THERMAL SIMULATIONS OF A PHOTOCATHODE R.F. GUN

B. Biswas#, Shankar Lal, K. K. Pant, Arvind Kumar and S. Krishnagopal
Beam Physics and FEL, Laboratory, Raja Ramanna Centre for Advanced Technology, Indore 452013, India

Abstract

We are developing a photocathode linac, which uses a 2856 MHz r.f. gun, with a copper cathode driven by a 102 MHz, 266 nm laser at inclined incidence. The laser photocathode r.f. gun is a 1.6 cell BNL/SLAC/UCLA type III r.f. gun. In this paper we present the dynamic thermal cooling simulations to calculate the structural deformations and consequent frequency drift of the gun. We have done a complete r.f.-thermal-structural-r.f finite-element analysis (FEA) of the gun in that order, using ANSYS/MULTIPHYSICS. We find that with the present coolant channel design the gun can operate at up to 2 Hz without any significant change in resonant frequency and field balance.

INTRODUCTION

There is a wide range of normal-conducting photocathode guns working or under development all around the world as injectors for x-ray free electron lasers and colliders [1-4]. Typically the S-band laser photocathode normal conducting guns deliver up to 150 MV/m peak accelerating electric field.

The S-band photocathode gun we are developing is a BNL type III gun [5, 6]. It has a simple longitudinal cooling arrangement unlike the circular cooling channels in higher r.f. pulse repetition rate guns. We have done the complete r.f.-thermal-structural-r.f finite element analysis (FEA) of the gun in that order. We found that it is necessary to model the gun with all its ports, to capture the high heat flux spots around these port discontinuities. We also found that the resonant frequency in the 1.6 cell photocathode gun is very sensitive to geometrical deformations. Hence we re-simulated the heated-deformed gun for its r.f. properties. As deformations are of the order of microns we morphed the r.f. region's FE mesh boundary to absorb the surface displacements by using the structural solution. This approach is different from regenerating the deformed structure in a CAD package and remeshing it for simulation – as the new mesh may not be similar to the original one and mesh-to-mesh differences will overshadow the desired detuning result. We show that we can go up to 2 Hz operation at maximum gradient with modest cooling parameters and no degradation in r.f. parameters. Higher repetition rates will need modification of the coolant channel design. However operation at lower gradients and higher repetition rates will still be possible.

bbiswas@cat.ernet.in

THE ELECTROMAGNETIC SIMULATIONS

The RF parameters of the 1.6 cell BNL/SLAC/UCLA type photocathode gun, shown in Fig. 1, are given below in Table 1.

Table 1: Parameters of the photocathode gun.

Parameter	Value
Type	1.6 cell BNL/SLAC/UCLA type III
Frequency	2856 MHz
Bunch Charge	1nC
Field balance	~ 1.04
Peak accelerating field	147 MV/m
Rep. Rate	1 - 10 Hz
Laser pulse width	FWHM 12 ps
r.f. pulse width , power	4 μs , 8 –10 MW
Power dissipated at 10Hz, 4 μs r.f. pulse	0.5kW

We simulated the full model of the photocathode gun in FEA package ANSYS [7] to get the resonant π-mode at 2856.1 MHz and field balance of 1.042 as shown in Fig. 2. Copper and SS conductivity were applied at respective regions for calculation of heat loss/flux.

The average heat-flux obtained for an r.f. pulse of 4 μs and 2 Hz repetition rate obtained is shown in Fig. 3. The maximum heat flux, around the r.f./vacuum ports, is nearly three times the peak heat flux without ports (at full cell exit wall) when compared with SUPERFISH. The inner diameters of the two cells were fine tuned by up to 5 μm to get the required field balance. This is quite similar to the fabrication learning curve where final cuts of the order of 5-10 μm were taken on inner diameter of the two cells of prototype aluminium and then ETP copper gun.

THE THERMAL SIMULATIONS

The gun material comprises of OFE copper and some SS316L seal plates, beam and vacuum ports. For thermal (conduction) analysis all the metallic volumes were simulated. The o-ring was also modeled. The convection bulk temperature in the two channels for water flow is shown in Fig. 4 -for the 147 MV/m peak gradient at 4 μs r.f. pulse and 2 Hz repetition rate. For clarity only a one-fourth model is shown. The inlet water temperature is 30°C and the water flow is at 1.8 m/s. The ambient temperature is also 30°C.

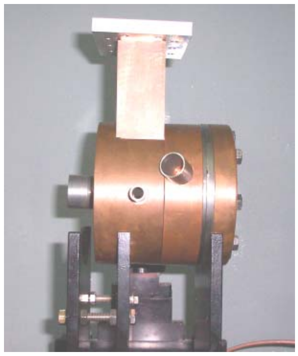

Figure 1: The 1.6 cell S-band photocathode gun OFE prototype .

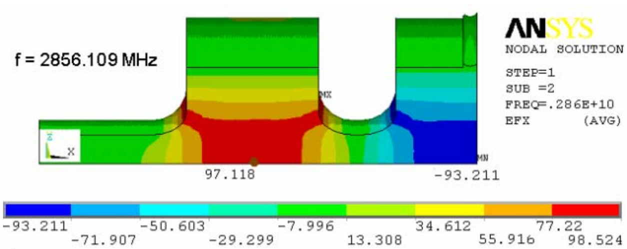

Figure 2: The axial electric field (not to scale) in photocathode gun.

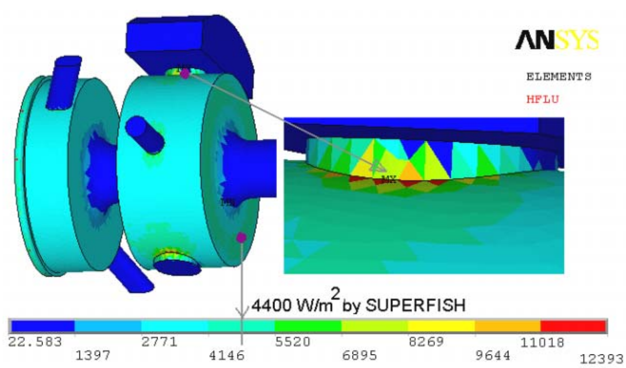

Figure 3: The heat flux for 147 MV/m peak field and 4 µs, 2 Hz, r.f. pulse.

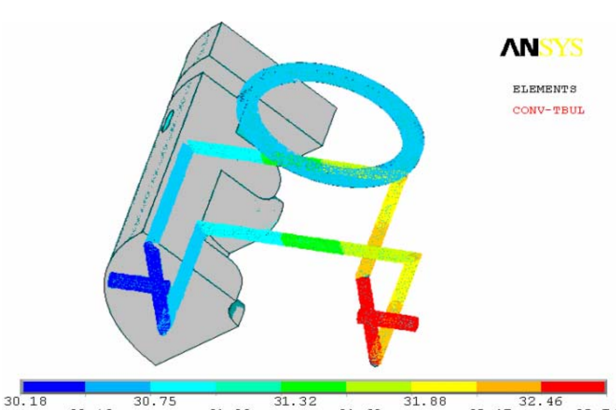

Figure 4: The coolant bulk temperature at 2 Hz r.f. cycle.

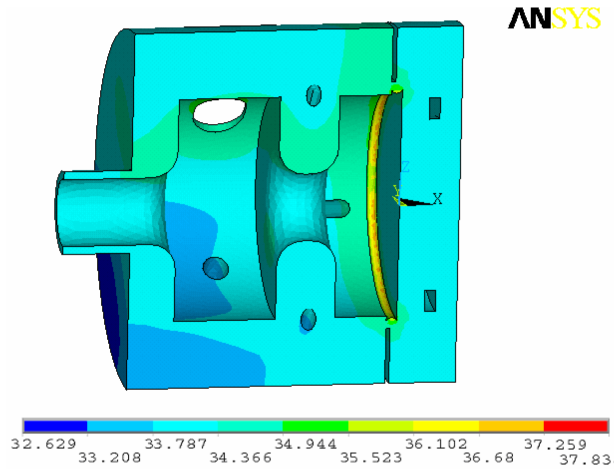

Figure 5: The temperature at 2 Hz r.f. cycle.

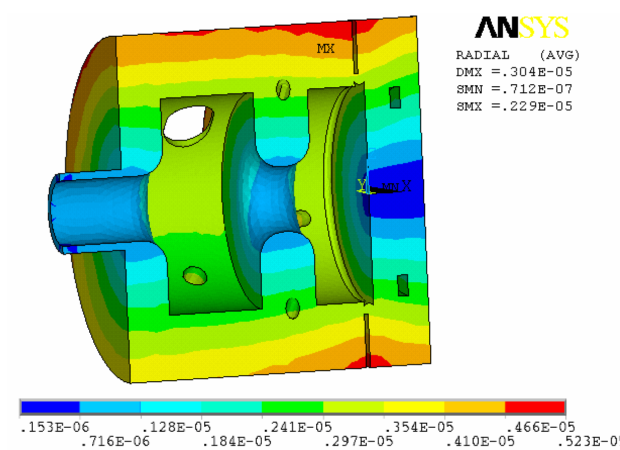

Figure 6: The radial deflections for 2 Hz r.f. cycle.

A fortran program was written to read the heat flux data from the surface faces of the outermost elements of the r.f. model into the common interface nodes of the structural model. The temperature distribution for the above 2 Hz case is shown in Fig. 5. The gun inner surface is quite *uniformly* heated by about 4°C. The o-ring is heated by 7.8°C because of poor thermal conductivity of SS and the small contact area.

THE STRUCTURAL SIMULATIONS

The full structure, including the vacuum region, was simulated for calculating the thermal strains. The thermal and electromagnetic elements were both changed to structural type. The temperatures from the thermal solution were read into the structure. The vacuum region was attributed dummy properties so that the structure was unaffected in solution. At cooling parameters of 2 Hz operation, the radial deflections are *uniformly* restricted to about 2 –3 *micron* as shown in Fig. 6. This reduces detuning and helps to preserve the field balance as is shown next.

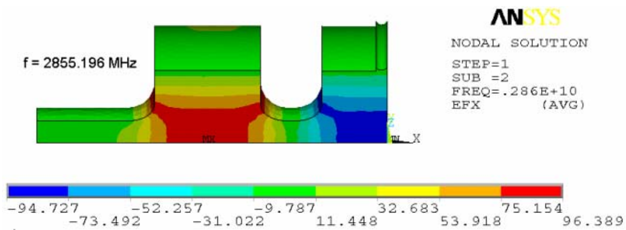

Figure 7: The axial electric field (not to scale) in photocathode gun and detuned frequency for 2 Hz r.f. cycle.

THE ELECTROMAGNETIC ANALYSIS OF THE DEFORMED CAVITY

The geometry of the vacuum region was *deformed* using the structural solution. Then the structural elements were reverted to electromagnetic high frequency type in ANSYS and an eigenmode solution was obtained. The frequency of the π-mode changed by –0.2 MHz to 2855.9 MHz and the field balance shifted from 1.042 to 1.044 as shown in Fig.7. The negligible change in field balance shows the uniformity of heating and hence optimization of the cooling layout. Thus the 2Hz repetition rate is just within the acceptable detuning range. The detuning is comparable with SUPERFISH which gives 46kHz/micron change of full cell inner diameter alone.

HIGHER R.F. DUTY CYCLES

We have simulated higher duty cycles of up to 10 Hz at 147 MV/m peak gradient and 4 µs r.f. pulse. The results show that we end up with larger deformations (+32 microns radially), temperature (57 degree) and detuning of - 0.9 MHz as shown in Fig.8, for unchanged cooling parameters (of 2Hz case). We do not wish to further push the water speed, as the channel diameter is only 6.5 mm and has many bends.

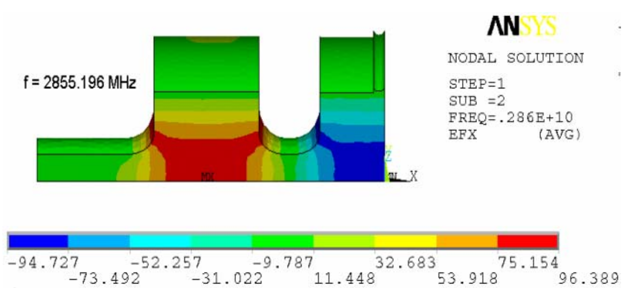

Figure 8 : The axial electric field (not to scale) in photocathode gun and detuned frequency for 10 Hz r.f. cycle at unchanged cooling parameters.

The present gun design does not allow annular cooling channels at the iris or full cell exit wall because of two component brazing assembly. In order to have annular channels, as for high repetition rate photocathode guns [8,9] the gun design will need complicated many component-brazing cycles. Instead we plan to increase the water channel diameter and reduce the path lengths to allow 10Hz operation.

CONCLUSIONS

The present coolant channel design in the 1.6 cell BNL/SLAC/UCLA type photocathode gun seems adequate for 2 Hz operation at 147 MV/m peak gradient and 4 µs r.f. pulse with 1.8 m/s water flow rate. The cooling is optimized to arrest deflections at the inner diameter to about 2-3 microns and a detuning of –200 kHz is seen. We have used a novel approach of complete r.f.-thermal-structural-r.f simulation cycle in the *same* FE mesh environment for the *full* model. Modeling ports in 3D helps to generate higher heat flux in regions around these ports which give temperature around these ports. rise than without ports as given by SUPERFISH. The cavity with deformed boundary was then re-simulated for resonant frequencies. This provides high sensitivity to r.f. detuning calculation as only boundary nodes are moved with the inner FE mesh unchanged. The technique developed could be used elsewhere also.

Higher water velocities are improper for a long, many-bend and narrow channel for water as it increases the pressure drop and pressure fluctuations due to flow round the corners. We are at present investigating the possibility of enhancing the flow rate by different methods to allow 10 Hz operations with minimal deformation and detuning.

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REFERENCES

[1] J.S.Fraser, et al., IEEE Trans. Nucl. Sci. 32 (1985) 1791.
[2] S.Anderson, et al., Proc. of PAC'99, New York, p. 2006.
[3] Luca Serafini, NIMA 341 (1991) 341.
[4] Kirk T. McDonald, IEE Trans. Electron Devices 35 (1988) 2052.
[5] D.T.Palmer, Ph.D Thesis.
[6] Arvind Kumar, et al., PRSTAB 5 (2002) 103501.
[7] www.ansys.com
[8] F.Marhauser, et al., Proc. of FEL'06 , p.560.
[9] X.J.Wang, et. al., Proc. of PAC'01, Chicago, p.2233.