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RF Simulation of the 187 MHz CW Photo-RF Gun Cavity at LBNL*

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(visiting from IHEP)

1 Introduction

A 187 MHz normal conducting Photo-RF gun cavity is designed for the next generation light sources. The cavity is capable of operating in CW mode. As high as 750 kV gap voltage can be achieved with a 20 MV/m acceleration gradient. The original cavity optimization is conducted using Superfish code (2D) by Staples **[1]**. 104 vacuum pumping slots are added and evenly spaced over the cavity equator in order to achieve better than 10^{-10}-Tor of vacuum. Two loop couplers will be used to feed RF power into the cavity. 3D simulations are necessary to study effects from the vacuum pumping slots, couplers and possible multipactoring. The cavity geometry is optimized to minimize the power density and avoid multipactoring at operating field level. The vacuum slot dimensions are carefully chosen in consideration of both the vacuum conduction, local power density enhancement and the power attenuation at the getter pumps. This technical note gives a summary of 3D RF simulation results, multipactoring simulations (2D) and preliminary electromagnetic-thermal analysis using ANSYS code.

2 3D RF Simulation

2.1 Basic RF parameters calculation

The 3D RF simulations using CST Microwave Studio (MWS) code include calculations of basic RF cavity parameters (Q0, frequency, shunt impedance, power density and etc.). Figure 1 gives the general layout of the cavity. The parameters-based model created in MWS includes vacuum solid only (see Figure 2). Background material is set as perfect electric conductor (PEC). Solution type is Eigen mode calculation.

Fig.1 3D model

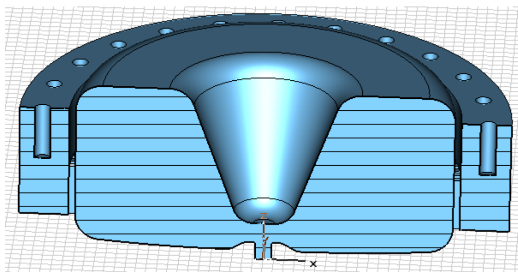


Fig. 2 3D model for RF calculation

Vacuum slots and getter pumps have small effect on basic RF parameters of fundamental mode. Table 1 shows the basic RF parameters with and without vacuum slots, getter pumps. The frequency shift due to power coupler is very small (see Table 2). It's important to try to keep the mesh same during different calculations to assure calculation accuracy. Figure 3 gives an example to further describe this important note.

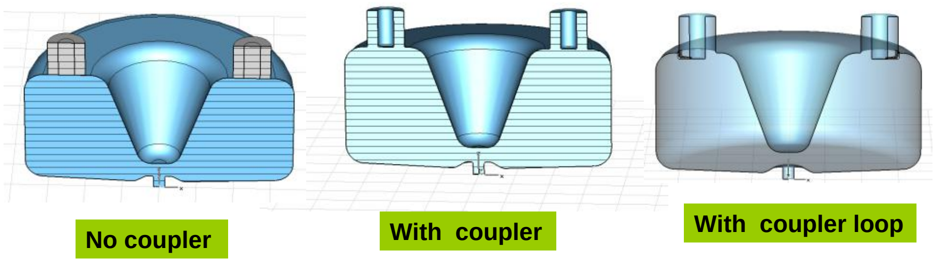
Table 1:

Model	Frequency (MHz)	Q0	Total loss (kW)	R (ohms)	R/Q	Vc (kV)	Stored energy (J)
Simple 2D (Superfish) **[2]**	186.87	31445	88.5118	6.36E6	202.1	750	2.3705
Simple 3D (MWS) **[3]**	186.80	31015	89.9984	6.25E6	201.5	750	2.3782
With slots and pumps 3D (MWS) **[4]**	187.01	30912	89.9909	6.25E6	202.2	750	2.3674

Table 2:

Model	Frequency (MHz)	Q0	Total loss (kW)	R (ohms)	R/Q	Vc (kV)	Stored energy (J)
No coupler **[5]**	186.804	30653	89.6	6.18E6	201.634	750	2.35938
With couplers **[6]**	186.606	30459	91.6	6.14E6	201.628	750	2.37939

Frequency shift due to coupler



Model	Frequency (MHz)	Q0	Total loss (kW)	R (MOhm)	R/Q	Vc (v)	Energy (J)
No coupler	186.804	30653	89.6	6.18	201.634	750000	2.35938
With coupler	186.606	30459	91.6	6.14	201.628	750000	2.37939
With coupler_loop	186.738	29630	94.4	5.96	201.104	750000	2.38391

Notes: In order to avoid the mesh difference, the ‘no coupler’ model is the same with the ‘with coupler’ model. But in the “no coupler’ calculation, I choose the coupler material as PEC.

Fig. 3: frequency shift due to coupler

2.2 Power Density Calculation

Over 100 vacuum pumping slots are added and evenly spaced over the cavity equator in order to achieve better than 10^{-10}-Tor of vacuum. The vacuum slot dimensions are carefully chosen in consideration of both the vacuum conduction, local power density enhancement and the power attenuation at the getter pumps. Table 3 contains the vacuum slots and pumps main dimensions. The bar width is equal to the slot width. The impact of the vacuum slots on RF performance and power shielding is analyzed using MWS **[4]**. Table 4 shows the maximum power density and the power density near the bar. Figure 4 shows the power density along the closed curve surrounding the bar. Due to mesh problem, the curve around the bar is a little bigger than the bar, so the attenuation calculated chose slot_depth=1.75cm. Figure 5 gives the analytical calculation of the power attenuation in the vacuum slots **[7]**.

Table 3:

Some Parameters	Value
Slot depth	1.25 cm
Slot width	1.0875 cm
Slot length	10 cm
Slot number	104
Pump length	10.5 cm
Outer Shielding radius	46.7 cm
Pump radius	1.5 cm
Pump center location radius	42.335

Table 4:

Max power density w/cm^2	In-bar power density w/cm^2	Out-bar power density w/cm^2	Attenuation (dB)
24.83	2.556	1.27e-4	43.03

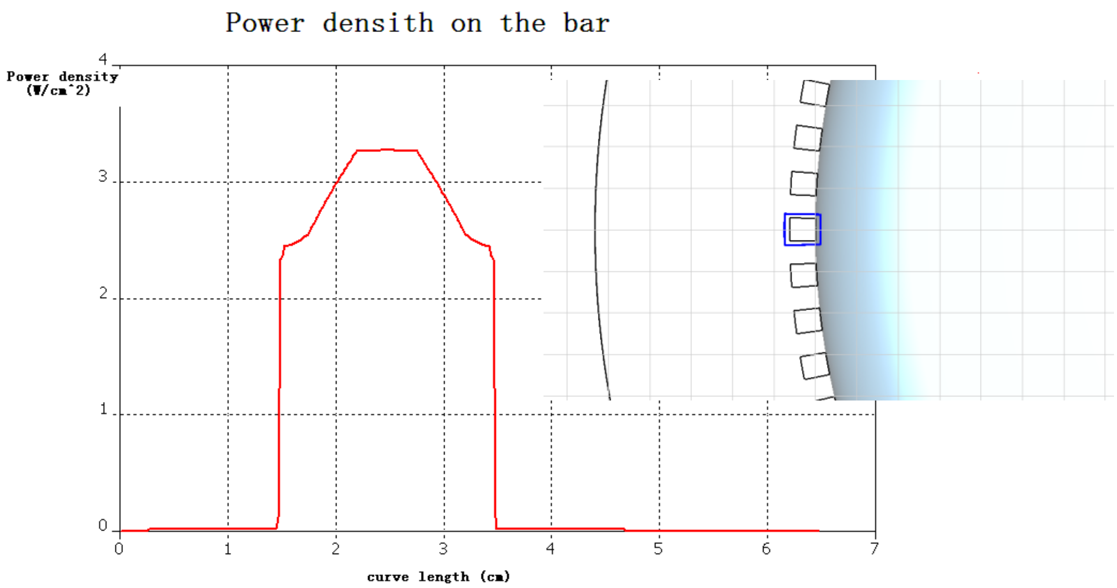


Fig. 4: Power density near the bar

Attenuation when slot depth=1.75 cm **Attenuation when slot depth=1.25 cm**

'd' is the slot depth;
'w' is the radius of the cavity;
'n' is the number of the slots;
'f' is the frequency;
The unit used here is SI.
'λc' is cutoff wavelength
'λ' is operation wavelength

$d := 0.0175$ $w := 0.36$ $n := 104$ $f := 1.87\times 10^{8}$

$\lambda c := \frac{2\cdot\pi\cdot w}{n}$ $\lambda := \frac{3\cdot 10^{8}}{f}$ $slot\_width := \pi\cdot\frac{w}{n}$

$\lambda c = 0.021749$ $\lambda = 1.604278$ $slot\_width = 0.010875$

$Atten := 54.5\cdot\frac{d}{\lambda c}\cdot\sqrt{1-\left(\frac{\lambda c}{\lambda}\right)^{2}}$

$Atten = 43.847578$

$d := 0.0125$ $w := 0.36$ $n := 104$ $f := 1.87\times 10^{8}$

$\lambda c := \frac{2\cdot\pi\cdot w}{n}$ $\lambda := \frac{3\cdot 10^{8}}{f}$ $slot\_width := \pi\cdot\frac{w}{n}$

$\lambda c = 0.021749$ $\lambda = 1.604278$ $slot\_width = 0.010875$

$Atten := 54.5\cdot\frac{d}{\lambda c}\cdot\sqrt{1-\left(\frac{\lambda c}{\lambda}\right)^{2}}$

$Atten = 31.319698$

Fig 5: analytical attenuation calculation

2.3 Higher Order Modes (HOMs) Analysis

Table 5 lists the first 21 HOMs. One conclusion can be obtained: many near TEM modes occur after adding pumps.

Table 5:

	Type	Frequency (MHz)	Q
Mode1	TM_{010}	187.01	30912
Mode2	TM_{110}	483.71	40428
Mode3	TM_{011}	526.74	39980
Mode4	Near TEM	593.44	9553
Mode5	Near TEM	594.59	9442
Mode6	Near TEM	597.95	9621
Mode7	TM_{110}?	598.42	38880
Mode8	Near TEM	601.89	9826
Mode9	TM_{021}	603.27	37495
Mode10	Near TEM	605.92	9797
Mode11	TE_{211}	606.48	43168
Mode12	Near TEM	608.46	9711
Mode13	Near TEM	609.39	9850
Mode14	TEM_{01}	673.26	15526
Mode15	Near TEM	682.19	15876
Mode16	TEM_{21}	707.99	16243
Mode17	TE_{311}	713.20	34145
Mode18	TM_{220}	715.12	52657
Mode19	Near TEM	749.84	18022

Mode20	TM_{120}	764.96	43456
Mode21	Near TEM	798.73	17359
Mode22	TE111	802.41	44168

3 2D Multipactoring Calculation Using Multipac 2.1 Code [8]

The multipactoring calculation using Multipac 2.1 is carried out through the following three steps **[9]**:

1) Calculate the time-harmonic electromagnetic fields;
2) Find the multipacting field levels;
3) Locate and identify the multipacting electron trajectories.

Two basic tools used in the analysis:

1) Counter functions: For those field levels where the enhanced counter function exceeds the number of initial electrons, multipacting occurs.
2) Distance function: the minima of the distance function shows the initial points of those electron trajectories that survive N impacts and are able to multipact. Then the electron trajectories are recalculated by using these minima as initial points and the impact energy is computed. If the impact energy is such that the secondary yield is larger than one, a multipactoring electron trajectory has been found. Figure 6 shows the initial points and secondary yield curve. Figure 7 shows the electric and magnetic field distribution. Figure 8 shows the counter functions ratios and final impact energy. It can be found multipactoring occurs at two low field levels which e_{20}/c_0 value over unity (about 4 to 6MV/m). No multipactoring occurs on operation field level (about 20MV/m).

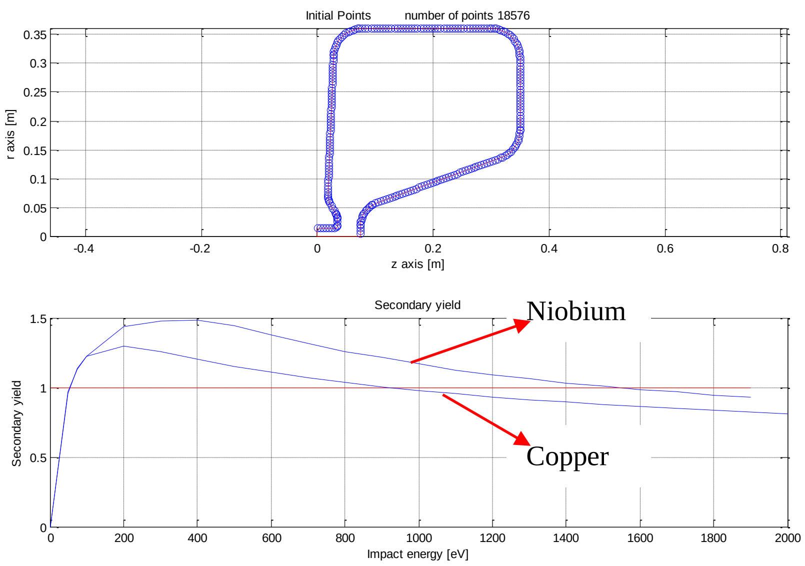


Fig. 6: Initial points and secondary yield curve

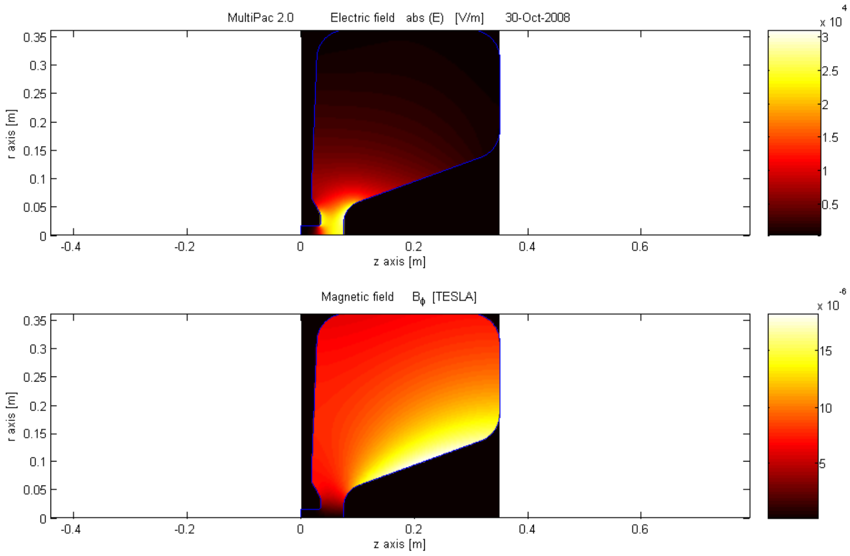


Fig. 7: Electric and magnetic field distribution

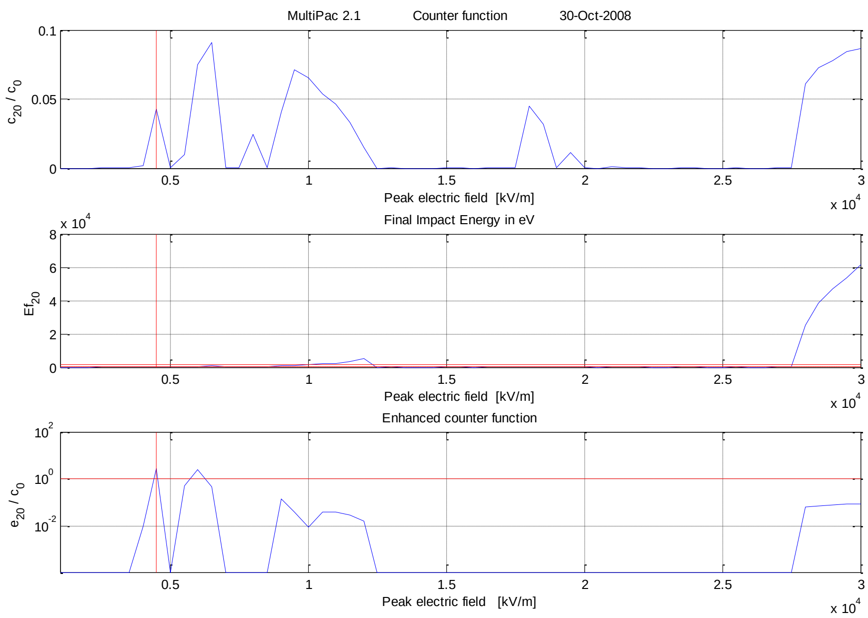


Fig.8: Counter function ratio and final impact energy

c_{20}: the number of free electrons after 20 impacts

c_0: the number of initial electrons

e_{20}: the number of secondary electrons after 20 impacts

Ef_{20}: the impact energy of the last impacts

4 Preliminary Electromagnetic-Thermal Analysis Using ANSYS Code

A preliminary electromagnetic-thermal analysis using ANSYS code for the cavity has been tried. The analysis starts with electromagnetic field simulation using High Frequency (HF) modal analysis in ANSYS, followed by scaling the fields to the design values and then applying the heat flux to cavity inner surface for thermal and structure analysis. A special macro has been developed to compute the stored energy, surface power losses from HF modal results, scale and apply the results to the cavity body for thermal and structure analysis in ANSYS.

4.1 Method Description

1) Electromagnetic analysis

- Import the model created in CST MWS; Model run time is reduced by using 6 degree of the cavity **[10]**;
- The imported model is adjusted to assure the vacuum volume shares its outer boundary with the inner boundary of the copper cavity;
- Electric wall and impedance boundary conditions are applied to the vacuum-to -copper cavity interfaces;
- The model symmetry planes are set as magnetic walls by ANSYS default setting;
- Vacuum volume is meshed with HF119 element.
- A modal high frequency analysis is run resulting in calculation of the cavity frequency and Q0 as well as normalized data for the E and H fields **[11]**;
- A macro consisting of an input file with a sequential list of ANSYS commands is written to get the normalized total power loss and stored energy. Then a scaling factor is figured out based on the known stored energy or total power loss calculated in MWS **[12]**.

2) Thermal analysis

- The cavity wall is meshed with solid87 element;
- The material of cavity volume is set as OFHC. Thermal conductivity of OFHC is given;
- A simple thermal boundary condition (298K water convection) is applied on the outer of the cavity ;
- It's important to delete all the HF119 elements before the thermal solution.
- Surface power density is read from the high frequency analysis results and renormalized using the scaling factor calculated in the HF analysis; then loaded onto the inner surface of the copper cavity;
- A static thermal analysis is run resulting in the renormalized temperature distribution **[13]**.

4.2 Preliminary calculation results

Table 6 gives the comparison of calculation results on basic RF parameters. A good agreement is achieved between MWS and ANSYS.

Table 6:

Parameters	CST MWS	ANSYS
Frequency (MHz)	186.798	186.824
Quality factor	31734.0025	30663.8
Stored energy (J)	2.35456	3.491411866667E-16
Total power loss (w)	90122.99	1.959689791200E-10
Maximum power density (w/cm^)	22.5785	22.8457
Renormalization scaling factor based on stored energy	4.445206919053E+14	
Renormalization scaling factor based on power loss	4.598839592098E+14	

Figure 9 shows the model for electromagnetic-thermal coupled field analysis. The model for electromagnetic analysis contains the vacuum solid only. It is meshed with HF119 elements (see Fig. 10). Model for thermal analysis is the cavity wall solid (see Fig. 11). Temperature distribution under simple thermal boundary condition (298K water flow convection cooling) is shown in Figure 12.

Fig. 9

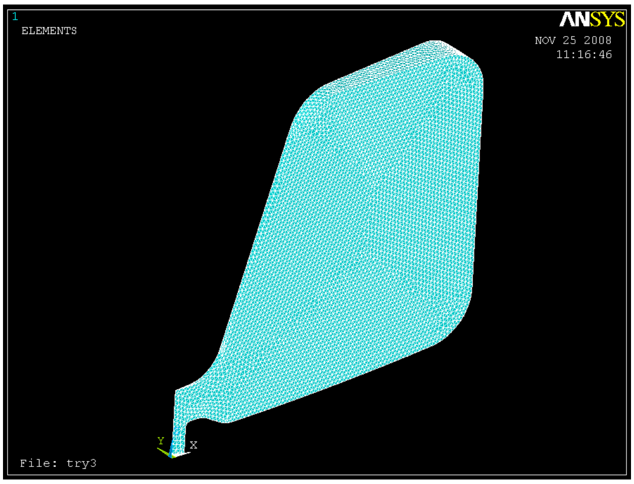


Fig. 10

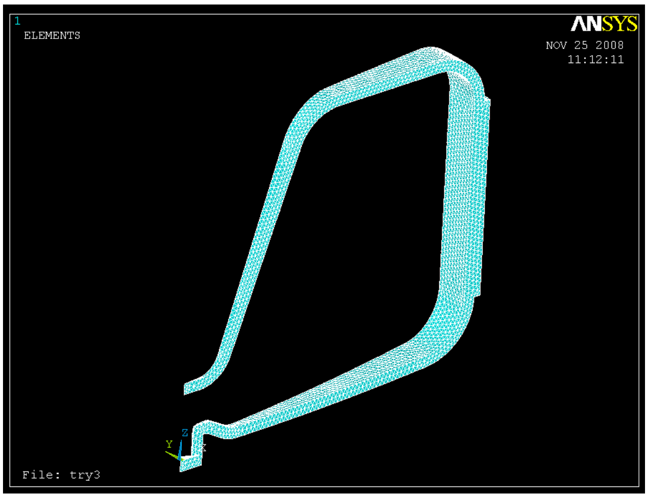


Fig. 11

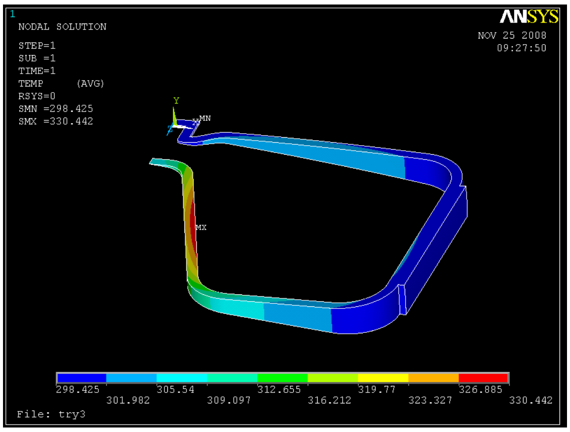


Fig. 12

Attachments ：

[1] LBNL_CAVITY→187m_prototype.xls

[2] LBNL_CAVITY→ SUPERFISH CALCULATION FOR 187M

[3] LBNL_CAVITY→SIMPLE 3D RF CALCULATION IN MWS

[4] LBNL_CAVITY→WITH SLOTS AND PUMPS RF CALCULATION IN MWS

[5] LBNL_CAVITY→NO COUPLER RF CALCULATION IN MWS

[6] LBNL_CAVITY→WITH COUPLER CALCULATION IN MWS

[7] LBNL_CAVITY→attenuation.mcd

[8] LBNL_CAVITY→MP ANALYSIS FOR 187M

[9] LBNL_CAVITY→neu2_multipac.pdf

[10] LBNL_CAVITY→ANSYS PRELIMINARY CALCULATION→ simple model.sat

[11] LBNL_CAVITY→ANSYS PRELIMINARY CALCULATION→ RF. txt

[12]LBNL_CAVITY→ANSYS PRELIMINARY CALCULATION→ macro for energy and power loss.txt

[13] LBNL_CAVITY→ANSYS PRELIMINARY CALCULATION→ thermal. txt

[14]LBNL_CAVITY→ PROGRESS PRESENTATION

Report1.ppt

Report2.ppt

Report3.ppt

Report4.ppt

Report5.ppt

Report6.ppt

multipactoring calculation.ppt

mp analysis for 187m.ppt

Note: attachment with uppercase is a file folder, with lowercase is a file.