International Scientific-Technical and Production Journal

The Paton WELDING JOURNAL

January 2010 # 1

English translation of the monthly «Avtomaticheskaya Svarka» (Automatic Welding) journal published in Russian since 1948

Founders: *E.O. Paton Electric Welding Institute of the NAS of Ukraine International Association «Welding»*

Publisher: *International Association «Welding»*

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http://www.nas.gov.ua/pwj

State Registration Certificate
KV 4790 of 09.01.2001

Subscriptions:
$324, 12 issues per year,
postage and packaging included.
Back issues available.

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NUMERICAL ANALYSIS OF THE PROCESSES OF HEATING AND CONVECTIVE EVAPORATION OF METAL IN PULSE LASER TREATMENT

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Mathematical model of the processes of heating, melting and evaporation of metal under the effect of a focused laser beam is suggested. The model allows describing thermal processes in the bulk of metal and gas-dynamic processes in a metal vapour flow occurring in laser treatment by using pulse lasers. Numerical analysis was conducted to study the processes of heating and convective evaporation of metal with a millisecond pulse of the Nd:YAG-laser beam affecting a low-carbon steel sample.

Keywords: *pulse laser, laser radiation, metal, temperature field, evaporation, metal vapour, Knudsen layer, gas-dynamic processes, mathematical model*

Investigation of physical processes occurring in interaction of the high-intensity laser beam with a material plays an important role in development of new technologies for laser welding and treatment of different materials, and first of all the metallic ones [1–4]. Of special interest for upgrading of such technologies as microwelding, engraving, drilling, etc. is investigation into the processes of interaction of the focused pulse and pulse-periodic laser beams with metals [5–8]. Such processes include absorption of the laser beam by metal, its heating, melting and subsequent evaporation accompanied by scattering of the metal vapour into a surrounding gas (convective evaporation mode). Normally, analysis of convective evaporation of metal to determine quantitative characteristics of the evaporation process (density, temperature and velocity of scattering of the vapour) is performed by using a model suggested by C. Knight [9]. This model is based on the assumptions that the vapour flow is unidimensional and stationary. However, both of the above assumptions are known to be invalid in a case of high-rate heating of metal with a focused pulse laser beam, as upon reaching boiling temperature T_b the melt surface at the heat spot centre continues heating up to the temperatures that are much in excess of T_b, and the vapour flowing from the heat spot experiences side unloading, this causing violation of the unidimensional flow pattern assumed in study [9]. The present study is aimed at analysis of applicability of different models describing convective evaporation of metal under the conditions of heating of a metal plate with the focused pulse laser beam (ionisation of vapour and formation of laser plasma being ignored).

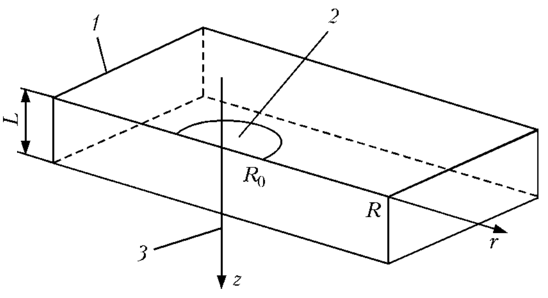

Figure 1. Scheme of heating of metal plate by laser beam: *1* — plate; *2* — heat spot; *3* — laser beam axis

Consider the process of heating of a metal plate with single pulse of the focused laser beam. Assuming the spatial distribution of the radiation intensity to be symmetric about the beam axis, formulate the mathematical model of heating of the plate in the axisymmetric statement. Introduce the cylindrical coordinate system as shown in Figure 1. Assume that radiation intensity I_0 is distributed uniformly over the heat spot with radius R_0 and remains constant during the pulse. Radiation intensity I_0 is determined through total energy W of the pulse, its duration τ and cross section area of the beam on the plate surface, $S = \pi P_0^2$, as follows: $I_0 = W/(\tau S)$.

The volumetric character of absorption of laser radiation can be ignored for the majority of metals. Then the thermal effect by the laser beam on a metal sample can be assumed to be a surface heat source distributed over the plate surface with density $q(r)$:

$$q(r) = \begin{cases} A(T_s)I_0 & \text{at } r \le R_0, \\ 0 & \text{at } r > R_0, \end{cases} \qquad (1)$$

where $A(T_s)$ is the coefficient of absorption of laser radiation, which depends upon the temperature on the metal surface, $T_s(r)$.

Write down the equation of thermal conductivity of a sample in the following form:

$$C(T)\rho(T)\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda(T)\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(\lambda(T)\frac{\partial T}{\partial z}\right),$$
$$0 < r < R, \quad 0 < z < L, \quad t > 0, \qquad (2)$$

where $C(T)$, $\rho(T)$ and $\lambda(T)$ are, respectively, the effective heat capacity of metal (allowing for the latent melting heat), density and coefficient of thermal conductivity.

Write down the boundary conditions for equation (2) in the following form: