Optimized Design for Vibration Resistant Power Module Package

IGBT based power modules designed for typical industrial applications cannot be transferred to Commercial, Agriculture and Construction Vehicles (CAV) applications without changes. This article describes the simulation flow to construct a more vibration resistant power module for CAV applications. Vibration simulation (modal and harmonic analysis) is a faster and more effective method for the optimization of a design concept rather than hit and miss trials. **Frank Sauerland, Infineon Technologies AG, Warstein, Germany**

Optimization of the package begins with the evaluation of mechanical behavior under a set of vibrational load characteristics (such as vibrational harshness [1-3]) for the new applications. Designs which meet the vibration criteria were further analyzed for suitable thermal behavior. This design flow leads to a thermally feasible and mechanically optimized component for CAV applications. In particular the potential of case specific design optimizations based on simulation, using an example of a bus bar in an IGBT based power module has been evaluated. The overall goal of the optimization was to design a module and its components that comply with the higher vibration requirement for CAV applications. The enclosure body and effectively the bus bars have to perform in a harsh vibration environment.

Vibration tests shows that a power module which is constructed for industrial systems satisfies the requirements for vibration resistance in a typical application but not the higher requirements for the CAV applications (Figure 1). In order to check the vibrational resistance of a power module for an industry application the module was shaken with 5 g force between 5-150 Hz. The module passed the test since no damage was found. The power module for a CAV was shaken with an increased 15 g force vibration profile between 5 Hz until 2000 Hz [4].

Optimization of vibration resistance

For a better understanding of the vibration resistance and the failure mode of the bus bars, the module can be simplified in the following way (Figure 2 left). The power module (Figure 2 right) consists of three bus bars which can be simplified as three springs and the plastic housing which can also be simplified as a spring. The springs are connected with the base plate on the one end and on the other end with a mass. Optimization of the vibration resistance involves increasing the elastic force of the housing and lowering the elastic force of the bus bars. The elastic force of the bus bar can be reduced by lengthening the feet. The elastic force of the housing can be increased by adding reinforcements.

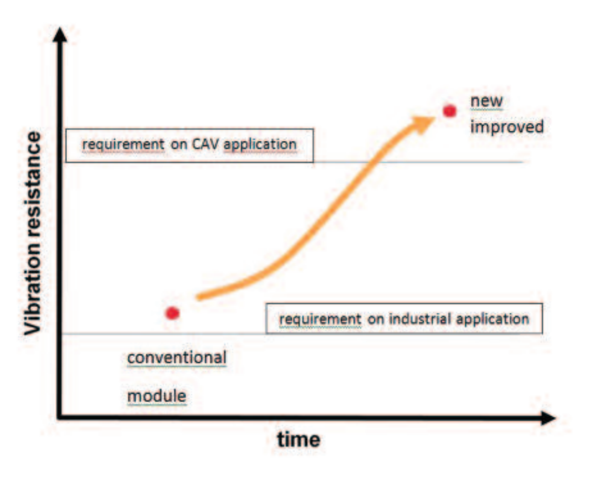
Frequency or modal analysis

Simulation of the modal analysis is a good aid to find the resonance frequency and to detect the weak spots of the module. The next picture shows the results of modal analysis and shows the first harmonic vibration. Figure 3A shows the deformation of the bus bars in the power module, Figure 3B shows the deformation of the housing during the first resonance frequency. Both simulations show that the critical points can be found in the housing and at the feet of the bus bars.

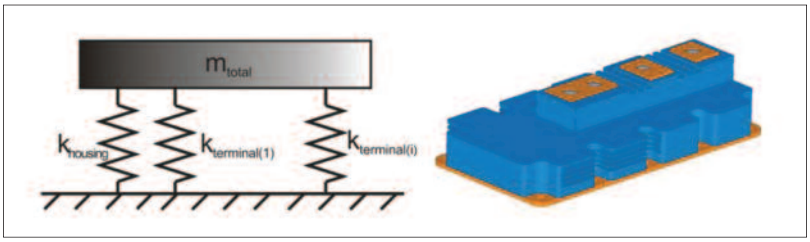
The simulation confirms the result from the vibration tests. For further improvement of the model with longer feet and a reinforced housing design, it is necessary to perform a frequency analysis.

The comparison of the new constructed bus bars with the conventional design

RIGHT Figure 1: Vibration resistance of the conventional and new power module



BELOW Figure 2: Model to simplify the module construction



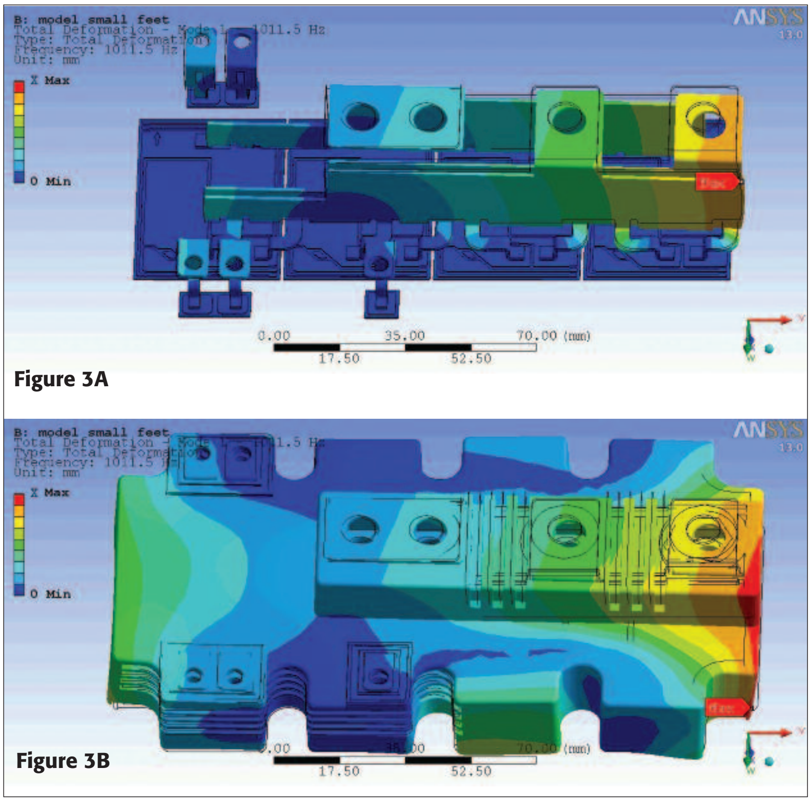


Figure 3: **Result of the modal analysis at the first resonance frequency**

under the same harmonic vibration shows a lower stress than in the new bus bars. Figure 4A shows the result of the frequency analysis of the module with the short feet, Figure 4B shows the result of the module with the long feet. The maximum stress produced in the feet of the old module was three times greater than in the new one. In the new and in the old modules the maximum stress was found to be in the same place.

The simulation is a faster alternative to producing and measuring the new bus bars and was equally effective in finding a solution.

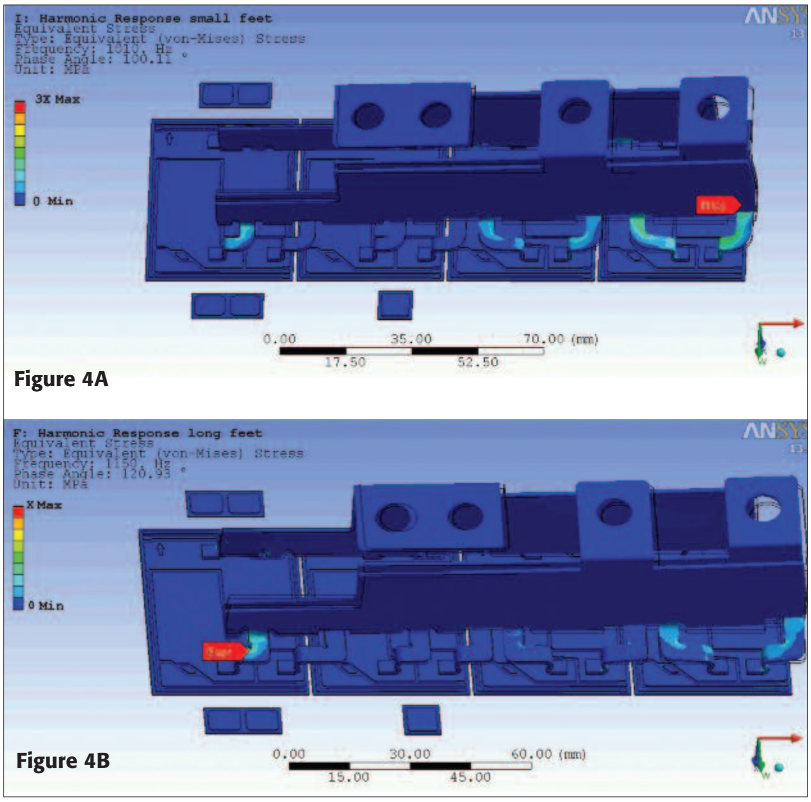


Figure 4: **Figure 4A shows the result of the bus bar with small feet, Figure 4B the result for the long feet**

Boundary conditions of electro-thermal analysis

The bus bar now must be tested for the electro-thermal properties.

For the power module it is very important that during operation the temperature does not exceed the highest value allowed. The improvement of the mechanical behavior of the bus bars cannot be done at the cost of the thermo-electrical behavior. Therefore the current carrying capability of the new design has to be investigated. An optimization procedure is done to investigate thermo-electrical and vibration behavior.

Figure 5 shows the circuit diagram of the half bridge and the three bus bars. The plus and the minus bus bars can be loaded with a maximum current of $I_{C\,nom}$ /4 x 20,5 per foot. The maximum allowed current for this application is IC nom with an effective value of $I_{C\,nom}$ / 20,5. In the AC bus bar the full current that flows through each foot is $I_{C\,nom}$ /4.

Application relevant thermal boundary conditions were considered for the electro-thermal simulation. The contact between the bus bar feet and the copper substrate of the DCB is fixed at a temperature and the areas of the connecting points also have a constant temperature.

Result of the electro-thermal simulation

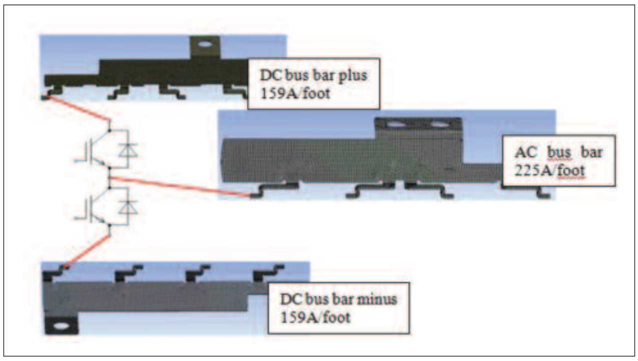
After determination of the overall conditions the simulation can be started. The temperature distribution of the three bus bars is illustrated in Figure 6. It shows that the maximum temperature in the bus bar is lower than the maximum specified temperature. Hence the simulation shows that the new bus bar fulfills the thermal requirements as well.

The simulation results show the final compliance of the design changes in both thermal-electrical and frequency analysis. As an example of the simulation flow, every design change of the bus bar requires this simulation cycle to be redone until the results are acceptable. Even with multiple iterations, simulation is a way to evaluate the optimization concepts faster and for less cost than by producing and measuring all possible designs.

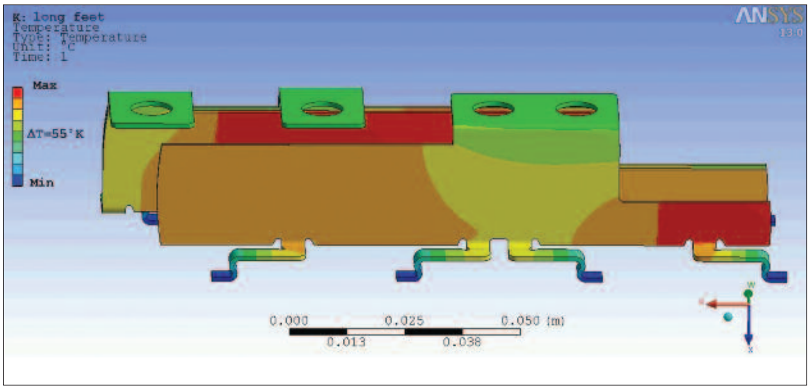
Conclusions

It was explained that the virtual investigation of a bus bar design alternatives using simulation is faster than other techniques such as hit and miss

RIGHT Figure 5: Circuit diagram of the half bridge and the three bus bars



BELOW Figure 6: Temperature distribution in the bus bars under electro-thermal loadings



trials. Modal analysis using simulation is seen to be a very good instrument to find the critical points of the design. Harmonic analysis calculated the stress level to compare different designs. After mechanical optimization, the improved design is investigated by the thermal-electrical simulation, which provides the thermal state at maximum current.

Literature

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