Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN : 2339-9095; Online ISSN : 2393-9109; Volume 2, Number 6; April – June, 2015 pp 76 – 79
Krishi Sanskriti Publications
http://www.krishisanskriti.org/jmsme.html

Analysis and Prediction of Thermal Behavior of Current Path for Circuit Breaker using FEA Model and DOE Approach

Vikrant Salunkhe[1], N.P. Gulhane[2], Sunil Dayalapalli[3]

[1]*M.Tech Scholar*
Veermata Jijabai Technological Institute, Matunga, Mumbai, India.
[1]*+91 7709736462, Vikrantsalunkhe111@gmail.com*
[2]*Associate Professor*
Veermata Jijabai Technological Institute, Matunga, Mumbai, India.
[2]*+91 (0)22 24198219, npgulhane@vjti.org.in*
[3]*Asst Manager*
SDDC, L&T Switchgear, Powai, Mumbai, India
[3]*+91 9004121499, Sunil.dayalapalli@lntebg.com*

Abstract: *The aim of this paper is to develop a model to analyze and predict the thermal performance of current path used in Molded Case Circuit Breaker (MCCB) for current rating 1600A. The three-dimensional steady-state FEA model is established and simulations are carried out using ANSYS software. The various parameters contributing the heat generation in current path are investigated.*

The Design of Experiment (DOE) methodology has been implemented to analyze the effect of the different geometrical parameters on temperature rise. A full factorial design is carried out using Minitab software. The significance of each parameter is studied and optimization is done in order to achieve the temperature within the threshold as per the standards. This model can be used to analyze the thermal behavior of current path during current flowing condition. The Regression Analysis is performed to establish a numerical relationship between affecting parameters and surface temperature. To validate the results experimental tests have been carried out in laboratory. There is a good agreement between experimental results and software results

Keywords- molded case circuit breaker, current path, thermal model, design of experiments, regression analysis.

1. INTRODUCTION

All electrical equipments generate heat due to Joule heating of the current conducting components resulting in temperature rise. The regulating bodies define the temperature rise limits for safe operation of the all equipments. Switchgears are designed to switch a wide range of currents. They provide over current and short-circuit protection. Also they must switch load current and isolate sections of the low-voltage distribution system. Generally circuit breaker conducts current when contacts are closed. In this a continuous current flows through the breaker. It results in heat generation through I^2R losses within specified volume of the current conducting components like movable contacts, fixed parts, joints and flexible connections. The circuit breaker has to effectively dissipate and conduct the heat that is generated within these components.

There are International Electrotechnical Commission (IEC) standards tests for circuit breakers. Molded case circuit breakers have to comply with IEC 60947-2 standards which include temperature-rise measurements at the circuit breaker terminals while carrying rated current [1]. So during the design phase of any circuit breaker thermal analysis is mandatory to predict temperature rise which helps in reducing design iteration cycle. Bypassing thermal analysis precludes the design of circuit breaker.

Thermal analysis is done either by building a laboratory model or by simulation using software. Generally once the basic design is completed, laboratory model is built to observe the response of the system. Later certain changes are incorporated to arrive at optimum design. Rebuilding the model for every change incorporated becomes a costly and time consuming affair. So it is beneficial to carry out the simulation work at this stage using commercial simulation software to predict the response of the system for the changes made.

In previous work, analytical tool based on thermal networking method by exploiting the similarity between thermal and electrical analogy to calculate steady state temperatures along current carrying path is described in [2]. The three-dimensional analysis of current path in circuit breaker is presented in [3]. The advanced thermal simulation in which non-metallic parts of the circuit breaker like casing, air within the circuit breaker are also included in the model [4].

In present work, first FEA model is developed for a given configuration of current path of MCCB in ANSYS. This model is used for analysis of affecting parameters and prediction of temperature rise using design of experiment approach.

2. THERMAL MODEL

The modeling of geometry of single-pole current path is carried out in Computer aided software, Pro-Engineer. It is necessary to understand the geometry of current path under consideration. The three-dimensional geometry of current path is shown in Fig.1. It consist of various parts including moving contact, fixed contact, braid (flexible connection) etc. as shown in Fig.

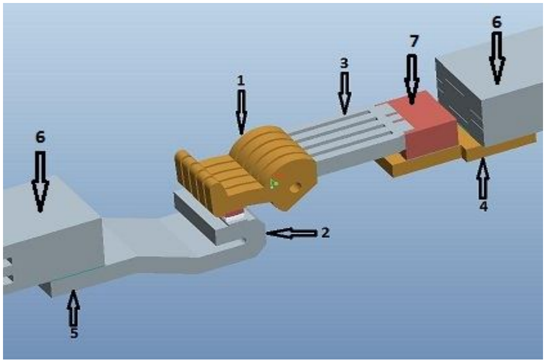

Fig.1. Main component parts of current of MCCB (1- moving contact; 2-fixed contact; 3-braid; 4- bottom terminal; 5-top terminal; 6-links;7-block)

During experimental testing, terminals of circuit breaker are connected to power supply by using one meter long links having cross-sectional area 1000mm^2. These links are also included in the model in order to consider the convective and conductive heat transfer effect of them. Further thermal analysis is carried out using commercial FEA software, the ANSYS Workbench 13. Due to need of thermal as well as electric boundary conditions, the Thermal-Electric model present in ANSYS Workbench is used for simulations. In thermal analysis, the crucial part is to assign accurate convective boundary conditions. The two links are in open space hence heat transfer to atmosphere takes place by natural convection. The convective heat transfer coefficients for link surfaces are calculated by using the correlations available for natural convections [5]. But inside the molded case circuit breaker, volume of atmospheric air exposed to the hot surface of current path is very less. Some amount of heat is transferred by conduction to casing, other parts in contact with current path by conduction and then it is dissipated to atmosphere by convection. Hence, it difficult to predict exact convective heat transfer coefficient for different surfaces along the current path. In this thermal model, effect of both conduction and convection is taken care by assigning overall heat transfer coefficient at different surfaces along the current path.

The experimental Thermography Test has been performed in laboratory for MCCB having current rating 1600A. Temperatures of individual parts are recorded using T-type Thermocouples. The ambient temperature recorded as 28°C. Keeping same electrical boundary condition and same geometry of current path as that of used in experimental testing, simulation is carried out in ANSYS. The various contact and joint resistances are measured experimentally. The effect of these resistances is taken care by adding additional thin layer of material between the joints and contacts along the current path. These layers are assigned with equivalent electrical resistivity calculated from experimentally measured resistance at corresponding joints. In simulation, heat transfer coefficient along the current path surface is corrected iteratively in order to match experimental test results. Once the ANSYS results are in good agreement with the experimental test results, all the Thermal boundary conditions were frozen and this ANSYS model is taken as a reference thermal model for further simulations. The thermal model is further validated with experimental test by changing geometry. There is a good correlation between experimental result and ANSYS model result. Fig.2. shows the ANSYS simulation results. The graph indicating the temperature at different locations along current path for both ANSYS and experimental test is plotted as shown in Fig.3.

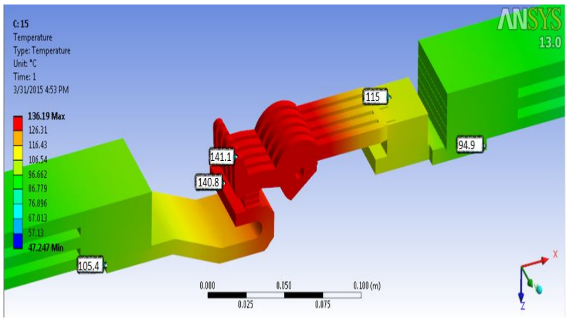

Fig.2. ANSYS model results showing temperatures along the current path

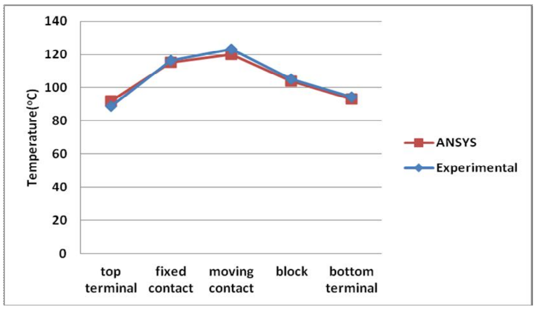

Fig.3. Comparison of ANSYS and Experimental Test results

3. DESIGN OF EXPERIMENT (DOE) METHODOLOGY

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. The objective of adopting DOE approach in this work is to study the effects of different geometrical parameters of current path on its temperature rise. So, investigation of different parameters both controllable and non-controllable is done. The important three geometrical parameters namely fixed contact, moving contact and braid are selected for DOE analysis. The forth important factor is contact resistance present between moving and fixed contacts. In this analysis contact resistance parameter is expressed in terms of milivolt (mV) drop across the contacts.

The DOE analysis is carried out using a statistical tool, Minitab.14. The full-factorial two-level design is selected for this analysis. The factors and their levels are as shown in Table.1.

TABLE.1 Different factors and levels

Factors	Level 1	Level 2
Fixed Contact Thickness (mm)	8	10
Moving Contact Thickness (mm)	5	6.35
Braid c/s Area (mm^2)	20	25
mV Drop across Contacts	2.5	5

These levels for the factors are chosen according to the dimensional boundary constraints. In a full factorial design, Minitab suggests a total of 16 DOE runs. As per these sixteen combinations, sixteen different geometries are developed in PRO-E software. The response (output) terms are set as top terminal temperature and bottom terminal temperature. Thermal simulations of the above said sixteen geometries are carried out in ANSYS using thermal model established previously. Simulation results are fed to Minitab for further analysis.

4. RESULTS

The results obtained by Minitab include main effects plots, Pareto charts are discussed in this section. The fig.4 shows the main effects plot for top terminal temperature. From main effect plots we can say that moving contact thickness is having less effect on top terminal temperature, while mV drop is having most significant effect followed by braid c/s area. The Pareto diagram shown in Fig.5 is a graphical overview of the problem, in ranking order of the most important factors, down to the least important factor. The factors crossing the reference line in Pareto chart are most important factors to be focused on.

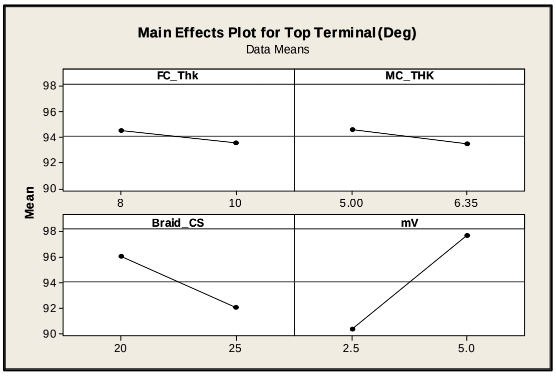

Fig.4. Main Effects Plot for top terminal

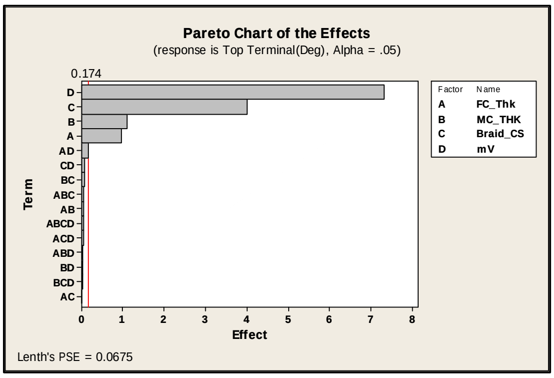

Fig.5. Pareto Chart of effects for top terminal

5. REGRESSION ANALYSIS-

In statistics, regression analysis is a tool used to fit a model to observed data in order to establish a relationship between variables and outputs. Here, regression analysis is done for developing a numerical relationship between terminal temperatures and four variable parameters. The equation (1) and equation (2) are the resultant regression equations for top and bottom terminal temperatures respectively.

Top Terminal Temperature =

$$110 - (0.477 \times FC) - (0.819 \times MC) - (0.802 \times Braid) + (2.93 \times mV) \quad - (1)$$

Bottom Terminal Temperature =

$$116 - (1.29 \times FC) - (0.923 \times MC) - (0.628 \times Braid) + (2.37 \times mV) \quad - (2)$$

The results obtained from regression equation are validated with ANSYS as well as experimental test results. The graph shown in Fig.6 indicates that there is very less deviation in temperature results of ANSYS, experimental and regression analysis. With the help of these equations, terminal temperatures can be predicted for any possible geometry.

6. CONCLUSION

The proper design of geometry of current path is important in order to achieve less I^2R loss responsible for temperature rise in circuit breaker. The obtained 3D thermal model allows analysis of thermal behavior of current paths of circuit breakers in steady-state condition. The thermal model provides the current path lengthwise temperature distribution and could be used for different geometrical changes in current path. The effects of different parameters on heat generation in current path are studied by using DOE analysis. The obtained regression equations are very useful for predicting the terminal surface temperatures with an error of less than 5%.

7. ACKNOWLEDGEMENTS

This work was supported by Larsen & Toubro Switchgear Design & Development Center (SDDC), Mumbai. The authors are grateful to Yogesh Patil, Asst. General Manager, L&T SDDC Mumbai, for providing technical assistance.

8. REFERENCES

[1] IEC-International standards for low-voltage switchgear and controlgear- Part 2: circuit breaker

[2] K. S. Cherukuri, a thesis on Thermal Network Theory for Switchgear under Continuous Current, 2007.

[3] Adrian T. Plesca, Thermal Analysis of the Current Path from Circuit Breakers Using Finite Element Method, World Academy of Science, Engineering and Technology Vol:6 2012-12-29.

[4] Rockwell Autom. AG, Aarau, Switzerland. Electrical Contacts, 2004. Proceedings of the 50th IEEE Holm Conference on Electrical Contacts and the 22nd International Conference on Electrical Contacts.

[5] Dr. Harlan H. Bengtson, P.E, Convection Heat Transfer Coefficient Estimating, A SunCam online continuing education course.