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Mechanical stress induced by electromagnetic forces on wire bonds of high power modules

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***Abstract*— This paper concerns the analytical determination and experimental characterization of electromagnetic forces exerted on high power IGBT wire bonds.**

Keywords: wire bonding; electromagnetic forces, mechanical stress

I. INTRODUCTION

In many applications, power electronics components allow transferring the electrical energy between the electrical source and the electrical machine. For many years, studies and efforts have been focused on integration of static converter: high power performances into reduced volumes. Consequently, due to the stress obtained, the power electronics reliability becomes an important field of study [1] [2]. One of the main causes of malfunction of these components is the wire bonding failure. Some mechanical stress or displacements can be attributed to electromagnetic forces [3]. For this study, we identify the distribution of such forces, and we propose explanations of the stresses and displacements generated.

II. ELECTROMAGNETIC FORCE EXPRESSION

A. Analytical expression

The magnetic field and the forces exerted on the wire have been determined using respectively the Biot-Savart law and the Laplace law. We split the wire in two segments in order to simplify the field and force expressions. We also verify that the most part of the induction field is concentrated near the upper wire loop, Fig(1a). We have calculated two types of forces: firstly, the own forces considering the wire as two assembled segments and flowed by the same current. Then, the parallel forces between two nearby wires Fig(1b), shows the direction of the forces exerted on the wire. $\boldsymbol{df_1}$ and $\boldsymbol{df_2}$ represent the elementary own forces and $\boldsymbol{df_{11'}}$ the elementary parallel force. Vectors are of bold type.

$$\frac{\boldsymbol{df_1}}{\boldsymbol{dl}} = \frac{\mu_0}{4\pi r} I^2 \tan\left(\frac{\alpha}{2}\right) \boldsymbol{e_r} \quad (1)$$

$$\frac{\boldsymbol{df_2}}{\boldsymbol{dl}} = \frac{\mu_0}{4\pi r} I^2 \tan\left(\frac{\alpha}{2}\right) \left(\sin(\alpha)\boldsymbol{e_z} - \sin\left(\frac{\pi}{2} - \alpha\right)\boldsymbol{e_r}\right) \quad (2)$$

$$\frac{\boldsymbol{df_{11'}}}{\boldsymbol{dl}} = \frac{\mu_0}{4\pi a} I^2 \tan\left(\frac{\alpha}{2}\right) \left(\sin(\theta_2) - \sin(\theta_1)\right)\boldsymbol{e_\theta} \quad (3)$$

a is the distance between two wires typically $a=1\ mm$, and θ_1, θ_2 are defined between two wires. L is the wire length $L=12.3\ mm$.

B. Results and discussion

We finally computed expressions (1), (2) and (3) in constant section bond wire of a 3D FEM model, Fig(2a). It allows us to determine the Von-Mises mechanical stress induced. The maximal stress value 16 kPa, is located at the tail of the wire, just in front of the heel area, Fig(2b). In another study, we demonstrated that with a 10 A current the thermo-mechanical stress within the wire reaches 11 MPa. It shows that the impact of electromagnetic forces is not relevant. Nevertheless, displacement measurements show significant X and Y axis displacements. This may be linked to electromagnetic forces identified previously. Effectively, the Z-displacement is completely attributed to the wire thermal expansion.

III. CONCLUSION

We have determined analytically the Laplace forces exerted on the wire bonding. The mechanical stress distribution results show that the impact of these forces is still insignificant compared to the thermal effects. Nevertheless measured displacements can be linked with electromagnetic forces.

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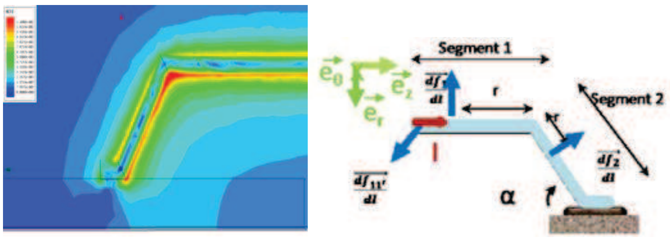

Figure (1a) and Figure (1b): Induction field distribution and force expressed.

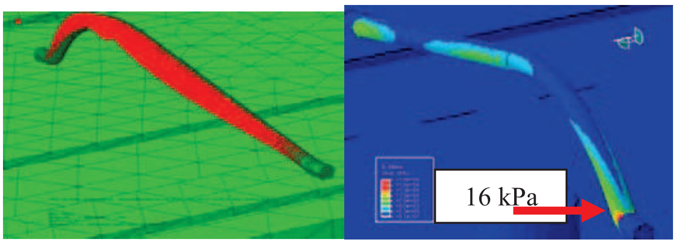

Figure (2a) and Figure (2b): Electromagnetic force applied and Von-Mises Mechanical stress distribution.