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Research Article

Thermal Simulation for Design Validation of Electrical Components in Vibration Monitoring Equipment

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Abstract

Estimation of heat dissipation rates and temperature distribution in resistive heating of electrical equipment is typically carried out by analytical methods. The advent of mathematical modelling through simulation coupled with higher computational ability enabled faster analysis of flow and heat patterns. 3D numerical simulation is one such method which helps estimate the temperature and flow patterns in complex 3D geometries. This paper describes thermo hydraulic simulation of different scenarios to predict the temperature distribution of various components inside a vibration monitoring system. The quantitative results help in design validation and selection of vibration monitoring system with a better design.

Keywords: *Heat dissipation rates, Vibration Monitoring Equipment etc.*

1. Introduction

Turbine generator units that run at low speeds in the range of 90-1000 rpm are usually aligned to be vertically supported. Vertical shafts are inherently more unstable when compared to horizontal mounting. The shaft vibration monitoring is the best technique for such slow speed machines. Monitoring bearing brackets' support structure vibration enables easy resolution of vibration issues. Hence it is prudent to put both shaft as well as bracket vibration sensors at different locations and monitor them in real time, followed by analysis of results.

The existing vibration systems are relatively bulky due to the presence of many current and voltage sensors for monitoring. A new compact design for vibration monitoring equipment is made to accommodate more diagnostic features and for ease of maintenance. In any electrical equipment, the printed circuit boards and ICs present in the equipment generate losses, dissipated as heat. In order to reduce the dimensions suiting modular nature of the equipment, it is quintessential to see that this heat is dissipated suitably to prevent damage to electrical circuits. Thermal analysis of the system is carried out by natural and forced convection methods, to optimize dimensions within allowable operating temperatures of operation.

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2. Approach

In the present study, four scenarios of the vibration monitoring system are analysed:

a. Existing design dimensions
b. Reduced dimensions (0.85x)
c. Improved ventilation (Multiple air holes of 3mm)
d. Increased flow conditions (fan)

The existing model of vibration monitoring system is created in Autodesk SimStudio tools on 1:1 scale incorporating all electrical components. The model is then exported to Autodesk design study for simulation. Material properties to the inner circuitry and outer enclosure have been assigned. The properties of air are defined at 35C.

Pre-solver conditions

The boundary conditions of total heat generation and film co-efficient have been applied to associated ICs and PCB boards. Coefficients for natural convection and forced convection are different and have been accordingly applied to the scenarios under study. A total of 26 W heat generated is distributed individually on each component rather than gross distribution onto PCB board.

In addition, initial conditions of temperature are assigned to the components. The components of model are then accordingly coarse and fine meshed. Autodesk CFD is used to simulate circuit board temperature distribution and flow in the equipment enclosure.

The following solver settings were defined:

- Steady state analysis
- k-epsilon turbulence model
- Intelligent solution control scheme
- Convergence criteria 1E-05

The scenarios, with ambient temperature and film co-efficient variations for natural and forced convection, have been simulated to assess the location of hot spots and flow deficient areas.

3. CFD Analysis

The enclosure consists of display board, PCB boards and ICs. The fluid domain in the model is of quiescent air. The transparent isometric and top views for the four scenarios of the model are displayed in Figs 1, 2, 3

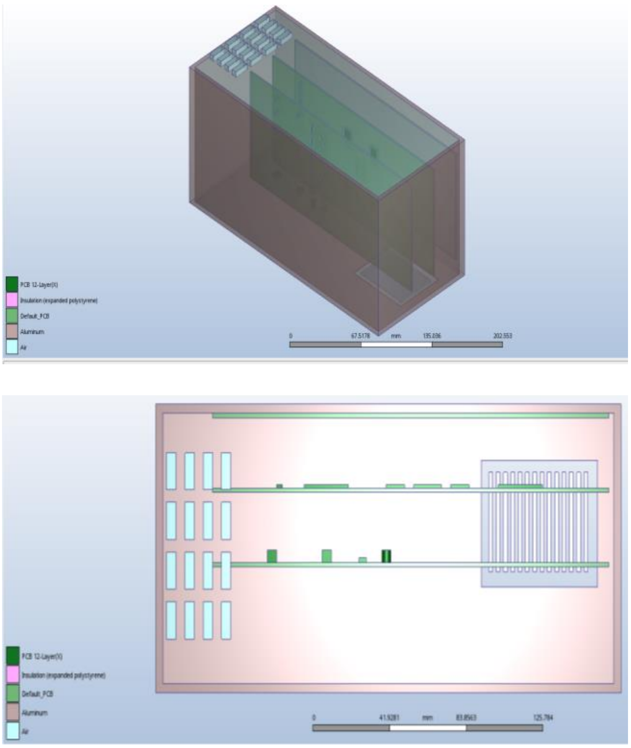
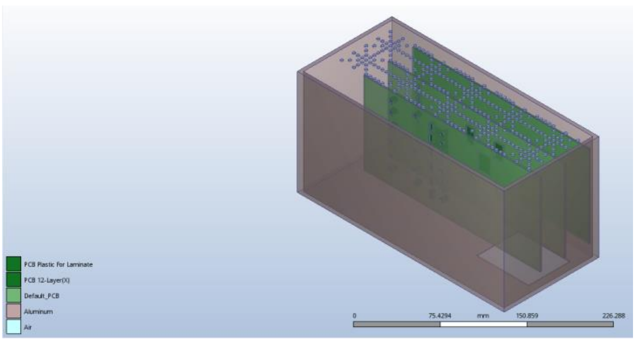


Fig.1 a, b. Existing design dimensions of the system



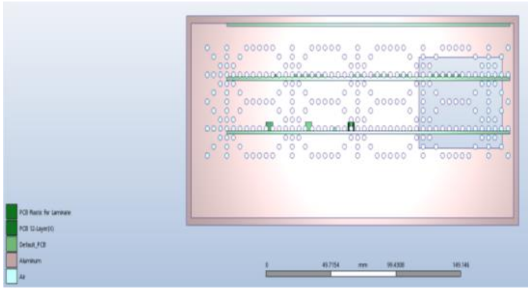


Fig.2 c. Improved ventilation in the system

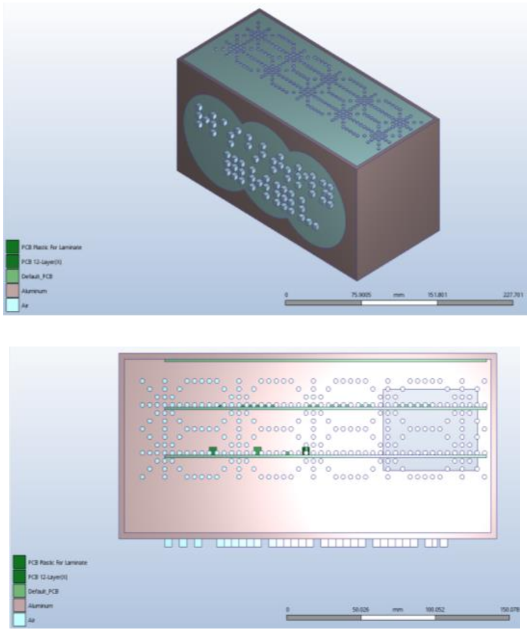


Fig.3 d. Increased flow conditions in the system

The medium inside the enclosure is classified as single phase, incompressible and internal flow. The simulation solver of Autodesk CFD adopts implicit discretization for transient analyses and explicit discretization for steady-state analyses. The following fluid governing equations with standard notation are solved iteratively:

Continuity

$$\frac{\partial}{\partial x_i}(\rho U_i)=0 \quad (1)$$

Momentum equation for forced convection

$$\rho\left[\frac{\partial U_i}{\partial t}+\frac{\partial U_i U_j}{\partial x_j}\right]=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial U_i}{\partial x_j}-\rho\overline{u_i u_j}\right)+S \quad (2)$$

The momentum equation for natural convection takes the following form as body forces in x, z are absent.

$$\rho\left[u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right]=-\frac{\partial p}{\partial y}+\mu\text{-}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g\beta(T-Tb) \quad (3)$$

Energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=K/\rho C\text{-}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \quad (4)$$

Components of model are then meshed and have a total mesh count of 470K.The mesh is displayed in Fig 4.

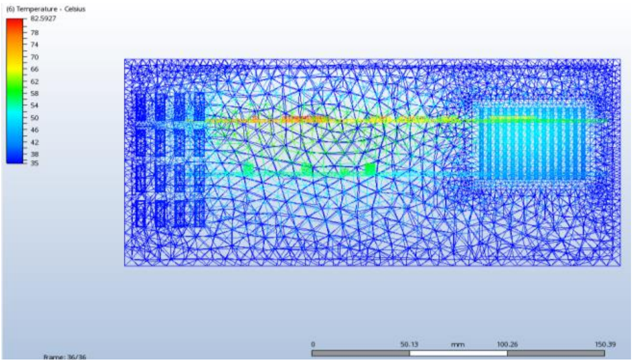


Fig.4 Mesh of model in top view

A steady state analysis is carried out for the temperature and flow distribution profiles, taking into consideration the first scenario described above. The results and post processing details of the four scenarios are also discussed.

4. Results

A cross section of front and side view displaying temperature pattern during an instant of the analysis is shown in Fig 5.

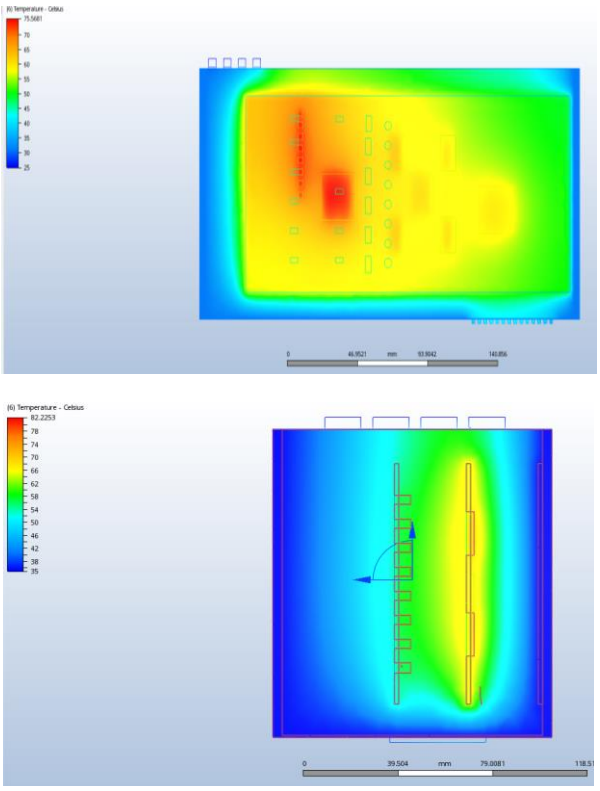


Fig.5 Sectional view of model during analysis

At the end of the analysis, the top surface of the enclosure, air entry side is displayed in Fig 6.

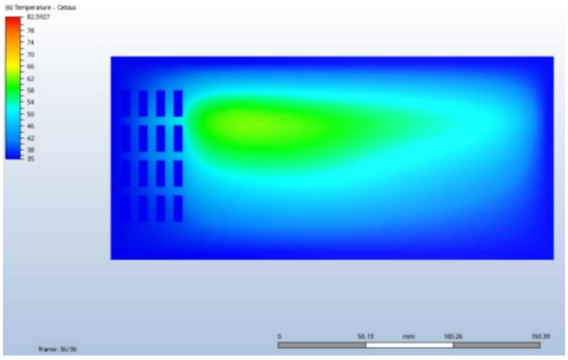


Fig.6 Top side temperature distributions at end of steady state run

The following observations are made:

- The maximum temperature is 83C, attained on top of an IC (DSP).
- The display board has no heat generation and is at ambient.
- The other ICs attain a temperature in the range of 60-75 C.
- The maximum temperature attained by casing is 66 C
- Temperature profile of the three boards in the enclosure is displayed in Fig 7.

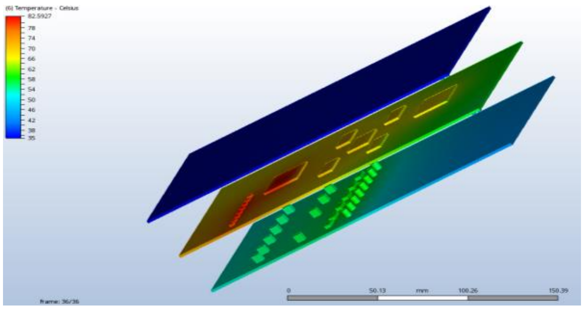


Fig.7 Isometric view of inner component temperature distribution

Temperature build curves obtained at different crucial points between temperature and iterations (convergence state) are displayed in Fig 8 to 11.

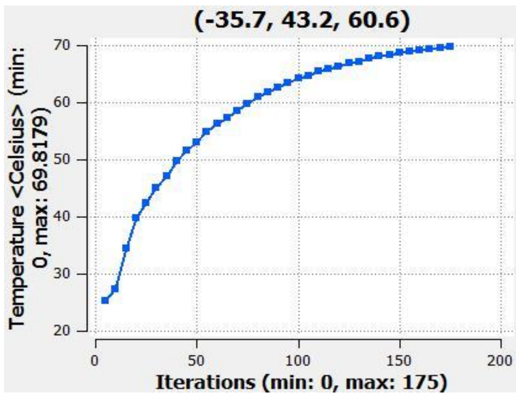


Fig.8 Temperature on PCB board

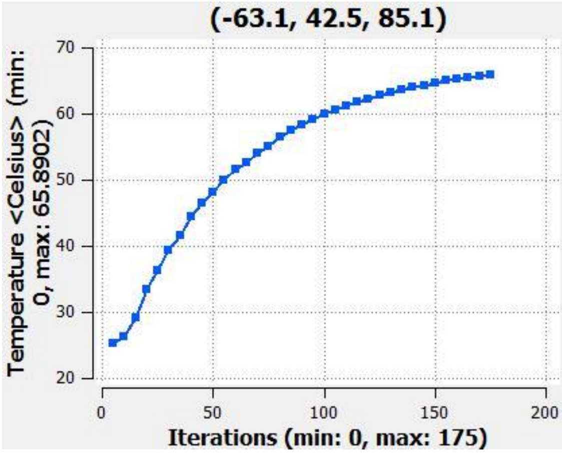


Fig.9 Temperature on enclosure (hot spot)

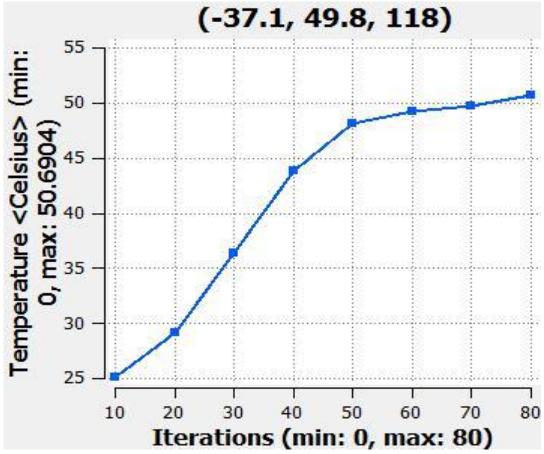


Fig.10 Average enclosure temperature (excl hot spot)

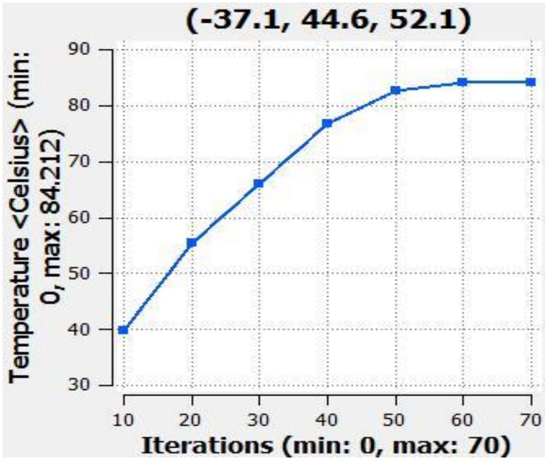


Fig.11 Temperature on IC (DSP) (highest point)

In a similar approach, the other three scenarios have been analyzed to obtain temperature distribution patterns. Summary of results is presented below in table 1. All temperatures are in Celsius.

Table 1 Temperature of components in different scenarios

Scenario	Highest Temperature on PCB board	Temperature on enclosure (hot spot)	Average enclosure temperature (excl. hot spot)	Highest temperature on IC (DSP)
Existing design dimensions of the vibration system	70	66	51	83
Reduced dimensions (0.85x) of the vibration system	67	63	48	86
Improved ventilation in the vibration system (Multiple holes of 3mm diameter)	58	55	41	78
Increased flow conditions in the vibration system (fan)	47	43	39	53

Conclusions

- In the case of existing design dimensions of vibration system, air being quiescent, certain ICs in the enclosure attain a temperature of 83°C. This is not agreeable as the safe operating temperature of industrial ICs is up to 85°C.
- In the case of reduced dimensions of the vibration system, air being quiescent, the temperature attained by the same ICs is 86°C. This is not acceptable as it is beyond the allowable operating temperature of 85°C for industrial ICs.
- In the case of improved ventilation in the vibration system in the form of 3mm holes on top side of

enclosure, air being quiescent, the temperature attained by the same ICs is 78 ^oC. This is acceptable as it is within the operating temperature of 85 ^oC for industrial ICs.

- In the case of increased flow conditions in the vibration system, air flowing through an external fan, the temperature attained by the same ICs is 53 ^oC. This is acceptable as it is well within the operating temperature of 85 ^oC for industrial ICs.
- The vibration monitoring system with existing design dimensions and fan flow ensures proper heat dissipation and is thus selected for implementation in industry.

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