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B. Brajuskovic, R. Lindberg and N. Sereno

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Poster paper

Thermomechanical optimization of the cathode design intended for the X-ray free-electron laser oscillator injector electron gun

B. BRAJUSKOVIC†, R. LINDBERG AND N. SERENO
Argonne National Laboratory, Advanced Photon Source, 9700 S. Cass Ave., Argonne. IL 60439-4800, USA

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The Advanced Photon Source at Argonne National Laboratory is developing a low-emittance thermionic gun for a proposed X-ray free-electron laser oscillator (XFEL-O) that will use a laser pulse-heated cathode. The cathode must operate at or slightly above 1500 °C for several nanoseconds and then cool down several hundred °C in approximately the same amount of time, with a 1-MHz heating–cooling cycle. A transient thermal analysis was performed to optimize the laser pulse shape needed to provide the desired temperature response of the cathode for several possible cathode materials. In addition, thermal stresses developed in the cathode during heating–cooling cycles were analysed. Both transient thermal analysis and thermal stress computations were performed using the ANSYS12 code. The computed temperature distribution and thermal stresses were utilized in the optimization of the cathode design. The results of the analysis are presented.

1. Introduction

Laser pulse heating is investigated as a possible method of heating a low-emittance thermionic cathode at the Advanced Photon Source (APS). A cathode made of cerium hexaboride (CeB_6) is a part of the low-emittance thermionic gun. The gun will function as desired only if the cathode can be heated to over 1500 °C and cooled to below 1300 °C within the 5-ns-long heating–cooling cycle and with a repetition rate of 1 MHz. Laser pulse heating is the only practical method that could produce spatially uniform temporal temperature peaks in these conditions (M. Borland, personal communication). Thermal and structural responses of the cathode to the laser pulse heating are modelled with finite-element analysis (FEA) code ANSYS12 in order to optimize both cathode design and laser pulse.

The main challenge in modelling the cathode response to the laser pulse heating is to properly recognize the nature of interaction between the laser beam and the material of the cathode. As the pulse length is in the nanosecond range, our assumption is that the temperature fields can be predicted correctly by solving the equation of thermal diffusion without the need to consider non-Fourier effects.

† Email address for correspondence: bran@aps.anl.gov

However, there are conflicting data in the literature (Gilath *et al.* 1988; Steen 1995) on whether the stress distribution can be predicted by a quasi-static structural model or thermoelastic wave propagation, and whether the spallation has to be considered for our combination of pulse lengths and laser intensity.

2. Thermal and structural analysis of the cathode response

In order to accurately capture temporal temperature peaks and yet limit the computation time, the model of the cathode was divided into three zones. In the cathode tip zone that extended 2.5 μm inwards, the mesh was finest and the mesh size in the direction of the heat transfer was 0.1 μm. The FEA results were compared with the analytical solution of the thermal diffusion equation and the comparison shown in figure 1 indicates a very good agreement.

The cathode response was modelled for several different temporal pulse profiles of a 250-μJ laser. The results, shown in figure 2, indicate that the 250-μJ laser is capable of producing the required temperature peaks and that the shape of the temperature response is defined with the temporal profile of the laser pulse. The shape of the response is similar to the experimentally observed change in laser-induced electron emission of the Injector test stand gun at the APS (Sereno, N., Borland, M., Harkay, K., Li, Y., Lindberg, R., Pasky, S. personal communication).

The results of quasi-static structural analysis, based on the temperature distribution at the time of the peak temperature for the load case 1 (see figure 2), are shown in figure 3. Maximum values of equivalent stresses (1.4 GPa) occur in the centre of the cathode tip but high-stress areas are also observed at the border between the exposed and unexposed areas of the cathode tip (the diameter of the tip is 1.2 mm, whereas the diameter of the exposed area is 1 mm).

3. Discussion

Good agreement between the FEA and analytical results, and similarity in the shape of the FEA computed cathode temperature change and experimentally

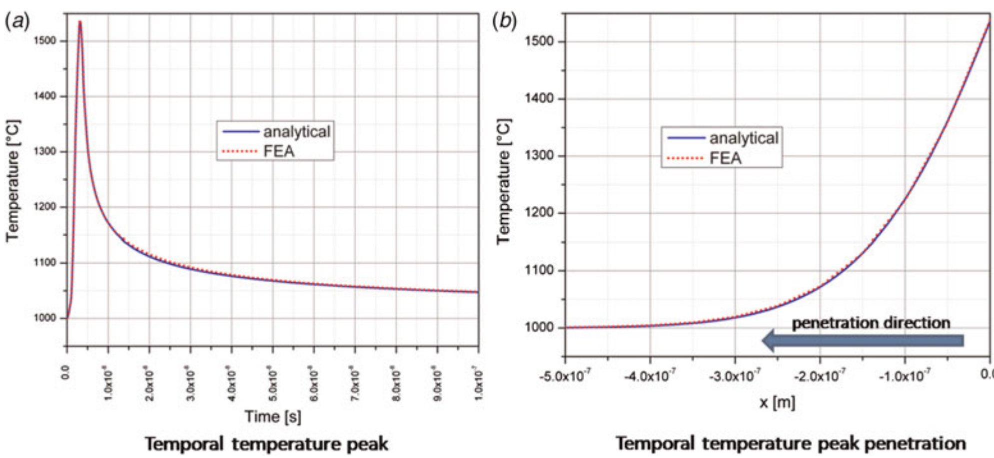

FIGURE 1. Comparison of FEA and analytically obtained results.

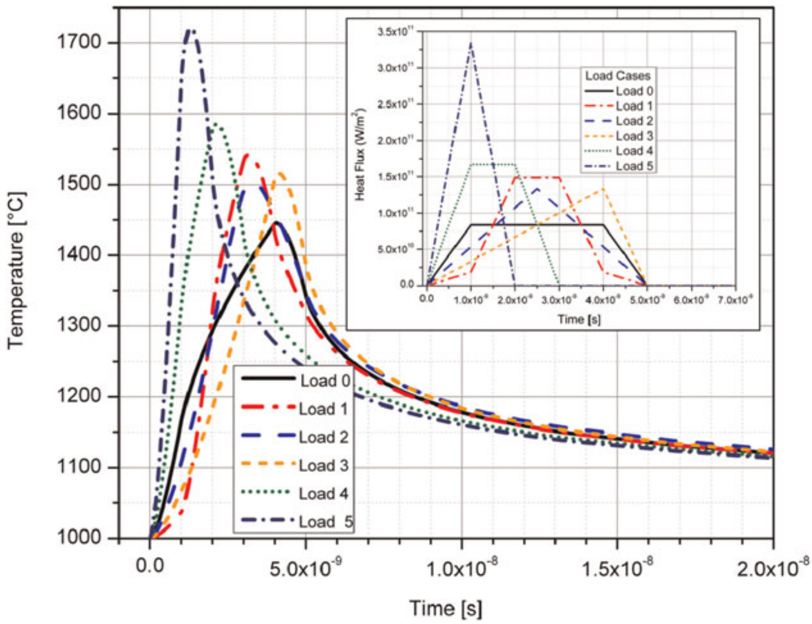

FIGURE 2. Cathode temperature response to various laser pulses.

observed change in cathode electron emission indicate that the FEA model accurately represents the cathode thermal response to the laser pulse heating.

With the proper combination of the initial cathode temperature and the laser pulse width of the 250-μJ laser, it is possible to heat the cathode tip to over 1500 °C in less than 1 ns, keep it at temperatures over 1500 °C for 0.5–1 ns, and allow it to cool below 1300 °C in less than 2 ns.

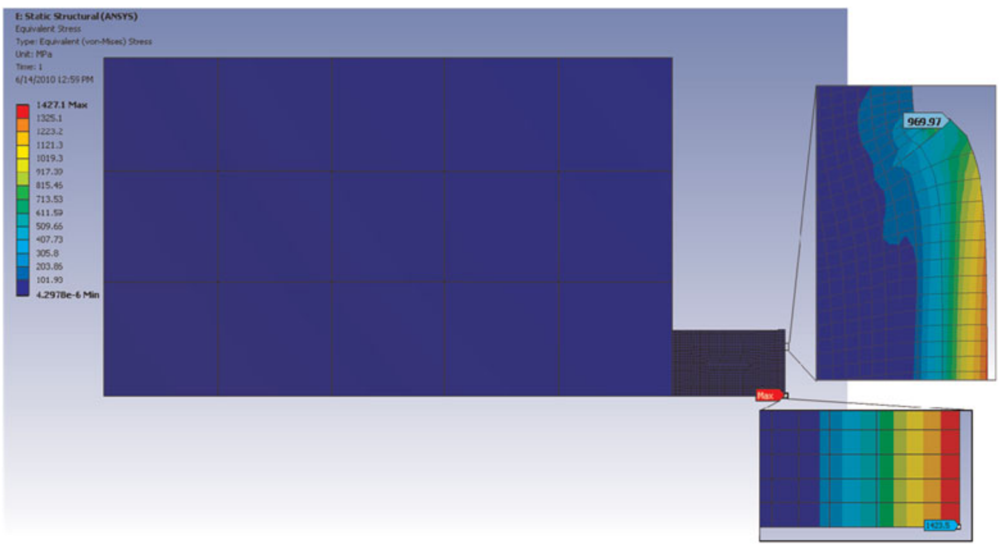

FIGURE 3. Stress distribution in the cathode for the surface peak temperature.

Preliminary stress distribution computations indicate high maximum stress values. Further investigation based on the thermoelastic stress wave propagation is necessary.

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REFERENCES

GILATH, I., SALZMANN, D., GIVON, M., DARIEL, M., KORNBLIT, L., BAR-NOY, T. 1988. Spallation as an effect of laser-induced shock waves. *J. Mater. Sci.* **23**, 1825–1828.

STEEN, W. M. 1995. *Laser Material Processing*, 3rd edn. Cambridge University Press. ISBN 0-521-48391-3.