Failure Mitigation methodologies in Complex Avionics systems to reduce the maintenance cost

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ABSTRACT:

Electronic Prognostic and Health Management systems are essential in monitoring electronic system health by predicting early fault to initiate a preventive maintenance schedules in civil and fighter aircraft's. The accurate prediction of Remaining Useful Life (RUL) depends on sensor errors, fidelity of system modelling, inaccuracies in processing data, prediction of deviations of actual conditions with that of the simulation environment. In the current work, a new methodology of system modeling, simulation and experimentation of the electronic enclosure for temperature profiling and structural integrality has been attempted by suitably managing internal arrangement of data cards and sensor modules. The system's performance has been characterized under steady and transient temperature conditions using suitable measurement and simulation tools. The set up was subjected to the accelerated thermal profile to monitor online temperature measurements at the identified hot spots on the test board. The measurements of temperature gradients are in a good match with the simulation results and thus validates the proposed model under the test conditions. The system is further tested with the FEM simulations for vibration profile to estimate its static and dynamic stress tolerances. The experimental and model simulation accuracies establishes a reliable prognosis approach to integrate physics based models & data driven models to get more accurate mitigation of failures to reduce maintenance cost of avionics equipment.

I. INTRODUCTION

In current scenario, ePHM (electronic Prognostic Health Management) has been implemented using model-based or data-driven approach. In model-based ePHM, the system modeling and physics-of-failure (PoF) modeling [1-2] is used for Prognostic of RUL Remaining Useful Life (RUL) estimation. Some research investigations based on data-driven techniques [3-5] have been used to learn from the experimental available data and applying them intelligently to extract valuable decision-making information for system health management. In the present era of high reliability demand, the individual prognostics approach is not very accurate in prediction and forecasting of the fault and hence a more accurate approach is required to reduce life cycle cost. The researchers have also attempted to combine the model-based and data-driven approaches [6-11] to achieve a reduced uncertainty in predicting RUL estimation.

The research work to address the challenges of data driven and model based analysis appears to be an interesting area [12-15] to investigate both theoretically and experimentally. In the present work a fusion prognostics method is proposed by applying both the model-based and data-driven approach to predict the RUL more accurately.

The process uncertainties due to measurement errors, model assumptions and inaccuracies can be accurately detected and appropriately combined with the physics based model and data driven model together for a better prediction of the information. The proposed approach is stepping through the FMECA, structural and thermal analysis of the system, identification of hot and stress spots for better attention. The paper verifies the prognostic model through simulation and experimental findings to claim a more accurate RUL.

II. FUSION PROGNOSTIC PREDICTION MODEL

The system plant is comprised of a single board computer and a chassis and can be digitally modeled using appropriate segmented blocks identified based on mentioned simulated characteristics. The structural and thermal modelling of the electronic system requires suitable measurable discrete process steps and their corresponding specifications. The prognostic fusion approach based on this modeling requires system characteristics under steady state and transient conditions. The model with its working elements used in the proposed fusion prognosis approach to ePHM as illustrated in Figure 1. The work flow operation of the fusion prognostic predication model in system implementation are envisaged as below

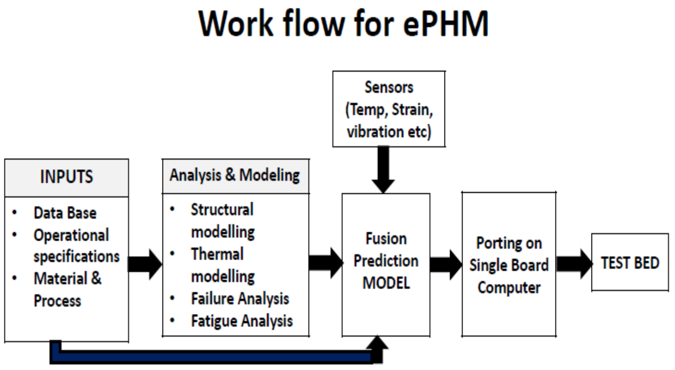

Figure 1: Fusion approach to PHM

The first step is to identify the critical parameters to be monitored in situ in determining the real time health of the system. Identification of the critical parameters is usually done by understanding the environmental impact due to the physical processes leading to system failure. The analysis considers stresses like thermal, structural, FMECA and FTA to identify critical situations of HoT spots, possible failure areas and their effects on the system [11-12]. In this context, the existing Microprocessor card in Flight Management computer is selected to develop predication algorithm for RUL using Fusion prognosis method.

The following steps are followed

Step 1: Modeling of chassis & Microprocessor card

Step2: Thermal analysis of chassis along with Microprocessor card installed with actual environmental conditions as per civil aircraft standard using FloTHERM-XT to identify hot spots for three ambient conditions 55, 70 & 80 deg C

Step3: Structural analysis of chassis with environmental conditions as per civil aircraft standard to identify critical location of higher stresses and displacement

Step4.: Instrument the card with thermal, Vibration & strain gauges at the identified hot spots & high stress locations.

Step4: Subject the Computer comprising of chassis & Microprocessor card for thermal & vibration test as per standard profile and carry out measurements.

Step5: Validate the analysis & Measurement results

Step6: Finalize the Thermal & structural Model and sensor instrumentation to use in predication algorithm

The thermal analysis and structural analysis is carried out on the model using the FloTHERM-XT & Ansys tools to identify the hot spots and critical location of stresses / displacements on the components of Microprocessor Card inside the computer chassis. The environmental and boundary conditions have been selected from aircraft qualification standard. The following section describes the outcome of thermal & structural analysis

III. THERMAL MODELING & ANALYSIS

The thermal modeling of steady state and transient analyses of the computer were carried out using FloTHERM-XT software. Figure 2 shows the thermal cycle profile used at 55, 70 & 80 deg C for the analysis.

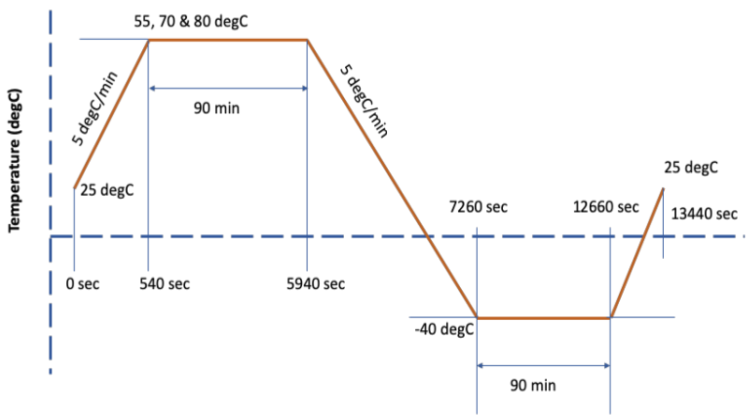

Figure 2: Thermal cycle profile used for analysis at 55, 70 & 80 deg ambient

Thermal profile analysis of the system has been carried out especially on the chassis of the system and on the most critical component microprocessor card. The thermal map simulation at three ambient temperatures 55^0,$70^0$and 80^0 C has been performed and the findings are depicted in figs.4,5 and 6 respectively. These observations have been used to predict the thermal hot spots on the microprocessor board as shown in fig.6. The maximum temperature gradient is observed at some of the critical locations is about 60deg at 55 deg boundary conditions as shown in Fig3. .

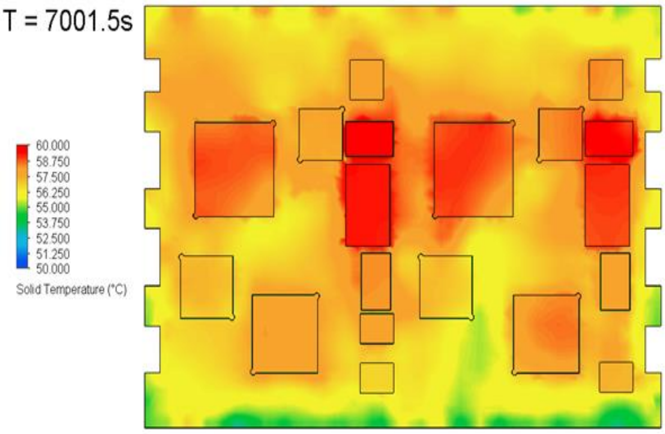

Figure 3: Thermal analysis plot of microprocessor card inside chassis at 55 deg ambient

Figure 4 & Figure 5 shows the thermal map on Microprocessor card at ambient 70 deg and 80 deg respectively. The maximum thermal gradient observed is 75 deg and 86 deg at a boundary condition of 70deg and 80 deg respectively.

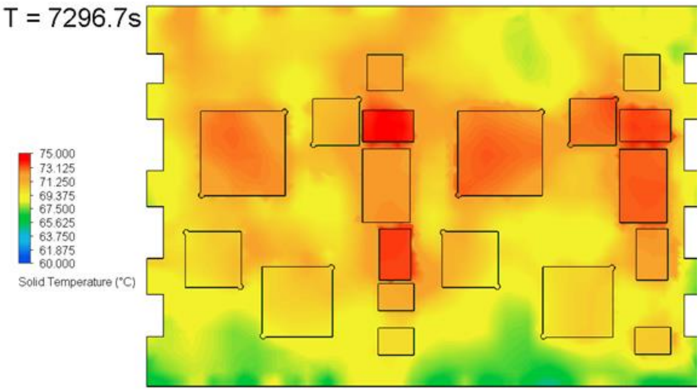

Figure 4: Thermal analysis plot of microprocessor card inside chassis at 70 deg ambient

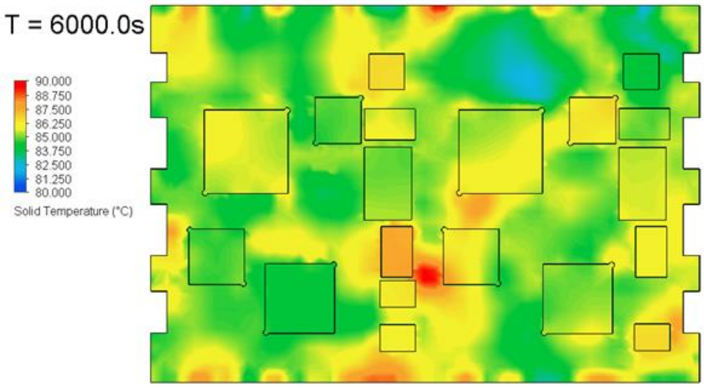

Figure 5: Thermal analysis plot of microprocessor card inside chassis at 80 deg ambient

Based on the thermal analysis at 55, 70 & 80 deg ambient the U36 & U34 are identified as Hot Spots as shown in Figure 6.

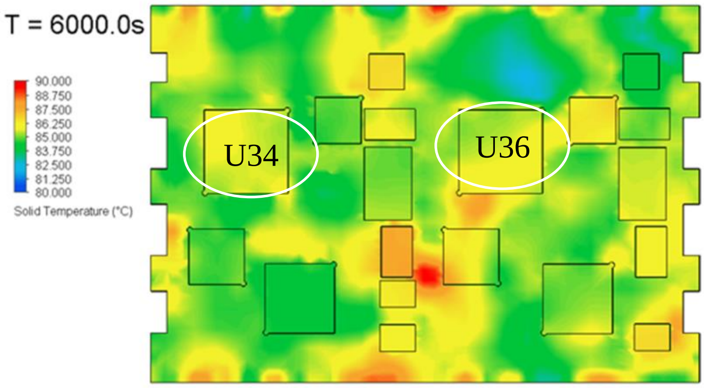

Figure 6: Hot spots on microprocessor board

The thermal reliability is primarily controlled by the system chassis and hence its thermal characteristics is also to be simulated and the thermal profile is presented in fig.7

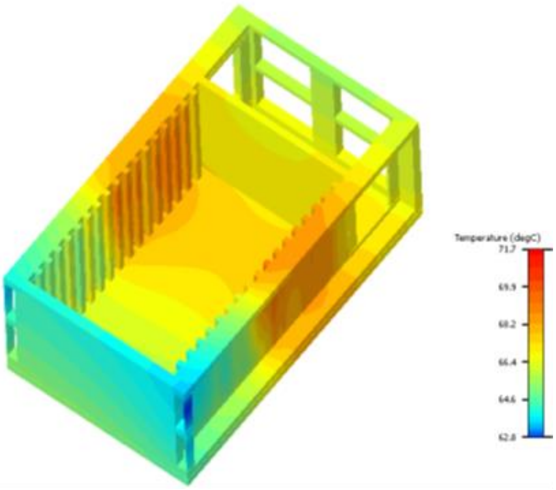

Figure 7: Chassis model and thermal profile at ambient 70 deg

The chassis wall temperature is observed as 72 deg at ambient of 70^0 C, which shows that the thermal conduction of chassis is very good.

Obviously for an accurate model specification, these simulated findings need to be validated with suitable experimentation. The following subsection presents the model setup and required thermal measurements.

IV EXPERIMENTAL VALIDATION OF THERMAL MODEL

The microprocessor card inside the chassis was instrumented at identified Hot Spot locations with temperature sensors as shown in fig.8.

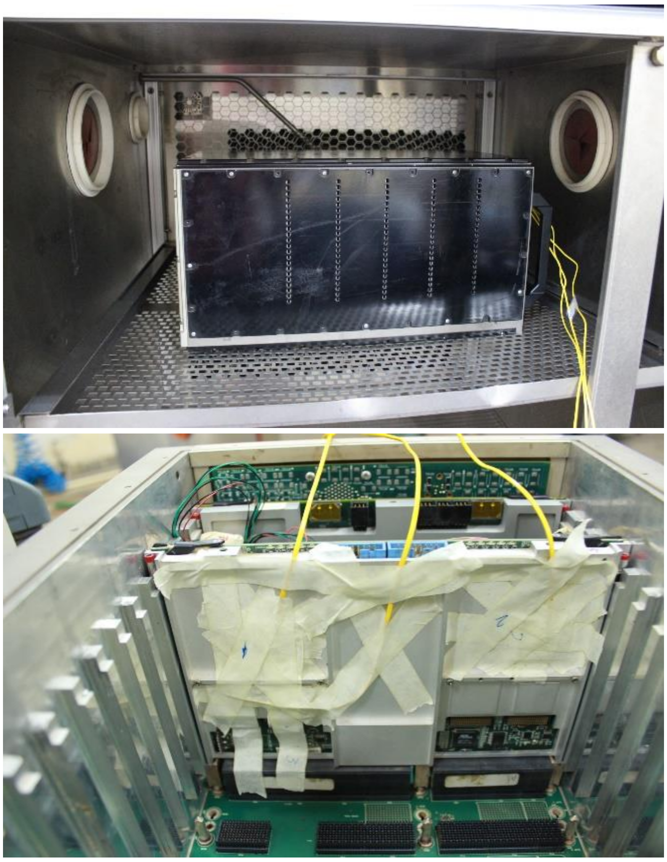

Figure 8: Experimental setup

The Computer chassis is mounted in the thermal chamber and is subjected to the same profile as per Figure 2. The simulated and measured temperatures at the identified Hot Spots at ambient of 55, 70 & 80 degC are plotted in Fig.9 & 10 respectively.

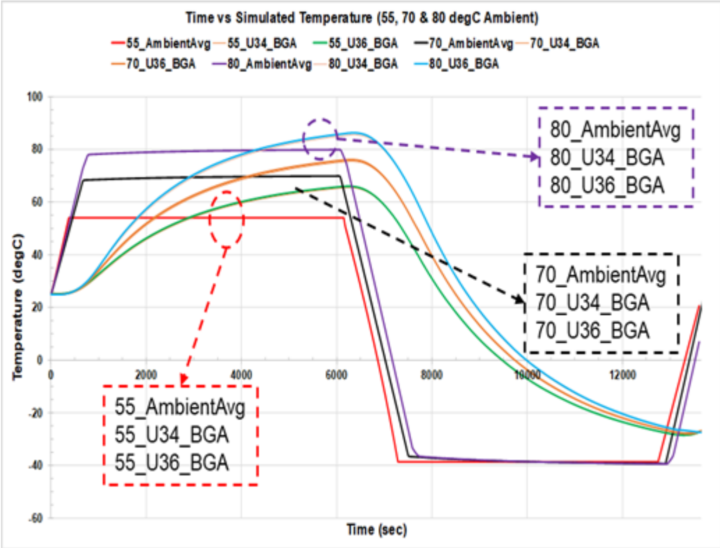

Figure 9: Simulated temperature profile on Hot spots at U36 & U34

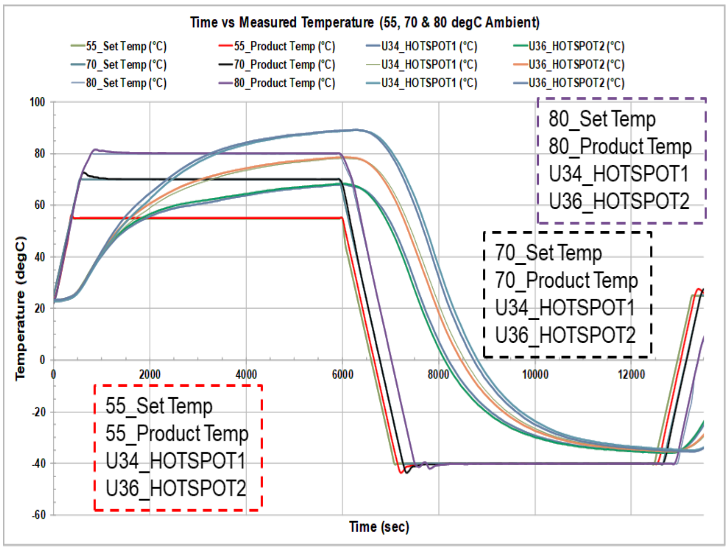

Figure 10: Measured temperature profile on Hot spots at U36 & U34

The fig 9 shows that the simulation temperature profile at various ambient temperature are in close agreement with the measured temperature profile at Hot spot IC's U34 & U36 as depicted in fig.10. The table below summarizes the simulation temp vis-à-vis measured temperature at U34 & U36.

Ambient Max Temp C	IC Component	Simulation Result (degC)	Measured Result (degC)
55	U34	62.2	65.0
	U36	63.5	65.4
70	U34	74.7	78.5
	U36	75.0	77.9
80	U34	85.5	88.8
	U36	85.5	88.2

The system mechanical tolerance capability is characterized by appropriate vibrational analysis and the same is discussed in the next subsection.

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V.STRUCTURAL MODELING & ANALYSIS

The experimental test set up is established and test article was subjected to the 3 axis sinusoidal vibration as shown in
Figure 3

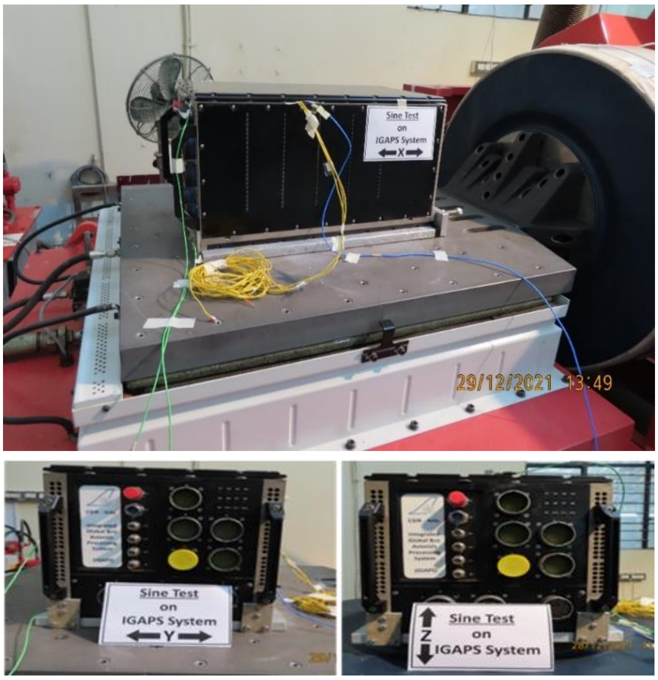


Figure 3: The test bed mounted on vibration table for sinusoidal vibration in 3 axis

The vibration profile given in

Signal Type	Frequency range (Hz)	Amplitude	Duration
Sinusoidal	5-15	2.54 mm(pk-pk)	1 hr each axis
	15-55	0.254mm(pk-pk)	
	55-500	15g	

Fig 12 : Vibration profile

has been subjected on the microprocessor card with orthogonally placed sensors to measure respective displacements along x, y and z axis. The displacement profile along these are presented in fig. 13 (a), (b) and (c) respectively.

Signal Type	Frequency range (Hz)	Amplitude	Duration
Sinusoidal	5-15	2.54 mm(pk-pk)	1 hr each axis
	15-55	0.254mm(pk-pk)	
	55-500	15g	

Fig 12 : Vibration profile

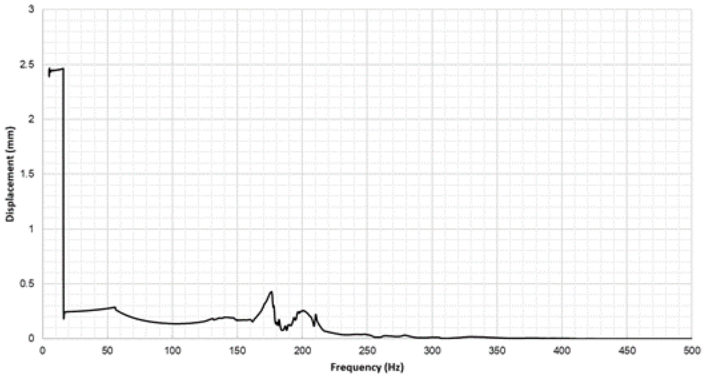


Fig 13a : Displacement in X axis for different frequencies

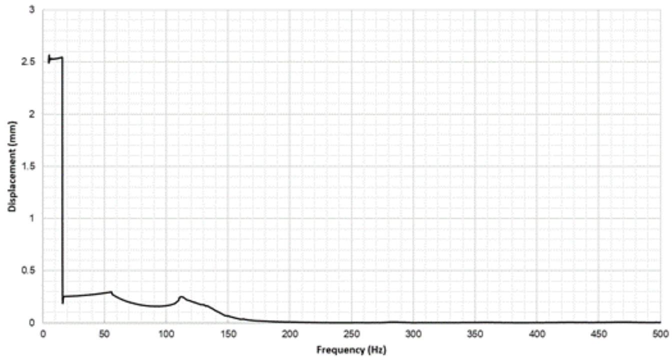


Fig 13b : Displacement in Y axis for different frequencies

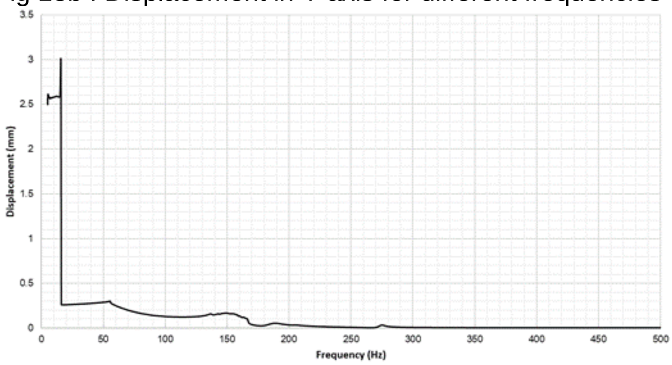
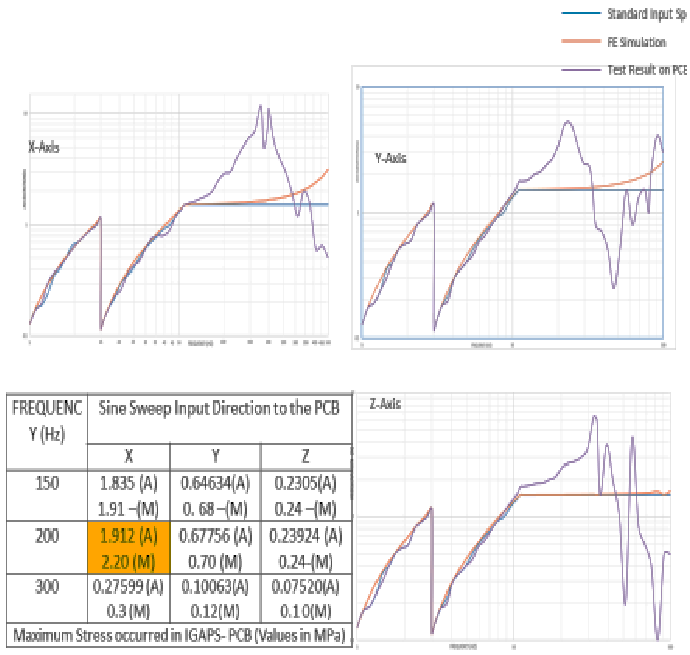


Fig 13c : Displacement in Z axis for different frequencies

These displacements are observed about 0.25mm and are within the acceptable limits.

The stresses occurred on Microprocessor card during sinusoidal vibration are measured and the Finite element simulation value (A) and Measured value (M) are tabulated in Figure 14 below



FREQUENCY (Hz)	Sine Sweep Input Direction to the PCB		
	X	Y	Z
150	1.835 (A) 1.91 –(M)	0.64634(A) 0. 68 –(M)	0.2305(A) 0.24 –(M)
200	1.912 (A) 2.20 (M)	0.67756 (A) 0.70 (M)	0.23924 (A) 0.24-(M)
300	0.27599 (A) 0.3 (M)	0.10063(A) 0.12(M)	0.07520(A) 0.1 0(M)
Maximum Stress occurred in IGAPS- PCB (Values in MPa)			

Figure 14: The comparison of simulated stress vis a vis measured stress on PCB during 3 axis sinusoidal vibration (A-Analysis, M-Measured)

The fig 14 shows that the maximum stresses observed in 3-axis finite element simulation of structural model at frequencies 150 Hz, 200Hz and 300Hz are having good match with measured experimental results.

III. CONCLUSION

The thermal model of an electronic system is presented under FloTHERM-X / Ansys simulation environment tools to predict boundary conditions under the operational specifications. The system model simulation performances has been validated through actual hardware subjected to thermal cycle in the system chamber and confirms the accuracy of the simulated results within 5%. The structural model of the system is characterized using FEM simulation tools for sinusoidal vibration as per desired specifications and displacements. The model is experimentally verified by actual hardware used for vibration and displacement measurements. The measured and simulated stresses of the model are within the accuracy of 3-4%. The proposed model establishes an accurate prognosis model of RUL estimation of an electronic system under thermal and vibrational stress.

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