PAMM · Proc. Appl. Math. Mech. **2**, 438–439 (2003) / **DOI** 10.1002/pamm.200310203

Altmann, K., Pflaum, C., and Seider D.

Semi-Unstructured Grids in the Laser Simulation Program LASCAD

Automatic grid generation is very important in industrial applications. Furthermore, in several applications discretization grids are needed which provide an anisotropic refinement and an accurate approximation of the derivatives of the solution. These requirements are fulfilled by semi-unstructured grids. In this paper, we report how semi-unstructured grids are used in the laser simulation program LASCAD[a] [3].

[a]LASCAD is a protected trademark of LAS-CAD GmbH

1. Numerical Simulation of Diode Pumped Solid State Lasers (DPSSL) .

In DPSSL the beam of a laser diode is used to pump a laser crystal (see [2]). After entrance into the crystal the pump beam is absorbed by the lasing atoms. The absorbed photons raise the atoms into a higher energy level. The population inversion generated in this way is used to amplify the laser beam by stimulated emission. However, only a fraction of the absorbed power is converted into laser light, dependent on the quantum efficiency of the laser up to about 30% can be converted into heat. The heat distribution remaining in the crystal constitutes an important technical problem for the design of solid state lasers. There is not only the necessity to remove the heat through heat sinks, but due to the temperature dependence of the refractive index of the crystal a 3D refractive index distribution is generated that modifies the optical properties of the laser resonator built around the crystal. Together with the thermal deformation of the surfaces of the crystal this can seriously effect beam quality and efficiency of the laser. Also there is the risk that high stress levels destroy the crystal. Therefore, it is important to support design of DPSSL by numerical simulation. The latter can be carried through in four steps:

1. Calculation of the heat source in the resonator by the use of analytical approximations or by ray-tracing.
2. Calculation of the temperature in the resonator by a FE-approximation.
3. Calculation of the deformation and stresses of the laser crystal by a FE-approximation.
4. Calculation of the mode structure of the laser beam by a Gaussian-mode analysis in combination with parabolic fits of FE-results or by a wave optics code solving Maxwell equations.

   These methods analyze the laser beam on a structured grid. Therefore, the temperature and deformation of the crystal are needed on a structured grid.

For the calculation of the temperature T and the deformation u, one has to solve a non-linear heat equation

$$\begin{aligned} \mathrm{div}\kappa(T)\mathrm{grad}(T) &= f \mid \Omega, \\ \mathrm{grad} \circ \vec{n} + \beta(T - T_r) &= 0 \mid \partial\Omega_{cool}, \\ T &= t_D \mid \partial\Omega_D \end{aligned}$$

and a linear elasticity equation:

$$\begin{aligned} \epsilon_{ij} &= \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right), \\ (\epsilon_{ij}) &= (\alpha_x, \alpha_y, \alpha_z)\,(T - T_0) + C^{-1}(\sigma_{ij}), \\ 0 &= \mathrm{div}(\sigma_{ij}), \end{aligned}$$

where C is a suitable 6×6 matrix (see [1]). To solve these differential equations, we applied a finite element discretization on semi-unstructured grids (see [4]) that have several properties which are very useful in the application of laser simulation:

- Semi-unstructured grids calculate temperature distribution and deformation on a structured grid inside of the domain. This is very helpful for a subsequent optical analysis.
- Semi-unstructured grids allow automatic meshing of general domains in 3D.
- Semi-unstructured grids can be stretched in x-, y, and z-direction.
- High accuracy can be achieved by using a small meshsize.
- The super convergence of the gradient inside of the domain leads to an accurate approximation of the stresses.

2. Numerical Results

Figure 1 shows a heat source and the calculated temperature in a laser crystal. The crystal is pumped from both end faces, and cooled at the barrel surface. Figure 2 depicts a resulting displacement and stress. These approximations are calculated on a semi-unstructured grid with linear finite elements (see Figure 3 and Figure 4).

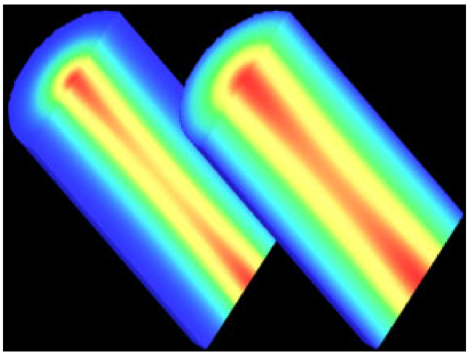

Figure 1: Heat source and temperature.

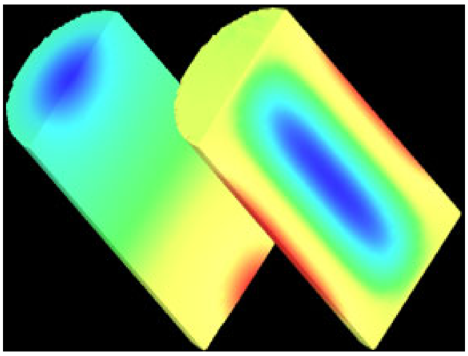

Figure 2: Displacement and stress.

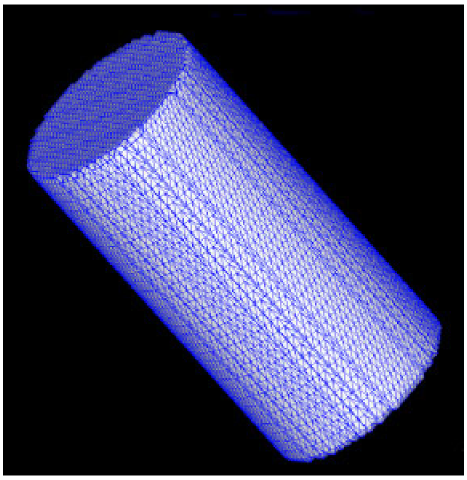

Figure 3: Semi-unstructured grid.

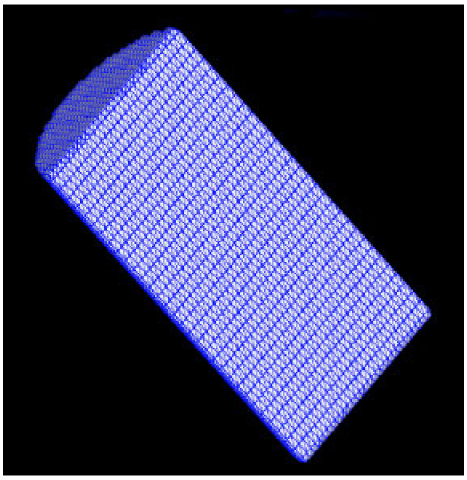

Figure 4: Cut of a semi-unstructured grid.

3. References

1 D. Braess, *Finite Elemente*, Springer, New York, Berlin, Heidelberg, 1997.
2 W. Koechner., *Solid-State Laser Engineering*, Springer, New York, Berlin, Heidelberg, 1996.
3 K. Altmann, *Simulation software tackles design of laser resonators*, Laser Focus World, 36(5): 293 -294, May 2000.
4 C. Pflaum, *Semi-unstructured grids*, Computing, 67(2):141–166, 2001.

Altmann, K., LAS-CAD GmbH, Brunhildenstr. 9, D-80639 Munich
Pflaum, C., Universität Würzburg, Institut für Angewandte Mathematik und Statistik,
Am Hubland, D-97074 Würzburg
Seider, D., Universität Würzburg, Institut für Angewandte Mathematik und Statistik,
Am Hubland, D-97074 Würzburg