Applications of Physics in Mechanical and Material Engineering

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Wydział Inżynierii Mechanicznej i Informatyki
Faculty of Mechanical Engineering and Computer Science

Research on Yb:YAG laser beam power distribution used in hybrid processes

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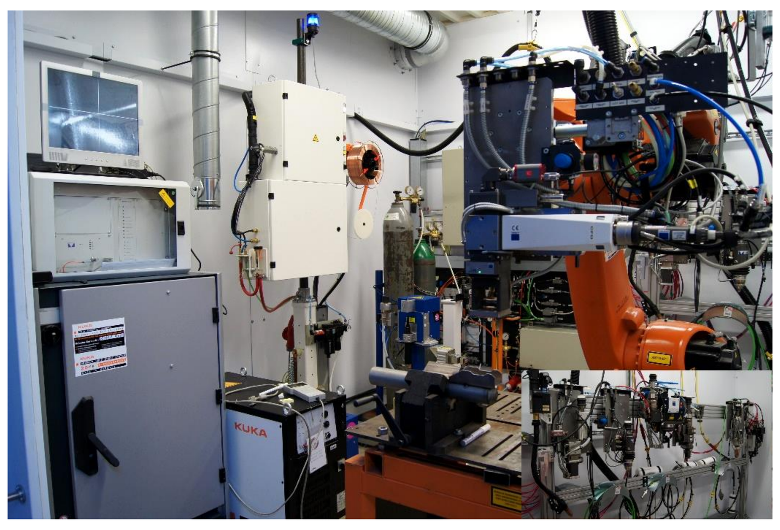
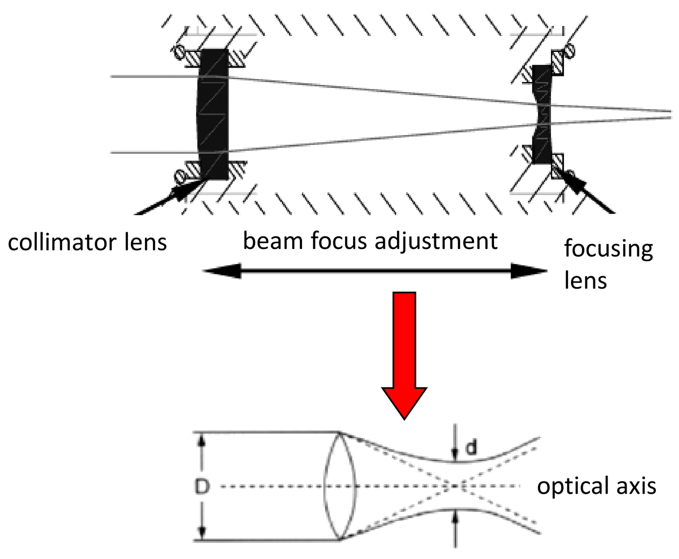
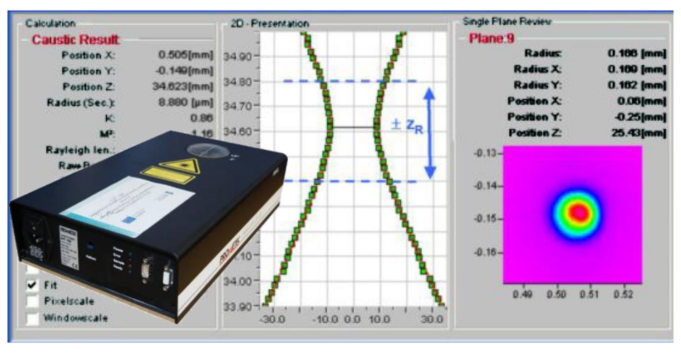
Experimental procedure



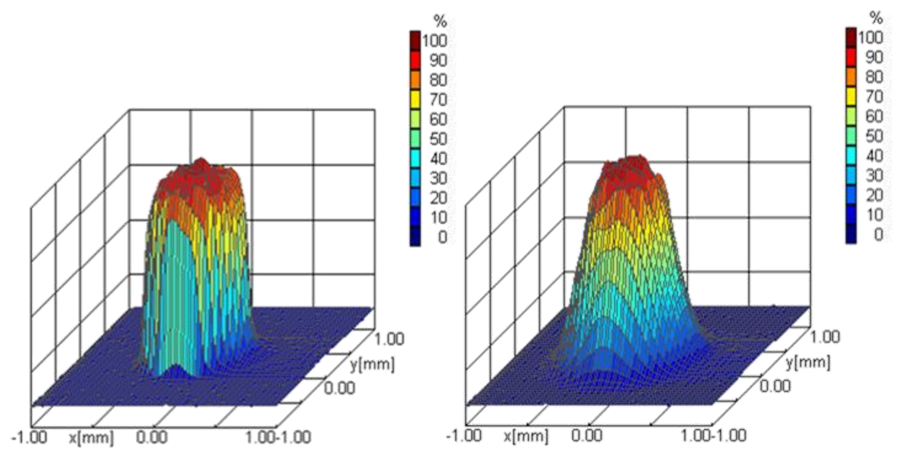
Welding station

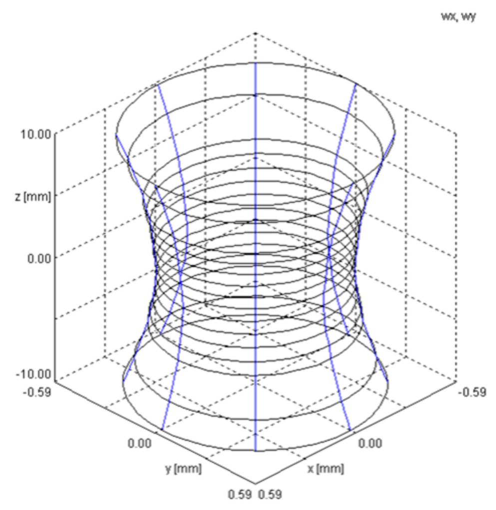


Collimator and focusing lens

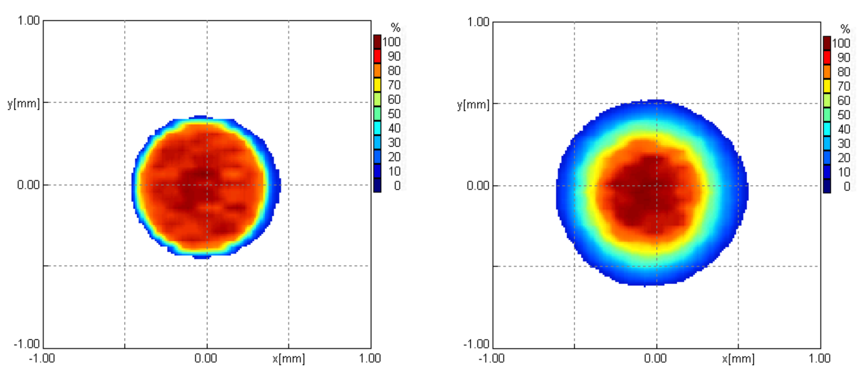


Beam analyzer UFF100





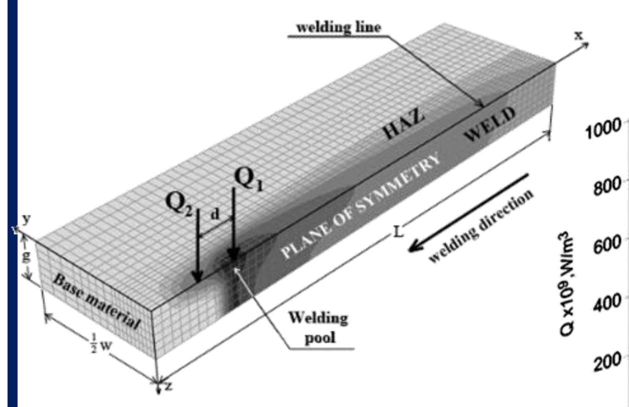
Yb:YAG laser caustics



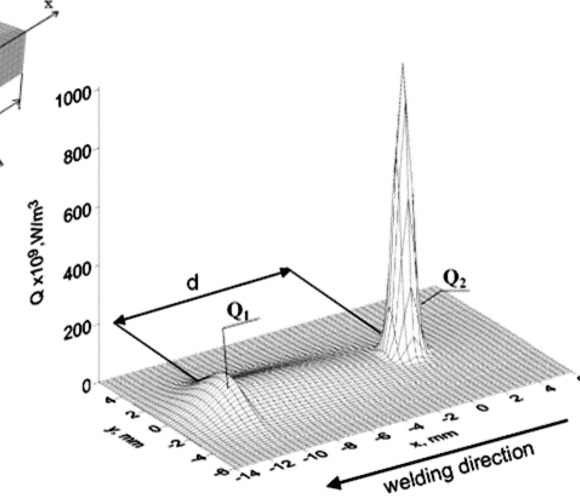
Heat source distibution analyzed by UFF100, focusing z = 0

Heat source distibution analyzed by UFF100, focusing z = 5mm

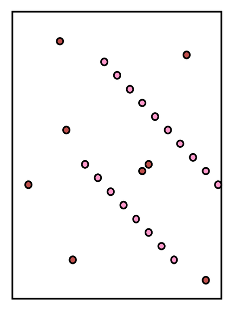
Geostatistical model



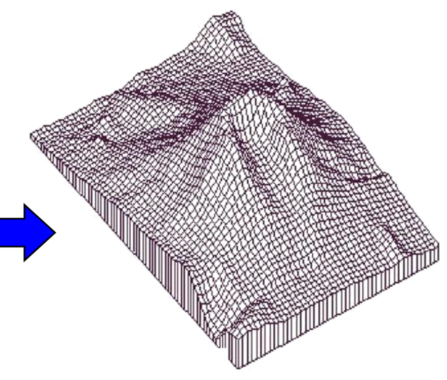
Schema of analysed system



Hybrid heat source distribution



Points of base data



Interpolated surface

The idea of geostatistical interpolation

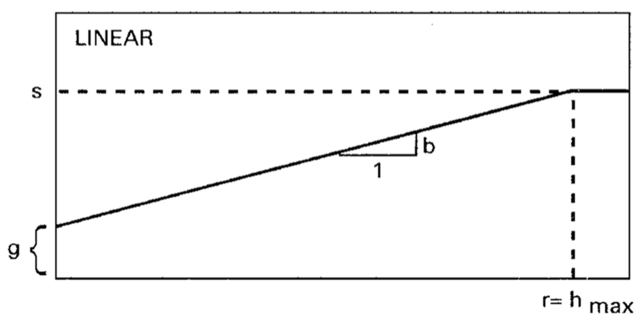
Kriging point interpolation

Predictor function $\tilde{f}(x,y)=\sum_{i=1}^{n} w_i f(x_i,y_i)$

Theoretical semivariogram $\gamma(h)=g+s\,h$

Kriging system of equations

$$\begin{bmatrix} 0 & \gamma(h_{12}) & \gamma(h_{13}) & \dots & \gamma(h_{1n}) & 1 \\ \gamma(h_{21}) & 0 & \gamma(h_{23}) & \dots & \gamma(h_{2n}) & 1 \\ \gamma(h_{31}) & \gamma(h_{32}) & 0 & \dots & \gamma(h_{3n}) & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \gamma(h_{n1}) & \gamma(h_{n2}) & \gamma(h_{n3}) & \dots & 0 & 1 \\ 1 & 1 & 1 & \dots & 1 & 0 \end{bmatrix} \mathrm{X} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \\ \lambda \end{bmatrix} = \begin{bmatrix} \gamma(d_1) \\ \gamma(d_2) \\ \gamma(d_3) \\ \dots \\ \gamma(d_n) \\ 1 \end{bmatrix}$$



Governing equations

Mass $\frac{\partial \rho}{\partial t}+\nabla\cdot(\rho\mathbf{v})=0$

Momentum $\frac{\partial(\rho\mathbf{v})}{\partial t}+\nabla\cdot(\rho\mathbf{v}\mathbf{v})=-\nabla p+\mu\nabla^2\mathbf{v}+\rho\mathbf{g}\beta_T\left(T-T_{ref}\right)-\frac{\mu}{K}\mathbf{v}$

Energy $\nabla\cdot(\lambda\nabla T)-C\left(\frac{\partial T}{\partial t}+\mathbf{v}\cdot\nabla T\right)=-\tilde{Q}$

Boundary and initial conditions

$$\mathbf{v}|_{\Gamma}=0,\quad \boldsymbol{\tau}_s=\mu\frac{\partial \mathbf{v}}{\partial n}=\frac{\partial \gamma}{\partial T}\frac{\partial T}{\partial s}$$

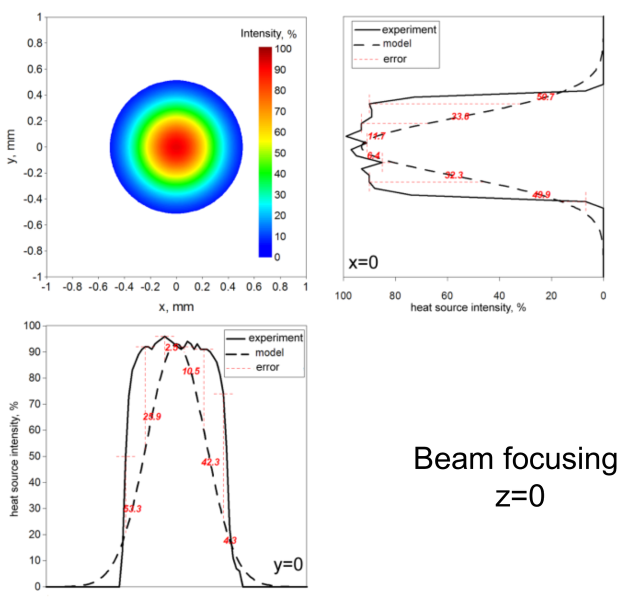
$$-\lambda\frac{\partial T}{\partial n}=-q_o^s+\alpha_k\left(T|_{\Gamma}-T_0\right)+\varepsilon\sigma\left(T^4-T_0^4\right)+q_v^s$$

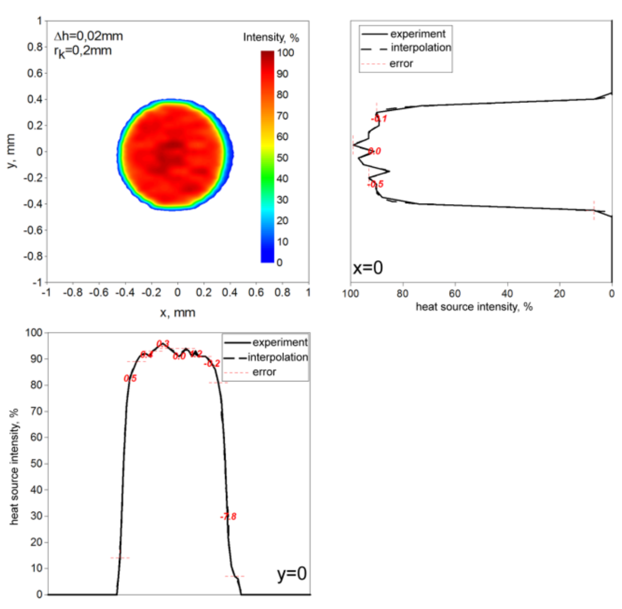
$$T|_{t=0}=T_{\infty},\quad \mathbf{v}|_{t=0}=0$$

Simulation results

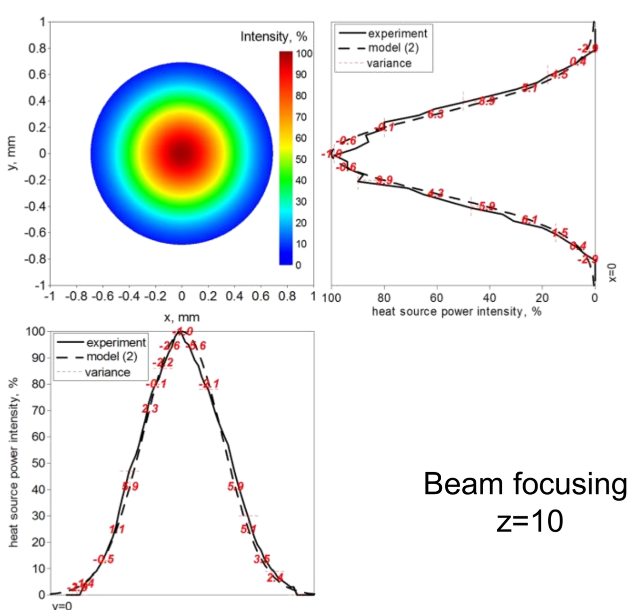
Analitycal source model (Gauss distribution)

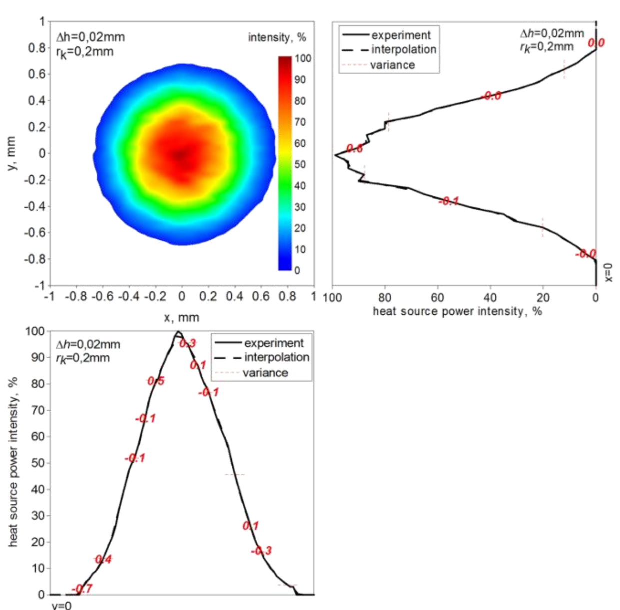
Interpolation source model (Point Kriging)





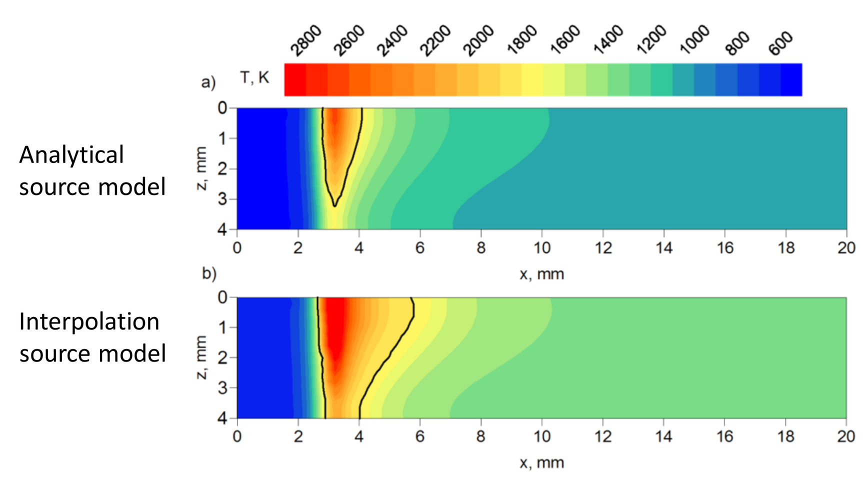
Beam focusing z=0



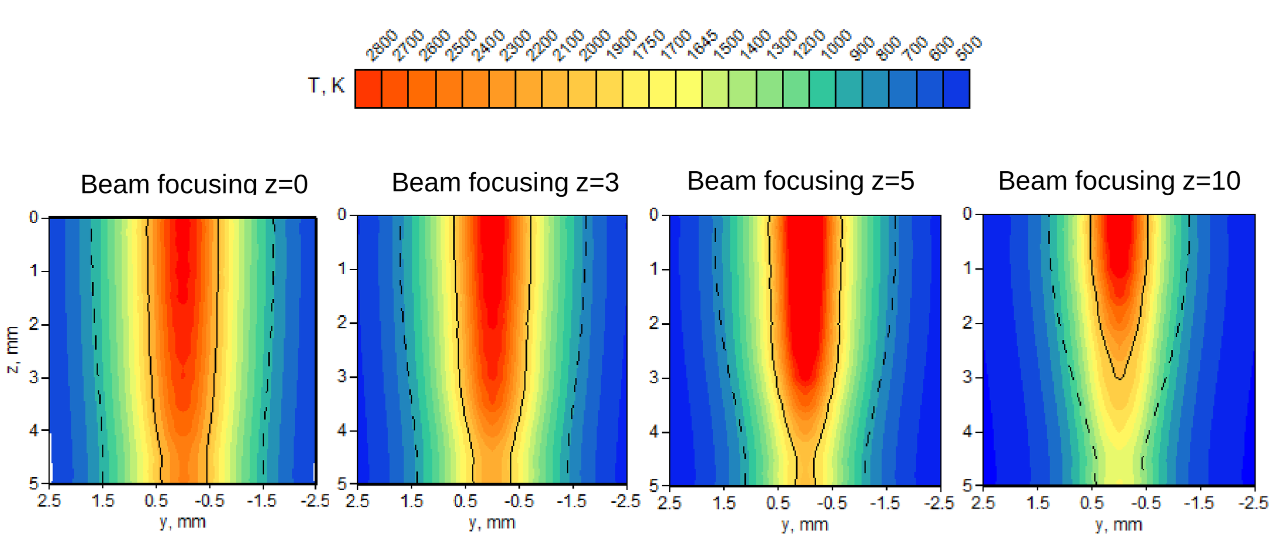


Beam focusing z=10

Single laser beam welding for different beam focusing

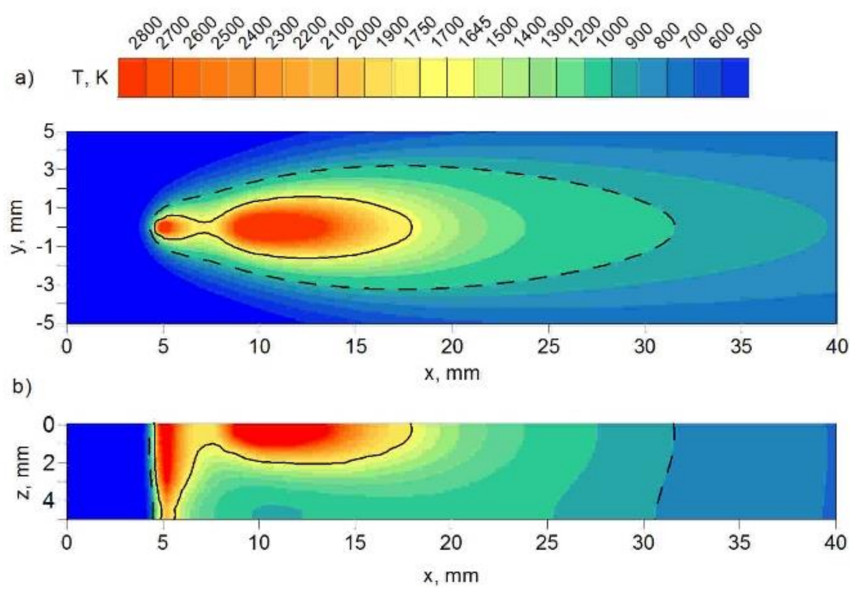


Temperature field in longitudinal section of the joint (y=0). Solid line marks fusion zone

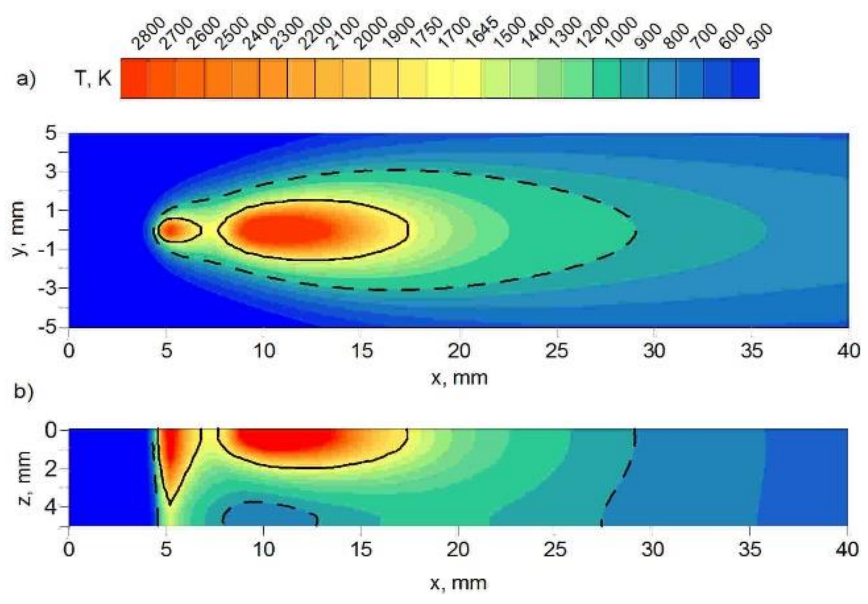


Temperature field in cross section of the joint (y=0) for different beam focusing. Solid line marks fusion zone, dashed line marks heat affected zone

Hybrid laser – arc welding



Temperature distribution a) at the top surface (z=0) and b) in longitudinal section (y=0) of the joint. Laser beam focusing z=0



Temperature distribution a) at the top surface (z=0) and b) in longitudinal section (y=0) of the joint. Laser beam focusing z=3

Summary

A part of pumped laser energy in in solid state lasers converts to a heat that acts as the heat source inside the laser material. This heat source contributes to the non-uniform temperature distribution in the gain medium which is dependent on the gain medium configuration and cooling geometry. This contributes to the radial heat dissipation and induces no desirable thermal lensing effects influencing beam shape, quality and output power stability. The above and many other issues concerning energetic characteristic of a laser beam are currently under particular investigation in the field of mathematical modelling and experimental research.

The major aim of this work is the determination of the influence of Yb:YAG laser beam power distribution on the formation of fusion zone in laser-arc hybrid welded plate made of S355 steel. The laser beam heat source is modelled on the basis of geostatistical kriging interpolation method. The electric arc is modelled using classic Goldak's heat source power distribution. Hybrid heat source energetic parameters are assumed with respect to experimental research on Yb:YAG laser beam characteristics as well as on electric arc current and voltage obtained during the real heating tests. Numerically predicted temperature field obtained for different hybrid heat source parameters is partially verified by experimental results.