Modeling and Control of Laser Hardening

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Abstract **The paper deals with the modeling of laser hardening of steel bodies. This way of heat treatment becomes more and more popular because of its high efficiency, velocity and accuracy of the process (for a comparison, the unit power delivered by the laser is even by six orders higher than in case of the classical induction heating). Moreover, the hardening system works without any additional devices necessary for subsequent cooling of the heated part, because heat produced by the laser beam is fast transferred to the interior of the body, which leads to a high hardness of the surface.**

Keywords **Laser hardening, control of laser, modelling of laser hardening**

I. Problem Formulation

Consider an arrangement of the hardening system according to Fig. 1.

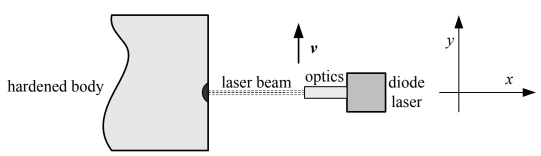

Fig. 1. Scheme of the laser hardening system

The particles generated by the diode laser are transferred to the optical element fixed on a robotic hand. The hand can move (at a small velocity $\boldsymbol{v}$ on the level of several mm per second) in the direction y . The optical element contains also a two-channel pyrometer that measures temperature in the centre of the beam. Its value is then used for automatic setting of the laser power. The surface of the beam can be preheated inductively.

The goal of this paper is to propose such a control mechanism of velocity of laser beam with respect of induction preheating, that the temperature at a given depth below the surface was constant.

II. Mathematical Model

The mathematical model of temperature field T in the workpiece is given by the partial differential equation [1]

$$\operatorname{div}(\lambda \operatorname{grad} T) - \rho c_{\mathrm{p}} \left(\frac{\partial T}{\partial t} + \boldsymbol{v} \cdot \operatorname{grad} T \right) = 0, \qquad (1)$$

where λ denotes the thermal conductivity of material, ρc_{p} stands for its heat capacity, $\boldsymbol{v}$ is the velocity of the movement and t is the time. The source of heat is the heat flux q_{in} entering the workpiece at the place of impact of the laser beam. This is given by the boundary condition

$$-\lambda \frac{\partial T}{\partial n} = q_{\mathrm{in}}, \qquad (2)$$

where n stands for the outward normal. The same way is used for determining the local heat flux q_{out} expressed by another boundary condition

$$-\lambda \frac{\partial T}{\partial n} = q_{\mathrm{out}} = \alpha_{\mathrm{gen}} (T - T_{\mathrm{ext}}), \qquad (3)$$

III. Control of the Leaser Head

The evolution of temperature at the given point under surface can be, with acceptable accuracy modelled using first order dynamical system in the form

$$\dot{T} = aT + b(\boldsymbol{v}),$$

where T is temperature and $\boldsymbol{v}$ is the velocity of the movement. The movement is controlled using a PI controller. The movement is turn on where temperature in the given point reaches the required value. Proportional component of the controller takes into account the difference between measured and required temperature and the integral component takes into account the heat accumulated in the material. The example of result of the control algorithm is depicted in Fig. 2.

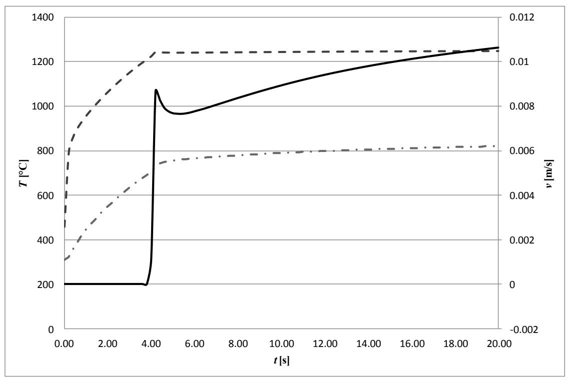

Fig. 2 Example of laser heat control, the surface of the matrial is preheated on the temperature 400ºC, solid line – velocity of the movement, dash-dotted line – temperature 3mm under surface, dashed line – temperature on the surface

IV. Acknowledgment

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V. References

[1] J. P. Holman, *Heat Transfer*. McGraw-Hill, New York, 2002.