks.

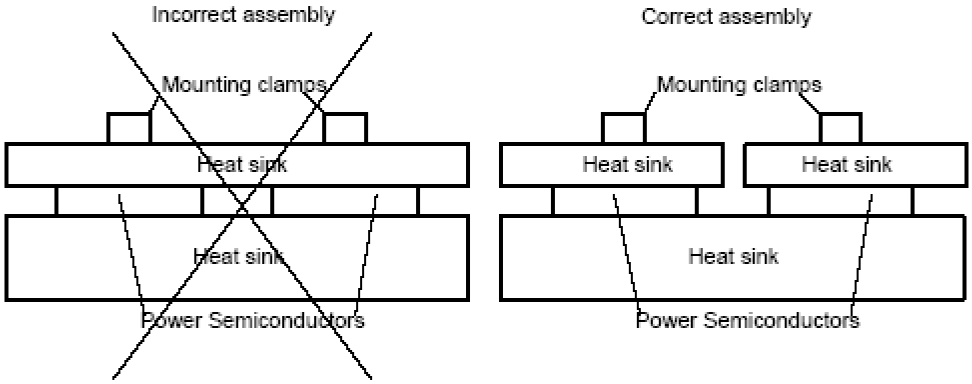

Figure 10 Devices should be individually clamped.

If the mounting clamp and the bolts have to be on ground potential, the right materials and the right air and creepage distances must be utilized. For more details about insulation co-ordination consult standards IEC 60664-1 and UL840. Insulating materials, as Vetresit®, a glass-fibre epoxy from Darrah Electric, can be used for the bolts allowing for a simplified or more compact stack compared with steel bolts, that either require insulation or need enough air strike distance between the live parts. If several devices are assembled together in one stack with the same mounting clamp, the devices must have the same rated mounting force. This is to avoid over-stress or too low a pressure for some of the devices in the stack. It is also advisable to use devices with the same pole piece diameter to simplify the heat-sink design in order to achieve good pressure distribution on all devices. If the heat-sink cannot spread the pressure evenly and devices with different pole piece diameters are used, there is a high risk that either the rim of the smaller device gets too high a pressure or the rim of the large device gets too low a pressure.

An example of a well-dimensioned stack is shown in Figure 11. Figure 12 shows a badly designed stack using only thin force spreaders and insufficient heat-sinks that do not spread the force evenly over devices with different diameters. Darrah Electric does not recommend this, but with well-designed heat-sinks and force spreader assemblies as shown in Figure 8 can be designed.

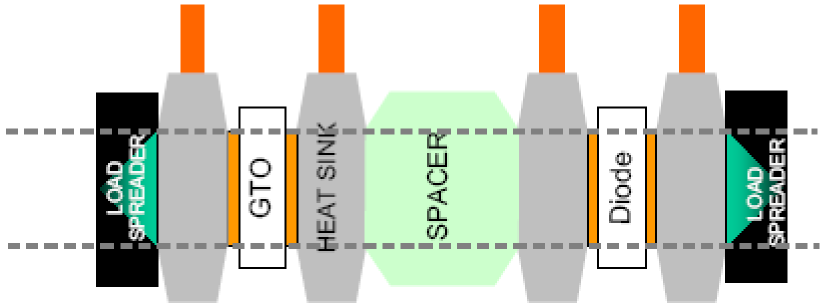

Figure 11 Well designed stack with effective load spreaders and similar device diameters.

Incorrect assembly Mounting clamps heat-sink Power Semiconductors heat-sink Mounting clamps heat-sink Power Semiconductors heat-sink Correct assembly heat-sink GTO Diode spacer heat-sink.

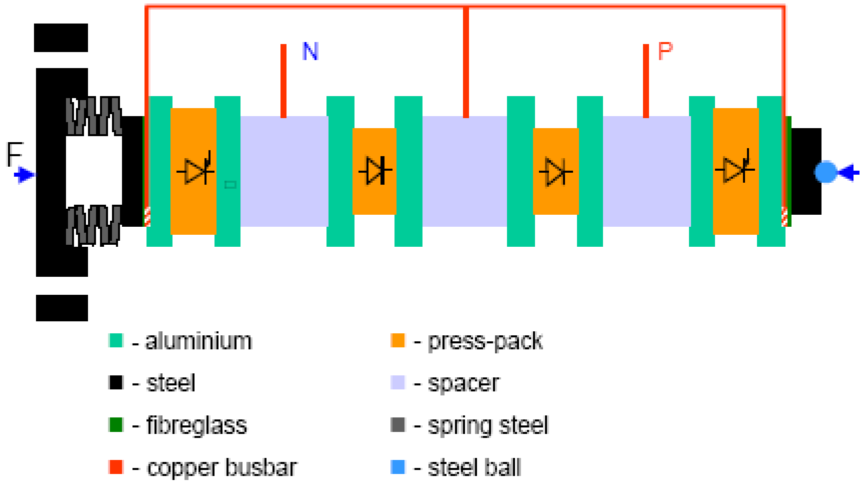

Figure 12 Poorly designed stack with ineffectual load spreaders and dissimilar device diameters.

Bus bars or their connections to the stack should have a flexible part to avoid mechanical stress to the stack assembly. Mechanical stress can occur either due to mechanical tolerances or due to heat expansion and contraction during changes in the electrical load. The gate cables for PCT and GTO should be laid properly to ensure that they do not come in contact with anode potential and also to minimize electro-magnetic disturbances. Twisted or coax cables are recommended to reduce EMC sensitivity. The cables should be as short as possible and they should preferably be laid in a 90 ° angle to the main current conduction direction. For water-cooled assemblies very stiff tubes used between the different heat-sinks can cause problems. This is due to mechanical forces caused by thermal expansion and contraction. Since water is electrically conducting the tube length between heat-sinks with different potential must be long enough. De-ionized water should be used together with water treatment equipment needed to remove conducting particles and to keep the water conductivity low. Darrah Electric recommends the use of non-corroding material such as stainless steel and Teflon for water tubes, not copper or aluminum. For equipment used at severe environmental conditions special care must be taken to ensure that the Press-Pak high power semiconductors are not harmed by vibrations, temperature variations, etc. Special care regarding vibrations must be taken in applications for rolling stock. **IMPORTANT: All of the above being said, it is not recommended to re-use clamps that have been in service for any period of time for obvious reasons.**

3.2 Example of a fixture

In Figure 13 an example of a stack is shown with a short reference to some of the issues mentioned in section 3.1.

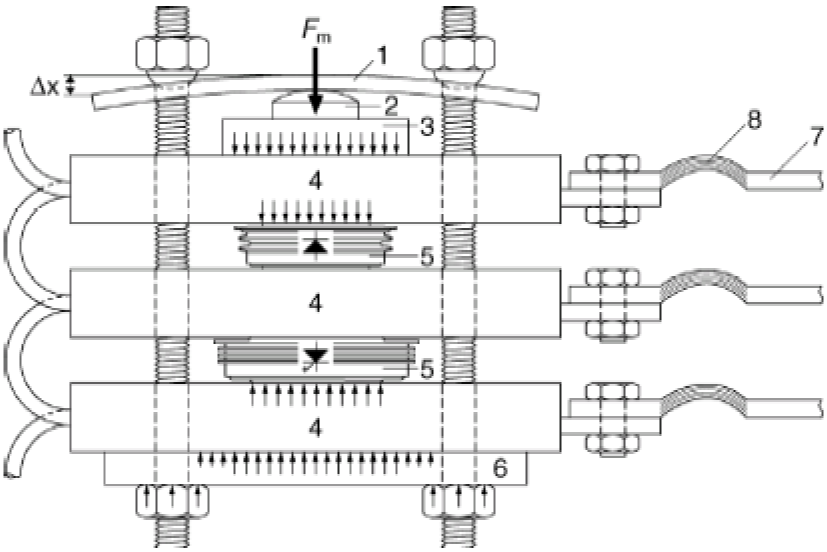

Figure 13 Example of a stack, illustrating the basic rules for correct clamping of Press-Pak high power Semiconductors:

3.3 Key Requirements

1. Leaf spring. Spring excursion Δx must be large in comparison with thermal expansion of stack parts in order to keep FM constant over time and temperature variations.
2. Spherical cup ensures that Fm is transferred symmetrically to the Press-Pak high power semiconductors and allows the parts within the stack to adapt to inherently present non-parallelisms.
3. Strong steel plate for homogeneous pressure transfer to heat-sink (4), symbolized by small arrows.
4. High-quality heat-sink: Clean and parallel surfaces with flatness and roughness as per paragraph 2.3.
5. Press-Pak semiconductor: Surfaces cleaned and covered with thin film of silicone oil before mounting.
6. Strong yoke ensures homogeneous pressure distribution on heat-sink (4), symbolized by small arrows.

7. Bus bars (7) connected to heat-sinks (4) by means of flexible connections (8) to avoid uncontrolled "external" forces disturbing homogeneous pressure distribution within the stack.
8. Before mounting the stack parts in the clamping system, the various surfaces should be cleaned with alcohol, ethanol or similar, and it may be advantageous to lubricate them with a *thin* film of silicone oil to improve the thermal contact, and to prevent corrosion if the stack is exposed to an aggressive environment. However, it should be noted that silicone oil or contact grease will never compensate for poor quality heat-sink surfaces!

4.0 Additional notes

4.1 Further things to consider

Unless the Press-Pak high power semiconductors and heat-sinks are mechanically well supported, long stacks with several devices should be transported in the upright position. Having the stack in its horizontal position can cause tension to the Press-Pak high power semiconductors with consequent damage, and vibrations or bumps may lead to device destruction. When designing a stack, the stack installation in a cubicle or at site should be taken into consideration, in order to simplify the installation in the cubicle and to ensure that the external connections fit. If using conductive material in the clamp, include connection points for grounding of the stack. Heavy stacks should have hooks or other support for handling purposes.

4.2 Clamps

Darrah Electric can provide a variety of clamps for any application. See Figure 14.

Figure 14. Clamps for Press-Pak semiconductors