Computational Study of Electromagnetic Fields, Eddy Currents and Induction Heating in Thin and Thick Workpieces

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Abstract. A set of 2D steady state finite element numerical simulations of electromagnetic fields, eddy currents distribution and induction heating pattern has been done for different thicknesses of a metal workpiece. Comparison between the calculation results show the importance of workpiece thickness on induction heating process including electromagnetic field distribution, eddy currents pattern, heating structure and coil efficiency.

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1 Introduction

Radio frequency induction heating is the process of heating an electrically conducting material (usually a metal) by electromagnetic induction, where eddy currents are generated within the workpiece and resistance leads to Joulean heating (I^2R) of the material in the form of temporal and spatial volumetric heating. Since induction heating is a non-contact process, the heating process does not contaminate the material being heated. Because the power goes directly into the heated metal, the process is clean, fast, repeatable, relatively efficient, and allows automatic control. This can be contrasted with other heating methods where heat is generated in a flame or heating element, which is then applied to the workpiece. For these reasons induction heating leads itself to some unique applications in industry and material processing.

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An induction heating installation has three important parts: the electrical power source for generation of high-frequency energy, the work coil (RF-coil) and the workpiece (metallic material) where the final transfer of the electrical energy into required heat is occurred. The RF-coil must establish suitable electromagnetic flux lines in the workpiece and this field must be powerful enough to do the job such as joining, treating, heating and testing. The frequency of alternative electrical current used depends on the object size, material type, penetration depth and coupling between the work coil and the object to be heated. In this aspect, the amount of induced eddy currents and power as well as their spatial distribution in the workpiece are the major parameters to be determined. Understanding the physics of these properties is quite crucial and important when designing induction heating systems.

Mathematical modelling combined with computer simulation is a powerful tool for induction heating design and optimization, induction coil design, equipment selection, as well as education and business presentations. The traditional approaches to induction heating system development were based on a pure "trial and error" method. These traditional methods for induction coil and process design were time consuming and expensive due to having to manufacture and modify several inductors. These methods were also limited in applied cases and could not provide the developer with a good understanding of what is going on in a given induction heating system or information on why a given induction system worked or did not work properly. Today, more and more induction heating designers are shifting their development process from traditional empirical methods to computer simulation or a combination of both. Computer simulation provides induction process designers with a wealth of information on the system dynamics. It also can be used to explain, demonstrate and predict the process sensitivity to changes of an induction system. The early mathematical models of induction heating involved closed form analytical expressions [1–5]. The extensive majority of induction heating have been modeled using the finite difference method (FDM) [6–8], the finite element method (FEM) [9–16], the boundary element method (BEM) [17–19], the hybrid FEM-BEM method [20–23] and the impedance boundary condition (IBC) [24–29]. Over the past 30 years, the numerical treatment of induction processes has developed to the point where, today, there are numerous software packages available commercially, some of which include capabilities to treat complex problems in which electromagnetic fields are coupled to material properties, thermal process, and mechanical deformations.

In this article, we try to investigate the effects of workpiece thickness on the strength and distribution of the electromagnetic fields, eddy currents and heat generation in the setup. To do it, different thicknesses of a cylindrical steel workpiece (i.e. tiny, thin and thick) are considered corresponding to real applications of the RF-heating system.

2 Mathematical model

2.1 Governing equations