Condition Monitoring of Automotive Smart Systems utilizing Piezoresistive Stress Sensor

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ABSTRACT

It is expected that advanced electronic components and smart systems would dictate the level of innovations in nearly all industrial sectors, including but not limited to automotive and other transport/logistics solutions, production equipment, energy and other infrastructure, etc. One such component is automotive electronic control unit (ECU), which controls the electrical system or subsystems in motor vehicles.

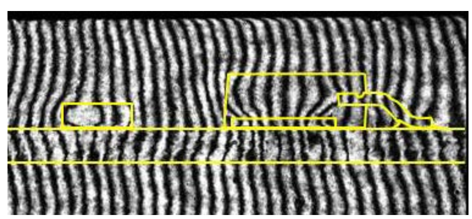
In a conventional ECU, a protective metal case is used to ensure reliability under harsh environmental conditions. Recently, an epoxy molding compound (EMC) was adopted to replace the metal case. The EMC technology reduced the manufacturing cost significantly, yet the presence of a large amount of outer EMC increased the stresses of ECUs during transfer molding process and operations (Gromala, Fischer, Zoller, Andreescu, Duerr, Rapp & Wilde, 2013, Kim, Han, Yadur & Gromala, 2014). The long-term reliability assessment of this newly adopted manufacturing technology should be conducted to make the technology a more viable alternative to various ECUs.

More recently, a silicon-based IForce piezoresistive stress sensor (Gromala, Fischer, Zoller, Andreescu, Duerr, Rapp & Wilde, 2013) was employed to assess the reliability of EMC-based advanced ECUs. In spite of serval advantages, most notably in-situ stress measurements during operations, the stress sensor provides only a local stress state around the sensor. It is inevitable, thus, to establish the relationship of the stresses between the stress sensor and the critical parts of ECUs such as solder joints, wire bonds, chips, etc., to be able to use the stress sensor in prognostics and health monitoring (PHM) systems.

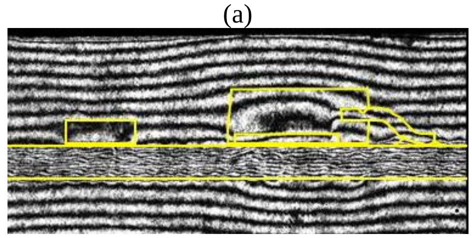
Finite element analysis (FEA) has been used widely to predict the stresses and strains field inside the electronic devices, and it can be employed to develop the relationship. However, an accurate relationship can be obtained only when the FEA model is verified and calibrated until numerical predictions match to experimental data (Han, Guo, Lim & Caletka, 1996).

In this paper, a model/sensor hybrid approach was implemented to conduct failure prognostics of an automotive electronic control unit (ECU). A 3-D finite element model simulating a complex ECU was built, and its predictability was calibrated and verified by an optical displacement measurement technique called moiré interferometry. Representative results of moiré interferometry is shown in Fig. 1 and a comparison with the calibrated FEA model is shown in Fig. 2.

The stress state of the ECU during thermal cyclic loadings are documented by piezoresistive-based stress sensors embedded in test vehicles. The silicon chip consists of two stress sensors, and it is packaged in a standard land grid array (LGA) package as shown in Figs. 3 and 4. In each sensor, there is a whole matrix of 12 sensing cells, being placed in a 4 × 4 array. Four cells in the corners are inactive.



(a)



(b)

Figure 1. Representative fringe patterns of molded ECU subjected to passive thermal condition: (a) U field and (b) V field

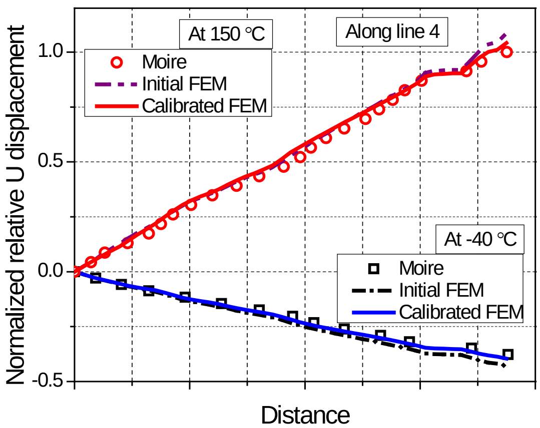


Figure 2. Comparisons of U displacements of molded ECU

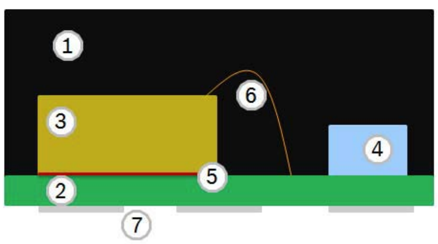


Figure 3. Construction of LGA Package: 1. mold, 2. PCB, 3. stress sensor, 4. ceramic, 5. die attach, 6. wire bond, 7. soldering pads (Palczynska, Gromala, Mayer, Han, & Melz, 2016)

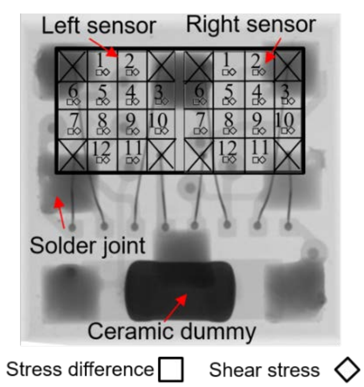


Figure 4. X-Ray image of LGA sensor package used in this study (Palczynska, Prisacaru, Gromala, Han, Mayer & Melz, 2016)

The in-situ loading history was obtained using the data obtained from a stress sensor in conjunction with a numerical metric that converted the stress signal into in-situ temperature excursion. The verified model was then utilized to develop a quantitative relationship between the stress senor data and the stress of the most critical locations in the ECU.

The results demonstrated that the proposed approach (predictive modeling with a stress sensor) will be an effective way to conduct failure prognostics of ECUs subjected to various operating conditions.

REFERENCES

Gromala, P.J., Fischer, S., Zoller, T., Andreescu, A., Duerr, J., Rapp, M. & Wilde, J. (2013). "Internal stress state measurements of the large molded electronic control units." in IEEE 2013 14th *Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems* (EuroSimE).

Kim, D.-S., Han, B., Yadur, A., and Gromala, P. J. (2014), "Electronic control package model calibration using moiré interferometry," in IEEE 2014 15th *Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems* (EuroSimE).

Han, B., Guo, Y., Lim, C. K., & Caletka, D. (1996), "Verification of Numerical Models Used in Microelectronics Packaging Design by Interferometric Displacement Measurement Methods," *Journal of Electronic Packaging, Transaction of the ASME*, Vol. 118, No. 3, pp. 157-163.

Palczynska, A., Gromala, P.J., Mayer, D., Han, B. & Melz, T. (2016), "In-situ investigation of EMC relaxation behavior using piezoresistive stress sensor." *Microelectronics Reliability* 62 (2016): 58-62.

Palczynska, A., Prisacaru, A., Gromala, P.J., Han, B., Mayer, D. & Melz, T. (2016), "Towards prognostics and health monitoring: The potential of fault detection by piezoresistive silicon stress sensor." in IEEE 2016 17th *Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems* (EuroSimE).