Simulation optimized design for vibration resistant Power module package

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Abstract

IGBT based power modules designed for usual industrial application cannot be transferred without changes to a Commercial, Agriculture and Construction Vehicles (CAV) application. This is because of the higher overall system requirements such as of vibrational harshness [1-3]. This paper 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 optimization of a design concept rather than using hit and trial methods. Optimization of the package initiates with the evaluation of mechanical behaviour under a set of vibration load characteristics for new applications. Designs which meet the vibration criteria were further analyzed for suitable thermal behaviour. Such a design flow leads to a thermally feasible and mechanically optimized component for CAV applications.

1. Vibration resistance measurements and simulation

1.1. Results of the vibration tests

This paper shows the potential of case specific design optimization based on simulation, using an example of a bus bar in an IGBT based power module. The overall goal of the optimization was to design a module and it components which complies with the higher vibration requirement for CAV applications. The enclosure body and effectively the bus bars have to perform in a harsh vibration environment. The results of the vibration test on non optimized bus bars are illustrated in the Fig. 1. The power module which is constructed for the industry application satisfies the requirements for vibration resistance in a typical industrial application. As a comparison after eight hours of vibration with 5g amplitude between 5-150Hz (industry standard) the bus bars showed no damage in contrary the bus bars which were submitted to a standard CAV test broke in a bend of a foot during three hours of vibration with 15g amplitude between 5Hz until 2000Hz [4].

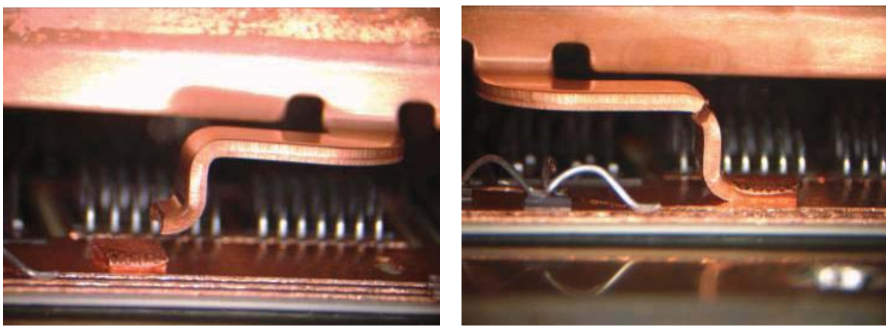

Fig. 1. Broken bus bar after a harsh vibration test

1.2. Theory: Optimization of vibration resistance

For a better understanding of the vibration and the failure of the bus bar, the module can be simplified in the following way (Fig.2 left). The Power module (Fig.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.

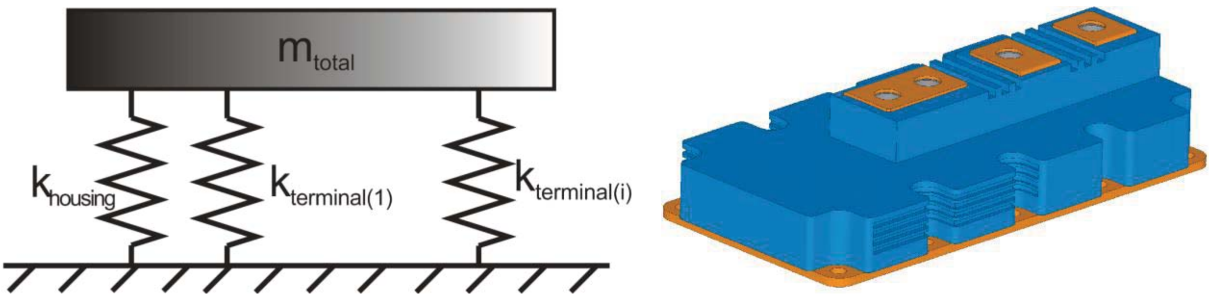

Fig. 2. Model to simply the module construction

The next picture shows the modification of the spring functions in bus bar and housing. The elastic force of the bus bar can be reduced by lengthening the feet. The elastic force can be increased by adding reinforcements.

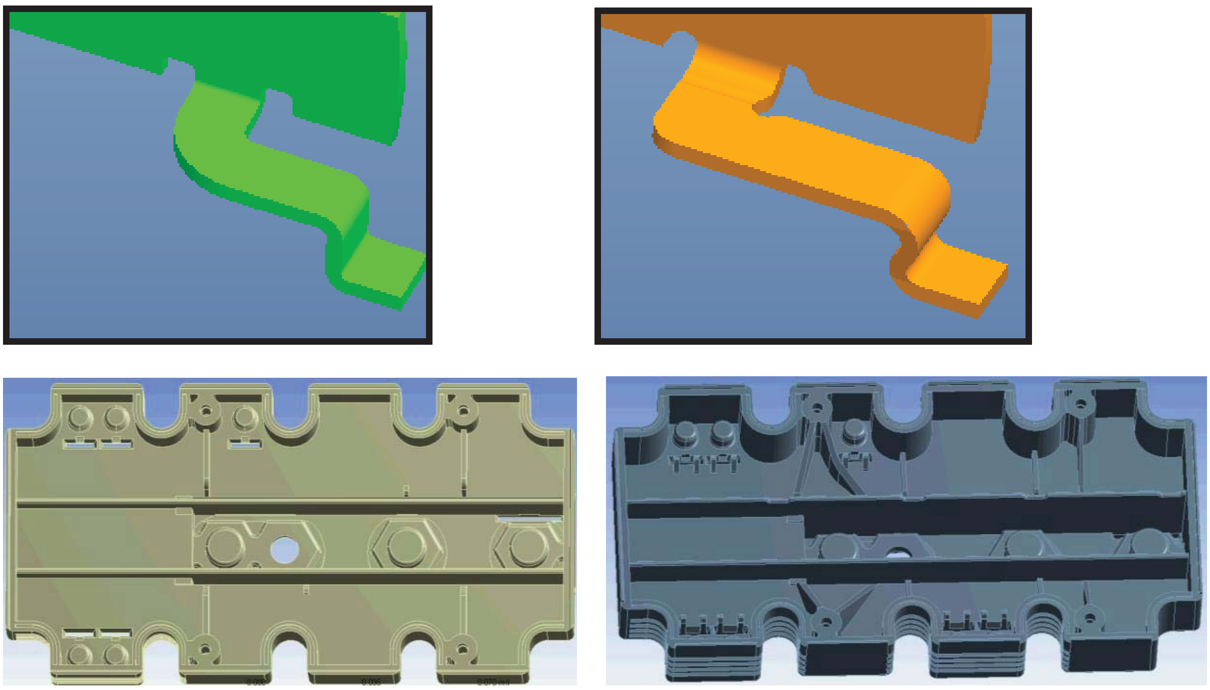

Fig. 3. Modification of the housing and the bus bar

1.3. Simulation: Frequency or modal analysis

The 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. The left picture shows the deformation of the bus bars in the power module, the right shows the deformation of the housing during the first resonance frequency. Both simulations shows that the critical point can be find in the housing and the feet of the bus bars.

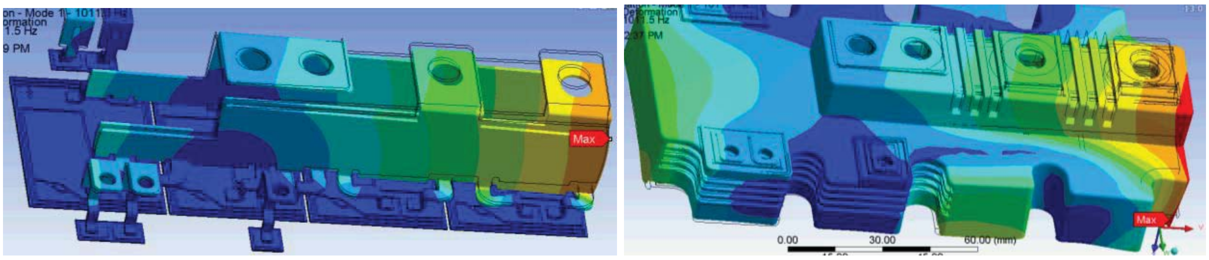

Fig. 4. Result of the modal analysis at the first resonance frequency

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

The comparison of the new constructed bus bar with the old one under the same harmonic vibration shows a stress reduction in the new bus bar. The left picture shows the result of the frequency analysis of the module with the short feet (as in Fig.3, upper left), the right shows the result of the module with the long feet (as in Fig.3, upper right). The maximum stress in the old module produced in the feet was 224 MPa. In the new module, the maximum stress produced was in the same place but with a value below 77 MPa.

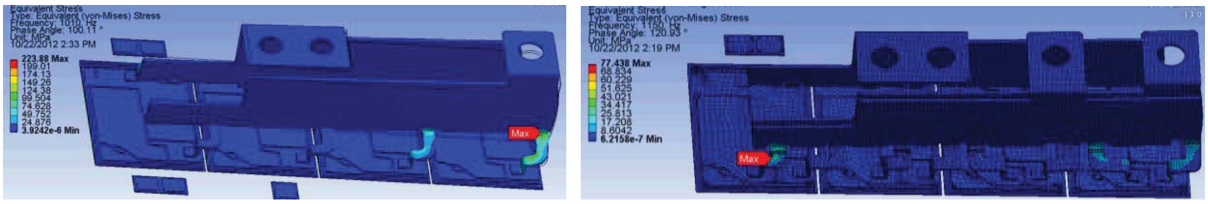

Fig. 5. The left picture is the result of the bus bar with small feet and the right picture is the result for the long feet

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

2. Simulation: Electro- thermal analysis

2.1. Boundary conditions

The new bus bar must be tested for the electro- thermal properties which result in a thermally good mechanical optimization.

For the power module it is very important that during operation the temperature does not exceed the highest allowed value, in this case 150°C. This is because on the limited operational temperature of the silicone gel [5]. The improvement of the mechanical behaviour of a bus bar 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 behaviour.

Fig. 6 shows the circuit diagram of the half bridge with the three bus bars (ac, plus and minus). The plus and the minus bus bar can be loaded with a maximum current of 159A per feet. The maximum allowed current for this application is 900A with an effective value of 636 A. In the ac bus bar the full current that flows through each foot is 225 A.

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 of 90 °C and the area of the connecting points have a constant temperature of 120°C.

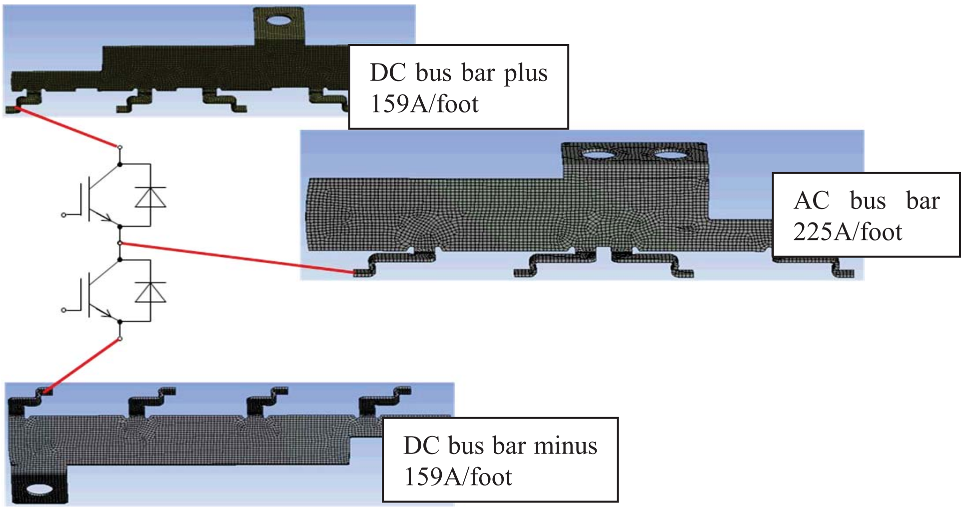

Fig. 6. Circuit diagram of the half bridge

2.2. Result of the electro thermal simulation

After the determination of the overall conditions the simulation can be started. The temperature distributions of the three bus bars are illustrated in the Fig. 7. It is easy to see that the maximum temperature in the bus bar is lower than 150°C which is in accordance with the specification of the silicone gel. Hence the simulation shows that the new bus bar fulfills the thermal requirements as well.

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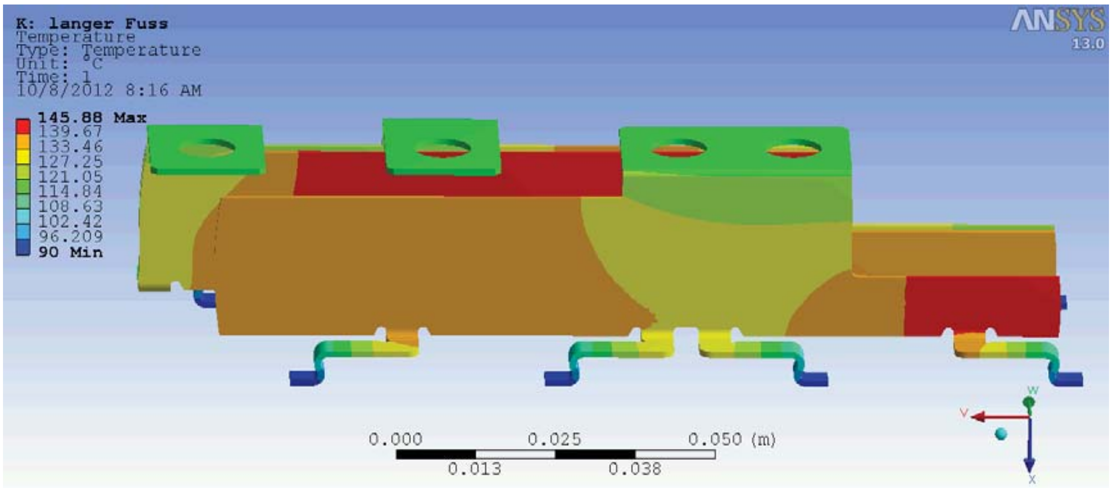

Fig. 7. Temperature distribution in the bus bars under electro-thermal loadings

The paper shows the final compliance of the design changes in both, thermal-electrical and frequency analysis. It is 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. For every case, simulation is a way to evaluate the optimization concepts faster and cheaper than by producing and measuring all possible designs.

3. Conclusion

This paper explained that the investigation of a virtual new design for bus bar using simulation is faster and cheaper than other techniques such as hit and trial methods.
The modal analysis using simulation is a very good instrument to find the critical points of the design. The harmonic analysis calculated the stress level to compare different designs. After the mechanical optimization, the improved design is investigated by the thermal- electrical simulation, which provides the thermal state at maximum current.

4. Literature

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