STEADY STATE THERMAL ANALYSIS OF AN INDUCTION COIL USED FOR INDUCTION HARDENING

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Abstract: This paper deals with the thermal analysis via finite element method of a single turn induction coil of an induction hardening machine. Basically, induction coils are designed to provide necessary heat for the specimen during the induction hardening. The induction hardening coil are manufactured of 99% oxygen free pure electrolytic copper. Therefore, copper is selected as a material for this analysis. The objective of this thermal analysis is to study the temperature distribution, thermal related quantities like Heat flux etc. and to evaluate the performance under severe conditions. In this present work, the effort has been made to analyze effect of total heat transfer from a single turn induction coil. Different temperatures are being taken into account while running the analysis. CREO software is being used for modelling of single turn induction coil, ANSYS workbench 18.1 software is being used for analysis of single turn induction coil.

IndexTerms **-** *Single Turn Induction Coil, Temperature, Heat Flux CREO, ANSYS.*

I. INTRODUCTION

In induction hardening, thermal stresses is one of the foremost copper failure modes of induction heat treating coils, especially in applications with alternating heat cycles. For the duration of a typical induction hardening process, power will be OFF when the part is loaded into the induction coil. After the part is loaded and placed into position, power will be turned ON and the level will be adjusted over the course of the heating process to ensure the proper heating configuration is achieved. After the heating cycle is finished, the power will be turned OFF while the part is either quenched in place or just moved to the next station while the part is still hot. Power will remain OFF until the next part is in position [4].

When power is turned ON, copper induction coil is being cooled and proper heat inside the coil is being dissipated. The copper will quickly rise to a temperature, then quickly achieve a steady state for the power and frequency setting due to the high thermal conductivity of copper along with very high heat transfer coefficients of high pressure demineralized water. When power levels are changed, the copper temperature will also change, as the copper material is dependent on temperature once the power is turned OFF, the coil copper temperature will quickly return to the temperature of the cooling water or initial room temperatures. As there is change in temperature, copper will expand when heated and contract when cooled. The level of contraction and expansion is based upon the temperature that is reached and the material properties of the copper is also temperature dependent [3].

This cycle of expansion and contraction leads to subsequent crack formation over certain number of cycles. Once a crack is formed, it will propagate quite quickly due to increased resistance of this section of the coil, which causes even higher temperatures to be reached. The crack eventually reaches the water pocket and a terrible failure occurs. The variables earlier identified as the sources of thermal stresses contain radiation from the part surface, frequency, current, concentrator losses, water pressure and coil wall thickness [2].

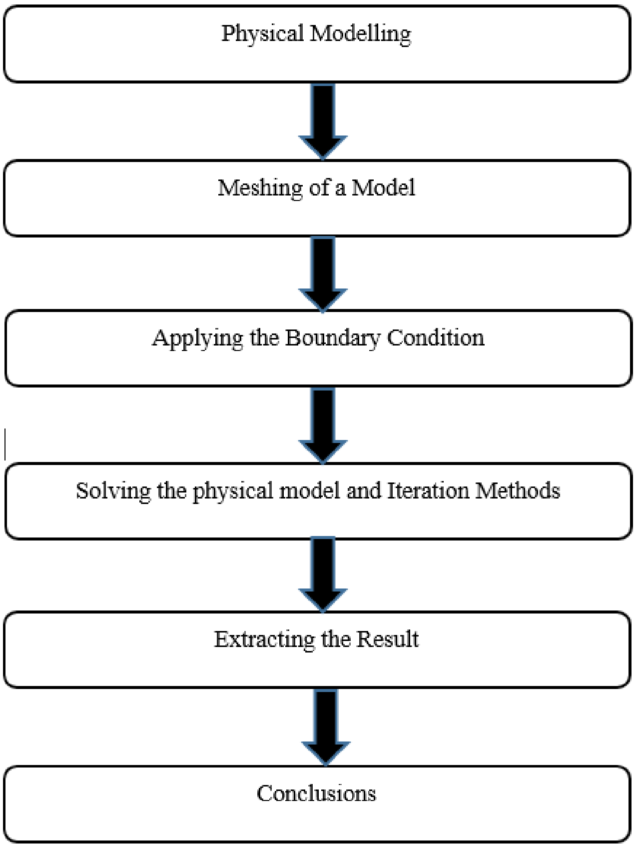
1.1 Finite element method:

It is a numerical technique for solving a physical problem governed by an energy theorem or a differential equation. It is different from other numerical methods because algebraic equations are being generated using integral formulations, the unknown quantities or quantities are been approximated using continuous piecewise smooth functions. This function is continuous and has infinite number of derivatives. The finite element method uses the continuous function but a function with an enough continuity in the derivatives, to consent the integrals to be evaluated. For, integral formulations such as variational method, no continuity is required in the first derivative. An equation composed of a several linear segments can be used as the approximate equations. Today this method is widely used to analyze the problems of heat transfer, fluid flow, electric and magnetic fields and many others. The procedure or steps involved in finite element analysis involves:

I. Discretize and select the element type.
II. Select a suitable displacement function.
III. Define strain / displacement and Stress / strain relationships.
IV. Derive the elemental stiffness matrix and equations.
V. Assemble the element equations to obtain the global or total equations and introduce boundary conditions.
VI. Solve for unknown degrees of freedom or generalized displacements.
VII. Solve for element stresses and strain and interpret the results.

II. RESEARCH METHODOLOGY

The research methodology for this work is as follows



2.1 Modelling of single turn induction coil:

The single turn induction coil is been modelled using CREO software, Such that all the dimensions are in mm. the model is been saved in the IGES format and then exported to ANSYS WORKBENCH 18.1.

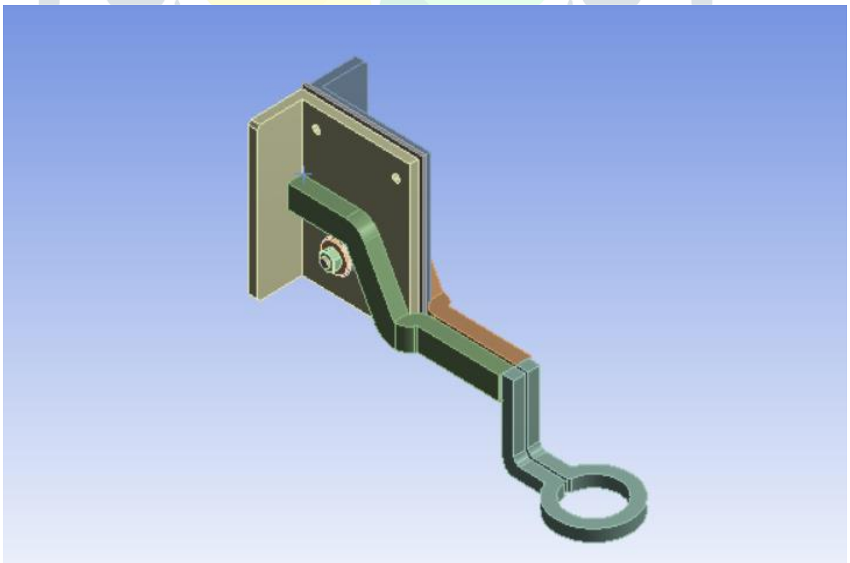


Figure 1: Physical Model of a Single Turn Induction Coil.

2.2 Meshing criteria:

The elements used to mesh the single turn induction coil are SOLID-87, SHELL-131, CONTA-174, TARGET-170.

2.2.1 SOLID-87:

The SOLID-87 is used to model the irregular meshes. The element has single degree of freedom, temperature, at each node. The element is applicable to the 3-D, steady state or transient thermal analysis. The geometry, node locations, and the coordinate system for this element are shown in figure2 below.

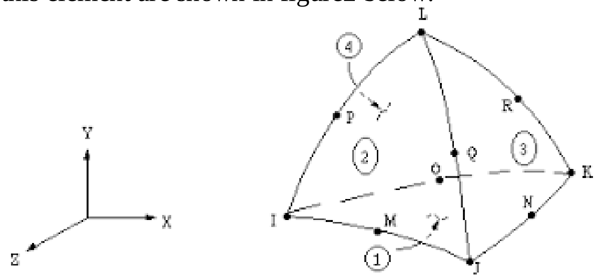


Figure 2: The geometry, node locations and the coordinate system of SOLID-87.

2.2.2 SHELL-131:

SHELL131 is a 3-D layered shell element having in-plane and through-thickness thermal conduction ability. The SHELL-131 element is having four nodes with up to 32 temperature degrees of freedom at each node. The conducting shell element is applicable to a transient, steady-state or 3-D thermal analysis. SHELL131 produces temperatures that can be delivered to structural shell elements in order to model thermal bending. The geometry, node locations, and coordinates systems for this element are shown in Figure 3. The element is defined by one thickness per layer, four nodes, a material angle for each layer, and the material properties. If the material is uniform and the analysis has no momentary effects, only one layer is needed with a linear temperature variation through the thickness.

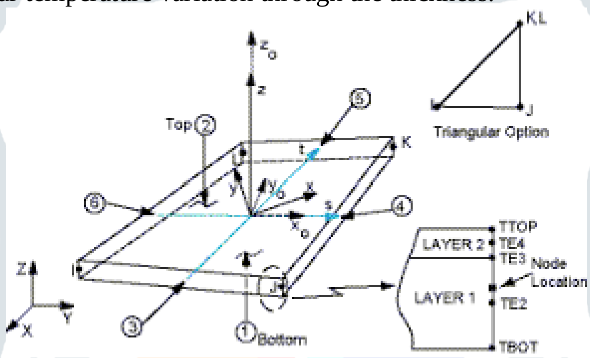


Figure3: The geometry, node locations, and coordinates systems for SHELL131 element.

2.2.3 CONTA-174:

CONTA174 is used to signify contact and sliding between 3-D target surfaces and a deformable surface defined by this element. The element is applicable to coupled-field contact and 3-D structural analyses. It can be used for both general contact and pair-based contact. The element has the same geometric appearances as the solid or shell element face with which it is connected as shown in the figure 4. Contact occurs when the element surface pierces an associated target surface. Coulomb friction, shear stress friction, user-defined friction with the USERFRIC subroutine, and user-defined contact interaction with the USERINTER subroutine are acceptable. The element also permits separation of bonded contact to simulate interface delamination.

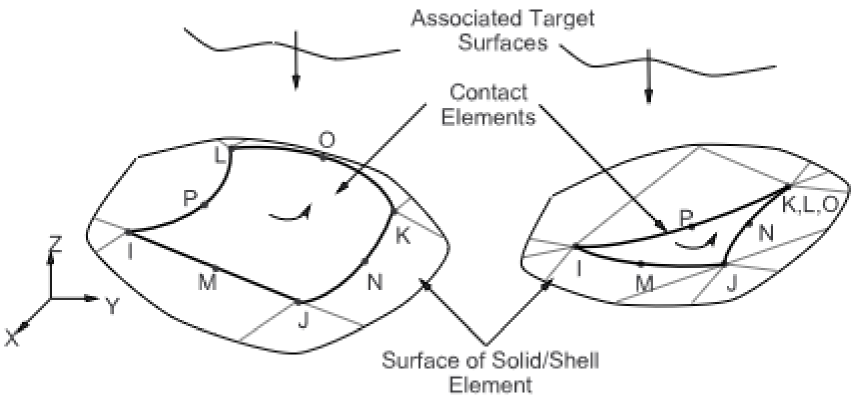


Figure 4: The geometrical characteristics of CONTA-174.

2.2.4 TARGET-170:

TARGE170 is used to signify various 3-D "target" surfaces for the connected contact elements (CONTA173, CONTA174, CONTA175, CONTA176, and CONTA177). The contact elements themselves overlap the solid, shell, or line elements telling the boundary of a deformable body and are possibly in contact with the target surface, defined by TARGE170. For rigid target surfaces, these elements can easily help in modelling complex target shapes. For flexible targets, these elements will overlap the solid, shell, or line elements describing the boundary of the deformable target body. The geometrical characteristics for TARGET-170 is shown in the figure 5 below.

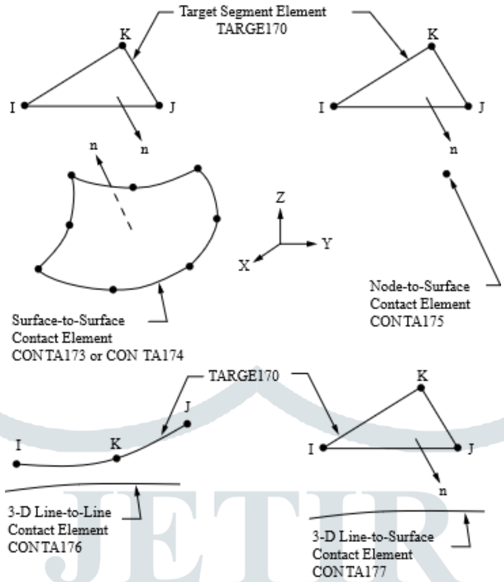


Figure 5: The geometrical characteristics of TARGET-170 element.

2.3 Meshing of the single turn induction coil:

The elements used for the meshing of the single turn induction coil are tetrahedral three-dimensional elements with 10 nodes (iso- parametric) as discussed above .In this reproduction of mesh, the meshing was developed in the contact zone. This is significant because in this zone the temperature fluctuates considerably. The meshing of the single turn induction coil is shown in the figure 6 below.

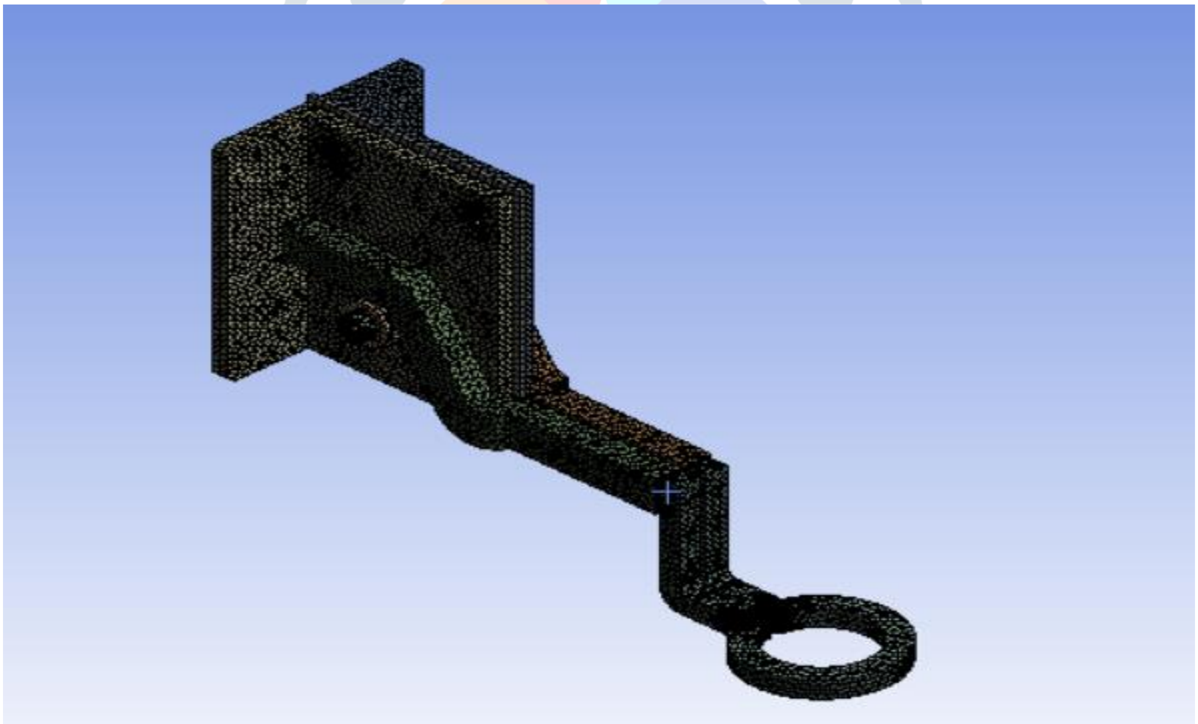


Figure 6: The meshing of the single turn induction coil.

The meshes have been tested with the convergence tool in ANSYS WORKBENCH 18.1. The number of elements and nodes forming mesh is given in Table 1.

Table1: The nodes and elements for single turn induction coil.

Nodes	1,72,620
Elements	98,402

The convergence graph is plotted with the x-axis with the number of iterations and y-axis with the temperature. The convergence plot is shown in the figure 7 below.

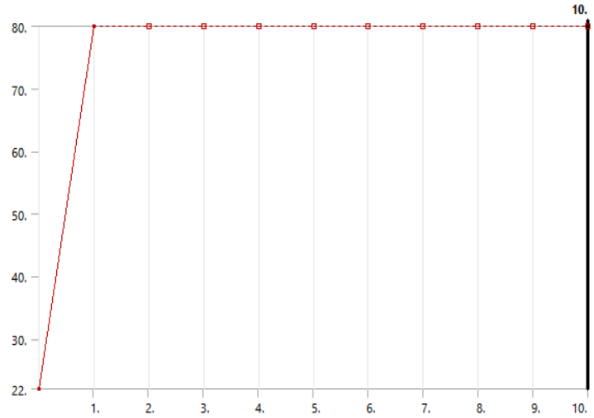


Figure 7: the convergence plot for the induction coil

2.4 Chemical composition of oxygen free 99% pure electrolytic copper

The chemical composition of the oxygen free 99% pure electrolytic copper is shown in the table 2 below.

Table 2: The chemical composition of the oxygen free 99% pure electrolytic copper.

Constituents	% by weight
Sn	<0.0003
Pb	<0.0005
Zn	0.0068
Fe	0.0098
Ni	<0.0002
P	0.0061
As	<0.0005
Sb	<0.0005
Ag	0.0008
Bi	<0.0005
Cu	99.95

2.5 Material properties of single turn induction coil:

The single turn induction coil is made up of the oxygen free 99% pure electrolytic copper. The material properties of the single turn induction coil is shown in table3 below.

Table3: The material properties of oxygen free 99% pure electrolytic copper.

Name	oxygen free 99% pure electrolytic copper
Model type	Linear, elastic, isotropic.
Default failure criterion	Max. Von Misses stress
Density	8300 kg/m^3
Young's modulus	$1.1E^{11}$Pa
Poisson's ratio	0.34
Isotropic Thermal conductivity	$401Wm^{-1}k^{-1}$
Specific heat	$0.385Jkg^{-1}C^{-1}$
Bulk modulus	$1.1458E^{11}$Pa
Shear modulus	$4.1045E^{10}$Pa
Tensile yield strength	$2.8E^{8}$Pa
Tensile ultimate strength	$4.3E^{8}$Pa

2.6 Boundary condition:

Thermal stresses are one of the major causes for the failure of the single turn induction coil. The minimum temperature of the single turn induction coil is been found to be 22^0C (ramped). The maximum temperature of the single turn induction coil is been found to be 80^0C (ramped).

2.7 Results and discussion:

A steady state thermal analysis estimates the temperature distribution and other thermal quantities of the single turn induction coil under steady state loading conditions. This analysis is done in ANSYS WORKBENCH 18.1, for the above mentioned material properties and the chemical compositions. The figure 8 shows the steady state thermal analysis of the single turn induction coil. The temperature distribution is found to be within the range. The maximum and the minimum temperature distribution of the coil is to be seen in the figure 8 below.

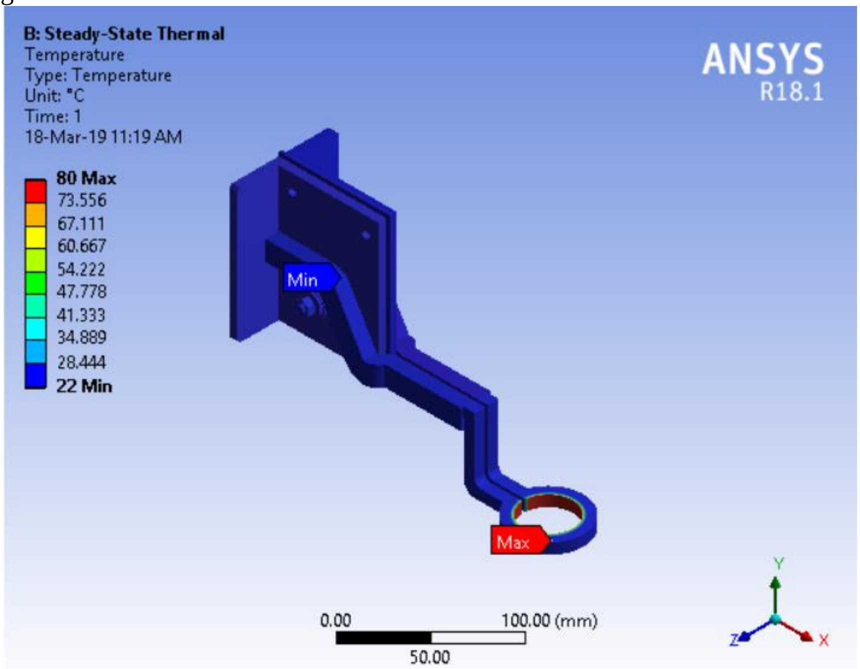


Figure 8: The temperature distribution of the single turn induction coil.

The total heat flux of the single turn induction coil is shown in figure 9 below. The total heat flux of the single turn induction coil is found to be 42.919W/mm^2. The maximum and minimum heat flux of the single turn induction coil is shown in the figure8 below.

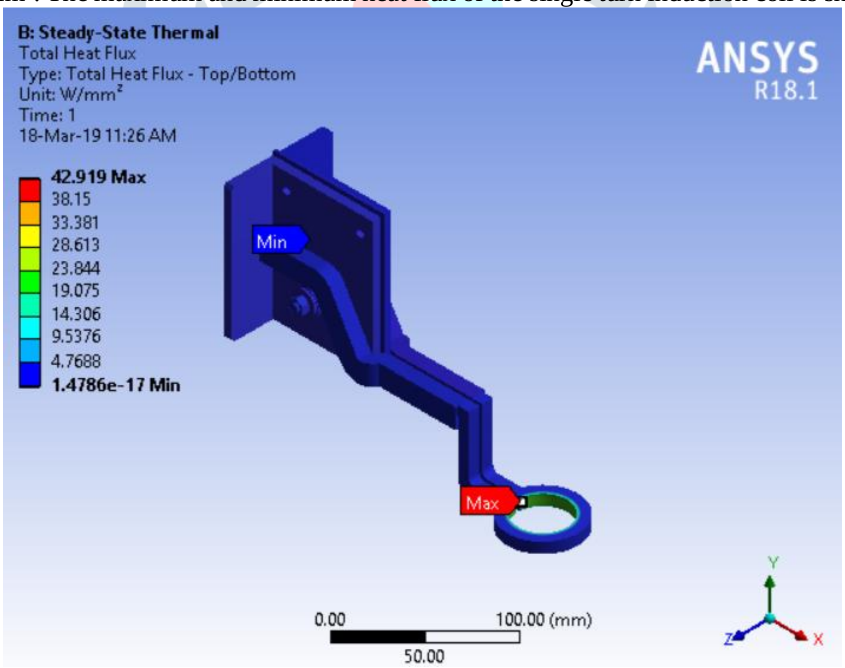


Figure 9: The total heat flux of the single turn induction coil.

The investigation into utilization of new alloy materials is needed which get better the coil efficiency and allow for larger reliability to induction hardening machine. The suitable fusion combined material which is lighter than oxygen free 99% pure electrolytic copper and has good modulus of elasticity, yield strength and density attributes. The low weight, the hardness, the static features also in case of high pressure and temperature of the resistance to thermal shock and the ductility afford long life time of the coil and maintain off all difficulty, most important of loading.

2.8 Conclusions:

The following conclusions are drawn from this work, is as follows:

- The thermal analysis for the single turn induction coil used in induction hardening machine is found to be within the permissible values.
- The maximum and the minimum temperature distribution as well as total heat flux of the induction coil is been calculated using ANSYS WORKBENCH18.1 software. The temperature distribution of the coil is found to be within the permissible values. The total heat flux of the single turn induction coil is found to be 42.919W/mm^2.The simulated values are been compared with the experimental results and validated.

III. Acknowledgements:

I would like to thank Mr. K. Nagadeva Singh for providing me the opportunity to carry out this work at EFD Inductions Pvt Ltd, Bangalore.

IV. References :

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