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A hybrid optimization algorithm for the thermal design of radiant paint cure ovens

A. Ashrafizadeh [a,*], R. Mehdipour [b], C. Aghanajafi [a]

[a] Department of Mechanical Engineering, K. N. Toosi University of Technology, No. 17 Pardis St., Mollasadra Ave., Vanak Square, Tehran 1999143344, Iran
[b] Department of Mechanical Engineering, Tafresh University of Technology, Tafresh, Iran

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ABSTRACT

Continuous paint cure ovens have many important industrial applications. In particular, convection ovens are extensively used in auto industries. Radiation paint cure ovens have attractive features as well and attempts have been made to design the oven and the radiation panels such that the moving loads experience desirable, nearly uniform, heating process. Due to the motion of the load and the variation of the radiation exchange factors during the curing process, the solution of this design problem corresponds to the solution of a dynamic optimization problem. This is computationally demanding in a realistic three-dimensional case and the computational cost needs to be minimized. Two-dimensional test problems provide opportunities for algorithm development and quick evaluation. This paper focuses on the convergence acceleration of this thermal optimization algorithm for a 2D test problem. By combining the features of an optimization algorithm with the capabilities of the neural network method, a hybrid design algorithm is obtained which is considerably faster than the original algorithm. It is shown that by employing a neural network trained by a simplified physical model, the computational cost can be reduced close to an order of magnitude without significant loss of accuracy.

1. Introduction

Cure ovens are extensively used in the industry to control the drying process of the coatings and paint layers on various body configurations. For example, the quality of the paint on an automobile body depends on the intensity, duration and mechanisms of heat transfer in a series of cure ovens which comprise the body paint shop. Useful information regarding the physical and chemical aspects of the paint curing processes is provided in a number of publications [1–3].

Continuous paint cure ovens can be generally categorized as convection, radiation and radiation–convection ovens. Traditionally, radiation–convection ovens have been used in auto industries. In this type of ovens radiation panels are used near the entrance of the oven and are responsible mainly for a relatively rapid heat-up process during which the paint layer is heated up and dried. Afterward, nozzles are used to blow in hot air. The convection section of the oven is mainly responsible for the holding period of the curing process. This latter part of the heat treatment process is highly energy consuming. Furthermore, there are safety concerns associated with the curing of chemical-based paint materials via convective heat transfer [4]. The other noticeable technical problem relevant to the convective ovens is the management of the air flow and temperature field such that a nearly uniform curing process occurs on all body parts. For complex geometries it is often necessary to block or change the caps of a number of nozzles to achieve a desirable velocity field around the body. Obviously, the objective is to control the heat transfer rate to the painted body by modifying the convection heat transfer coefficient.

A radiation paint cure oven provides an attractive alternative that overcomes some of the difficulties associated with the classical convection and radiation–convection ovens just described. In terms of the energy consumption, radiation ovens are considerably more efficient and in terms of the pollution and safety measures, they posses obvious preferences. However, in spite of the fact that the radiation panels can be more easily positioned toward hidden parts of the body, convective ovens still provide a better solution for the problem of uniformity of the heating process. Technological advances in radiation ovens may overcome this relative shortcoming in the near future.

Radiation exchange between the heat source panels and a stationary load is discussed in many text books [5,6]. Finite element-based radiation exchange models [7–9] and the classical

* Corresponding author. Tel.: +98 21 84063219; fax: +98 21 88677274.
E-mail addresses: ashrafizadeh@kntu.ac.ir, aliash03@yahoo.com (A. Ashrafizadeh), raminme56@yahoo.com (R. Mehdipour), aghanajafi@kntu.ac.ir (C. Aghanajafi).

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