ELECTROMAGNETIC, THERMAL, AND STRUCTURAL ANALYSIS OF A PHOTOCATHODE RF GUN FOR THOMX

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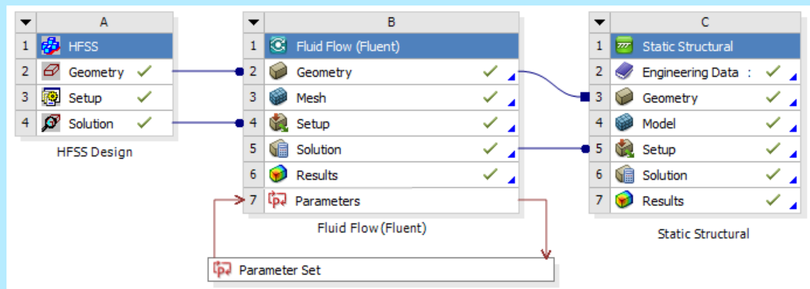
Introduction

The successful operation of accelerator cavities has to satisfy both RF and mechanical requirements. It is highly desirable that electromagnetic, thermal and structural effects such as cavity wall heating can be addressed in an integrated analysis. The Commercial Finite Element Analysis (FEA) code ANSYS provides the ability to link electromagnetic to thermal and structural analyses as shown below. This multi-physics tool is applied to the THOMX RF gun, which would substantially reduce the cost and time of a design cycle.

The multi-physics simulation is done in three steps:

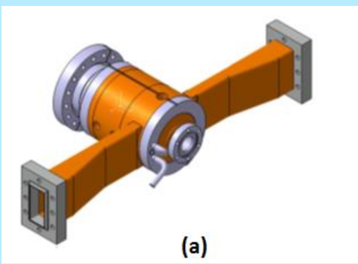
- Electromagnetic simulations for the vacuum region (ANSYS-HFSS)
- Thermal Simulation for the cavity metal body (Fluent)
- Structural simulation for the cavity metal body (Static Structural)



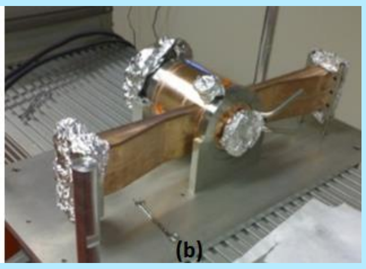
ANSYS Workbench Analysis Schematic

Electromagnetic Analysis (ANSYS HFSS)

The ThomX RF Gun is a 2.5 cell standing wave copper cavity, operating on the TM_{010}-like accelerating mode, with field phase advance per cell is π. The electrons are emitted on the cathode through a laser (hitting the surface) and are then accelerated by an axial longitudinal electric field component.



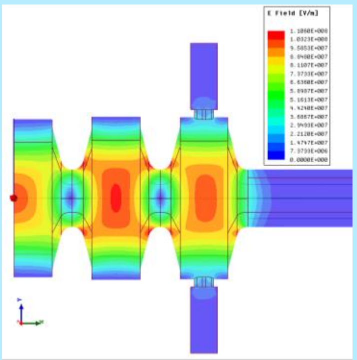
3D model design Gun



Prototype after final brazing

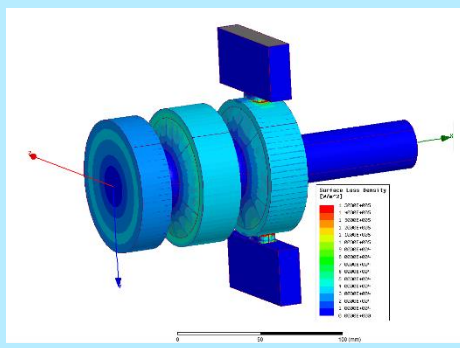
The RF cavity shape, as proposed, has several innovative electromagnetic features:

- elliptical irises to reduce surface electric field,
- symmetric couplers for dipole mode minimization,
- racetrack geometry to minimize quadrupole field components.



Electric field distribution

- E_{peak} on cathode = 100 MV/m @ 10 MW for 50 Hz RF cycle and 3 μs RF pulse
- E_{max} on iris surface ≈ 110 MV/m



Heat flux distribution

- Max heat flux = 150 kW/m² for 10 MW at the coupling slot area
- RF pulsed heating: ΔT ≈ 60 °C below the threshold of 110 °C in the case of copper.

Parameters	Simulated Values
π-mode Frequency	2998.55 MHz
Quality factor Q	15000
Shunt impedance	49 MΩ/m
Peak Accelerating field	100 MV/m @ 10 MW
Filling time	0.7 μs
Repetition rate	50 HZ
RF pulse, input RF Power	3μs, ≤ 10 MW
Esurf/Eacc	1.07
Average dissipater power	1.5 kW

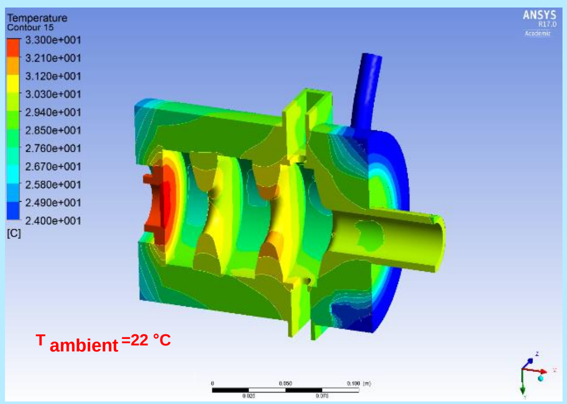
RF Gun parameters

Thermal Analysis (ANSYS FLUENT)

- The goal of mechanical design is to define a cooling pipes system made in the copper cells, in ordre to take under control the deformations of the structure, providing a temperature increase as small and uniform as possible.

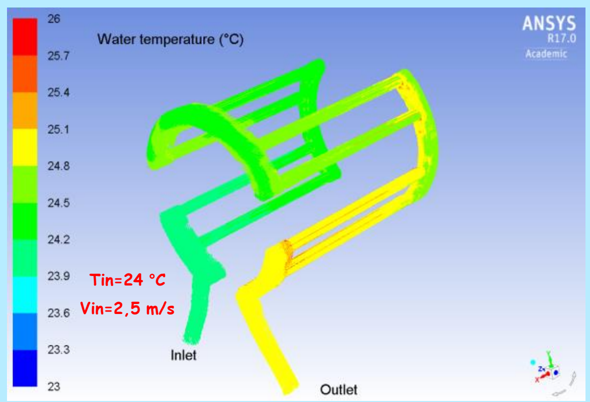
Straightforward model: HFSS-Fluent analysis

- EM field has been imported as heat flux (W/m²) on the internal cavity surfaces
- Water velocity inside tubes (diameter 8 mm) is set to 2.5 m/s, this value derived from considerations channels pressure and corrosion problems. Higher values of fluid velocity, until 3 m/s, could be in case adopted. The inlet water temperature is 24 °C and the ambient temperature is 22 °C. Natural convection with air on the external surface is taken in account.



Gun body temperature distribution

- Average Gun Temperature ≈ 29,8 °C
- $T_{max\ Gun}$ ≈ 33°C at the photocathode location

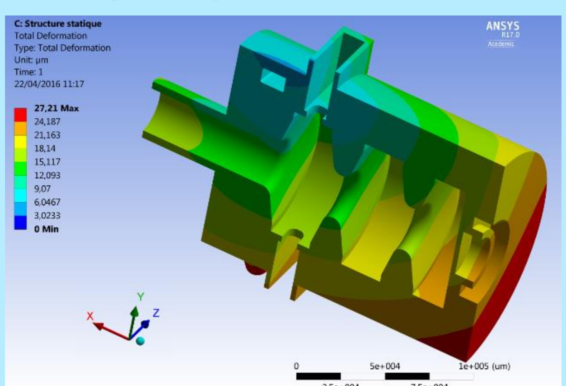


Cooling water temperature along tubes

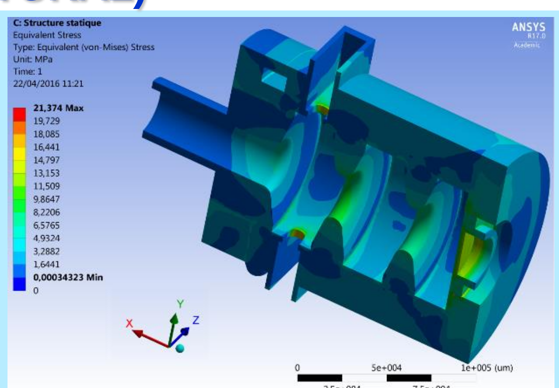
- $\Delta T_{water\ max}$ ≈ 1,4 °C
- Pressure drop Δp ≈ 0,5 bar

Static Structural Analysis (ANSYS STATIC STRUCTURAL)

- The goal of the model is to calculate the total deformation, due to thermal load acting on the body gun using coupled analysis fluent and Static Structural.
- The total deformation (displacement) is below 20 μm for the cells surfaces
- The stress on copper parts is always below the yield strength of 62 MPa (for soft copper)



Gun body Total Deformation (displacement)



Gun Body Equivalent Von-Mises Stress

Conclusion and Prospects

The present coolant channel design in 2.5 cell photocathode gun seems adequate for 50 Hz operation at 100 MV/m peak gradient and 3 μs RF pulse length with 2.5 m/s water flow rate. A novel approach of complete RF-Thermal-Structural simulation in the same finite element (FEA) environment for the full model has been used. By using one program for all the simulations any problems of transferring loads between different softwares were eliminated. RF Gun prototype for THOMX was constructed and the RF characteristics were confirmed. High power test is foreseen using the PHIL photoinjector test line at LAL Orsay.