Computational Analysis for Induction Heating of Moving Wire

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Introduction: Induction heating is used for various industrial manufacturing processes. It can be us at low frequencies (~50 Hz) for initial preheating before deformation, at higher frequencies (~ 4KHz -10 KHz) for process involving metallurgical heat treatment. The main advantage includes; the fast heating rate, great precision in heating localization, instantaneous start/stop and its good reproducibility.

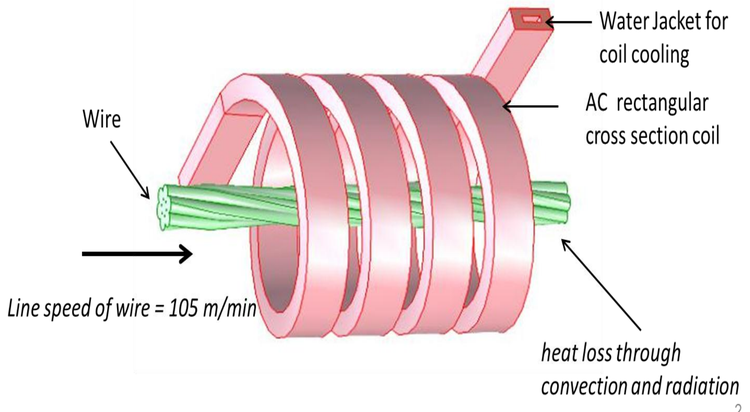

Figure 1. Induction heating of strand wire[2]

The need arises to study the surface temperature variation along the length of the wire moving at constant line speed, within the residence time of the load (wire), and the significance of skin effect and it's dependence on the frequency and the power supplied.

Computational Methods: Induction Heating of AC/DC module is used to study the skin effect with 3D model as shown in Figure 1 and with the help of Coil Group Domain; 2D axisymmetric model of the complete furnace is solved to study the surface temperature variation along the length as shown in Figure 2. The important equations computed are :
Power supply across the coil

$$V_{Coil} = \sum_i v_i \qquad J_s = \frac{\sigma V_{Coil}}{2\pi r}\phi$$

Maxwell equation, involving Ampere & Faraday law :

$$\nabla \times H = -J = -(J_{induced} + J_s) = -(\sigma E + J_s)$$

$$\sigma \frac{\partial E}{\partial t} + \nabla \times \frac{1}{\mu}(\nabla \times E) = -\frac{\partial J_s}{\partial t}$$

Electromagnetic heat generation inside the load

$$\rho C_P \frac{\partial T2}{\partial T} + \rho C_P u \cdot \nabla T2 = \nabla \cdot (k \nabla T2) + Q$$

$$Q_{rh} = \frac{1}{2} R_C (J \cdot E),\ Q_{ml} = \frac{1}{2} R_C (J\omega B \cdot \mathrm{H}), \qquad Q = Q_{rh} + Q_{ml}$$

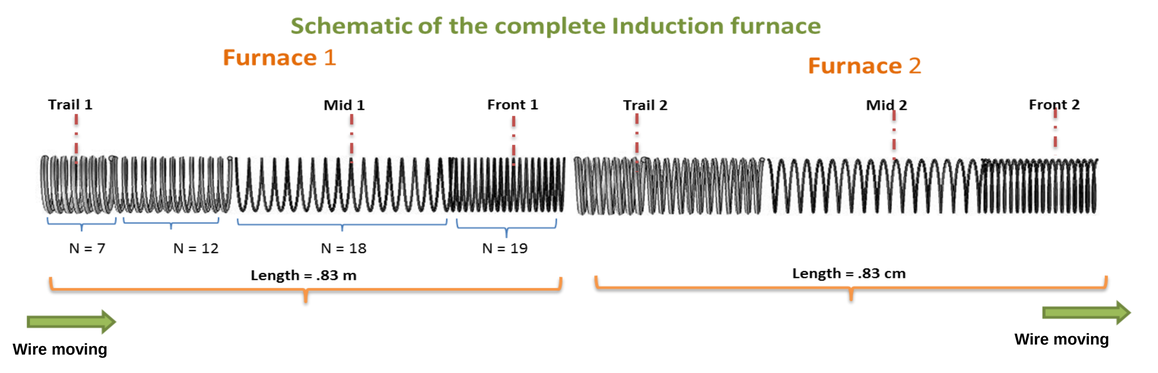

Figure 2. CAD model of the Furnace

Results: To optimize the problem size, we modeled the complete furnace into 2D axis symmetric model and assumed the helical strand wire as cylindrical one with the same power consumption per unit volume. We studied the variation of the surface temperature along the length of the wire (Figure 3)

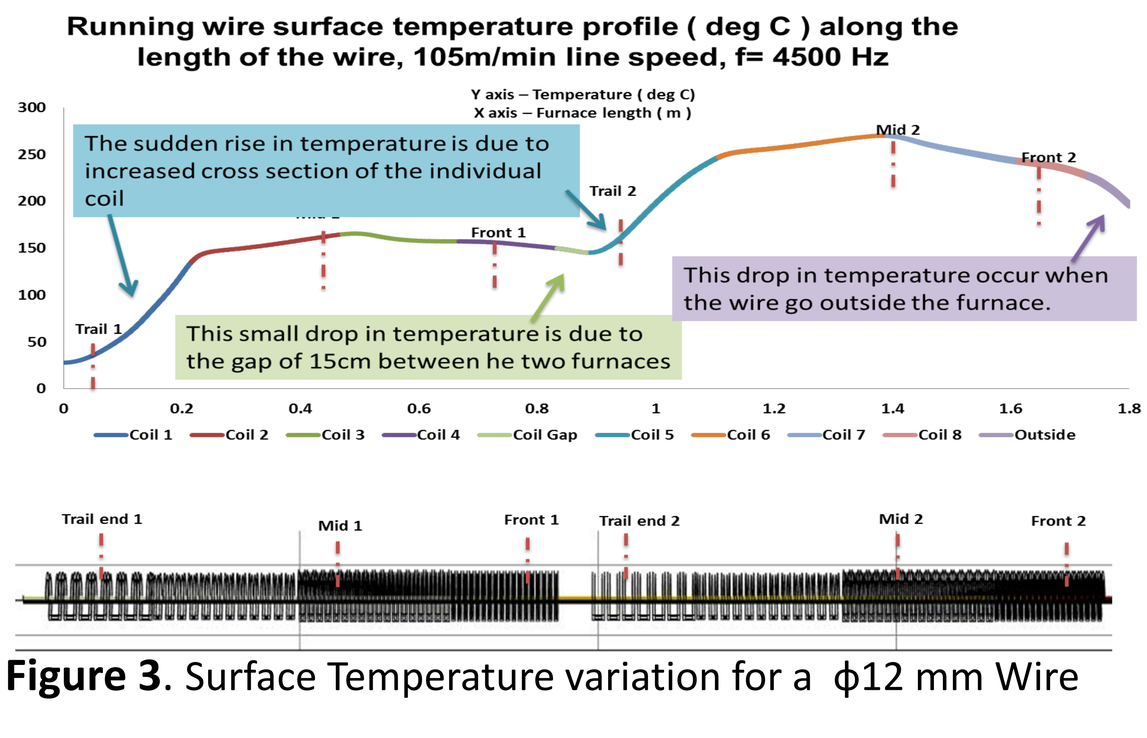

Figure 3. Surface Temperature variation for a ϕ12 mm Wire

Skin effect phenomena, in 3D modeling is best explained when we opted to go with the boundary layer meshing as shown in Figure 4 where the result obtained with the normal tetrahedral meshing was not helpful.

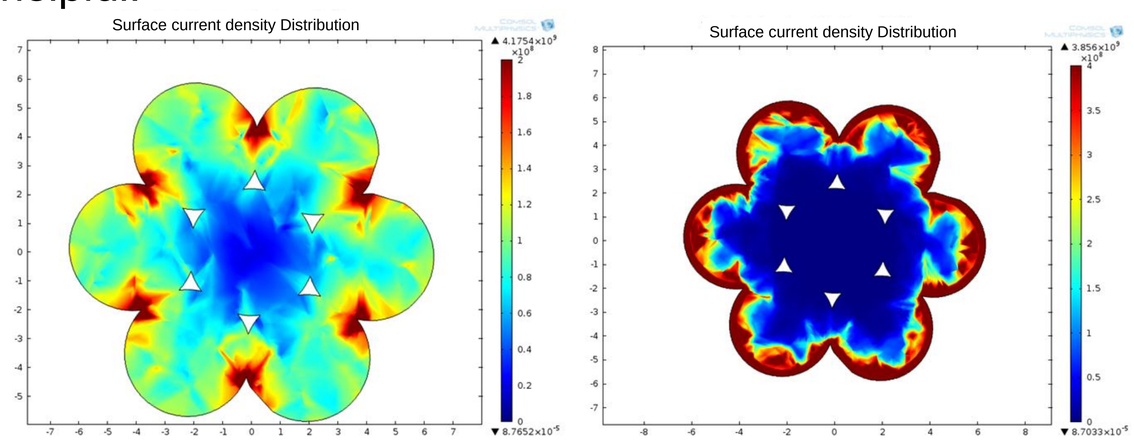

Figure 4 . Surface induced current: Normal Mesh Vs BL Mesh

Conclusions: With these preliminary study, we have gain understanding of the induction heating phenomena and the basic physics involved in this. Next, we are moving further to fine tune the model as per our requirement and therefore, will study the impact of operation parameter such as Frequency, Voltage etc., across the coils and the variation of line speed, over the thermal profile and ultimately the changes in mechanical properties of the wire**.**

References:

1. F. Bay et al, A numerical model for Induction heating process coupling electromagnetism and thermomechanic, Int J. Numer. Meth. Engng 2003, 58:839-867
2. Davies E J, Conduction and Induction Heating, Peter Peregrinius Ltd.: London, 1990