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Numerical Solution for a Transient Temperature Distribution on a Finite Domain Due to a Dithering or Rotating Laser Beam

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ABSTRACT

The temperature distribution due to a rotating or dithering Gaussian laser beam on a finite body is obtained numerically. The authors apply various techniques to solve the nonhomogeneous heat equation in different spatial dimensions. The authors' approach includes the Crank-Nicolson method, the Fast Fourier Transform (FFT) method and the commercial software COMSOL. It is found that the maximum temperature rise decreases as the frequency of the rotating or dithering laser beam increases and the temperature rise induced by a rotating beam is smaller than the one induced by a dithering beam. The authors' numerical results also provide the asymptotic behavior of the maximum temperature rise as a function of the frequency of a rotating or dithering laser beam.

Keywords: *Crank-Nicolson, Fast, Fourier Transform (FFT), Nonhomogeneous Heat Equation, Rotating or Dithering Gaussian Laser Beam*

INTRODUCTION

The impact of laser beams on metals or other materials is of great interest in industry and military. This is mainly due to the fast processing time and precise operation. A deeper understanding of the physics requires a modeling of the heating process. There are many previous works on the theoretical and numerical modeling of temperature profiles induced by laser radiation in solids (Araya & Gutierrez, 2006; Bertolotti & Sibilia., 1981; Burgener & Reedy, 1982; Calder & Sue, 1982; Cline & Anthony, 1977; Lax, 1977 and 1978; Moody & Hendel, 1982; Sanders, 1984). However, most of these studies are limited to a scanning Gaussian beam. Until

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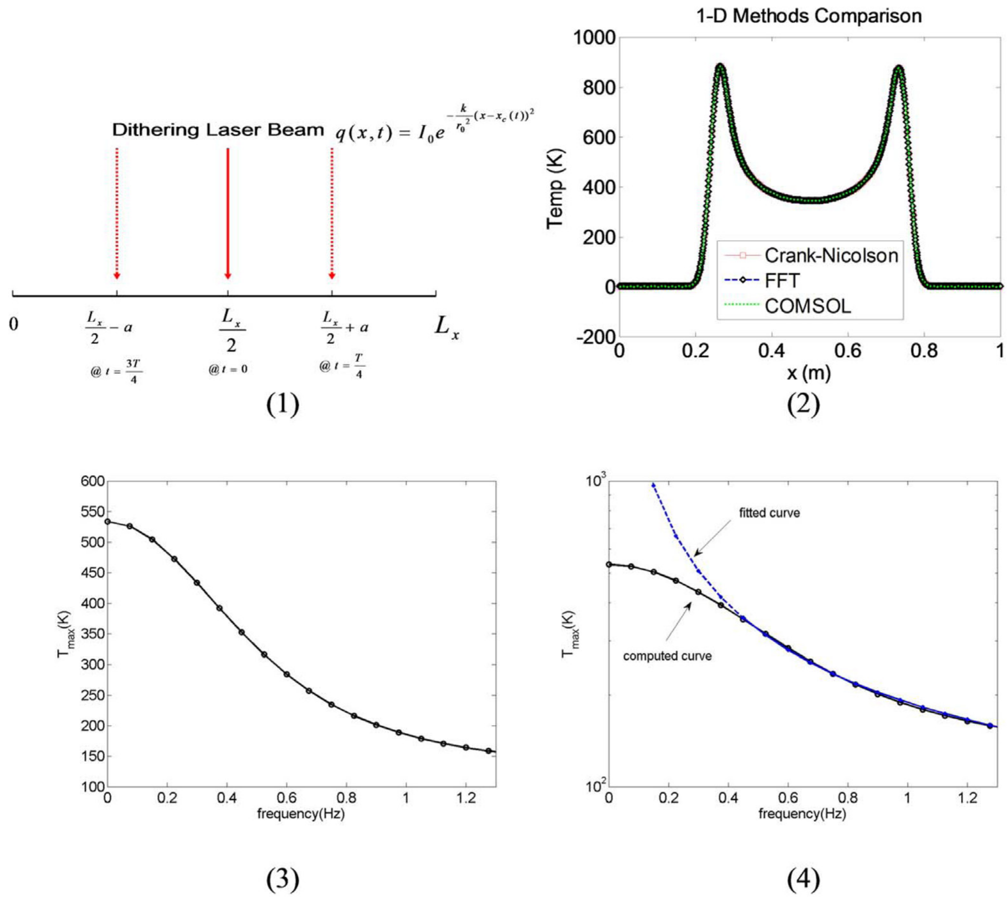
Figure 1. (1) A dithering laser beam on a 1-D rod. (2) 1-D temperature distribution along the rod from various numerical methods. (3) 1D maximum temperature rise of steel AISI 4340 versus frequency of the dithering laser beam. (4) The curve in (3) is well approximated by the function $T_{\max} = 137.0864/\text{frequency} + 51.6960$.



recently laser forming of plates using a rotating or dithering laser beam has been studied (Sistaninia et al., 2009). A more detailed study of the temperature rise induced by a rotating or dithering laser beam on a semi-infinite domain is newly provided by Zhou (2011). In this paper we want to extend the study in Zhou (2011) to a more realistic finite geometry and figure out the quantitative relationship between the maximum temperature rise and the frequency of the rotating or dithering laser beam.

It should be pointed out that the models used here are heat equations, which are deterministic. In order to be able to include random effects (e.g. laser beam jitter) it is desirable to use stochastic differential equations instead of heat equations. This will be the direction of future work.

We organize our paper into five sections. In the first four sections we present the numerical modeling of the temperature distributions induced by a dithering or rotating laser beam in one-dimensional, two-dimensional and three-dimensional finite solids, respectively. Conclusions and future work are given in the last section.

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