Analysis of Thermal Stresses Produced on TCABR Tokamak Vacuum Vessel due to Baking Process

Pedro Leo Oliveira Marques*[1], Ruy Marcelo de Oliveira Pauletti[1], Juan Iraburu Elizondo[2],
*pedro.leo.marques@usp.br, [1)]Polytechnic School, University of São Paulo, Brazil;
[2)]Physics Institute, University of São Paulo, Brazil;

Background

Plasma-wall interactions inside a tokamak's vacuum vessel may cause erosion and deposition of particles in its inner walls, polluting the plasma in successive shots. A ***baking*** **(heating) system** is planned to be installed on the TCABR tokamak and would allow the deposited particles to be removed by heating the vacuum vessel's inner walls to 200 ºC. However, this baking system could produce large levels of thermal stresses and produce structural damage if designed poorly.

a) b)

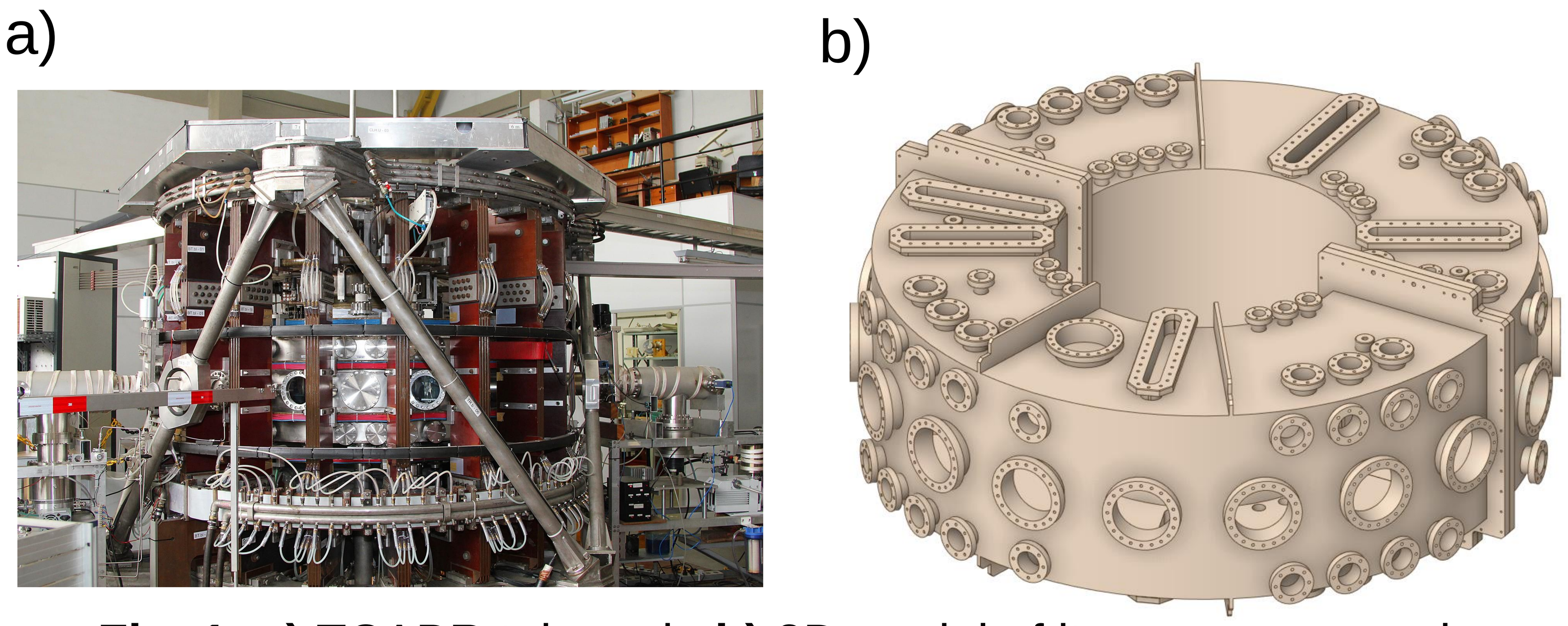

Fig. 1: a) TCABR tokamak. **b)** 3D model of its vacuum vessel.

Objectives

- Obtain temperature field produced by baking process
- Evaluate the stresses produced by temperature field and other loadings (gravity, pressure difference)
- Check if the stresses are large enough to damage the vacuum vessel or its support structure

Methodology

- Finite Element Method (FEM) to obtain numerical solution for differential equations governing the problem:

Heat conduction differential equation

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial x}\right)+\dot{e}=\rho c\frac{\partial T}{\partial t}$$

↓ **FEM**

$$[K]\{T\}=\{Q\}$$

System of algebraic equations

- One way coupling of thermal and structural FEM models:

Heat Transfer FEM Model → $\{T\}$ → Structural FEM Model → Stresses on vessel and structure

Results

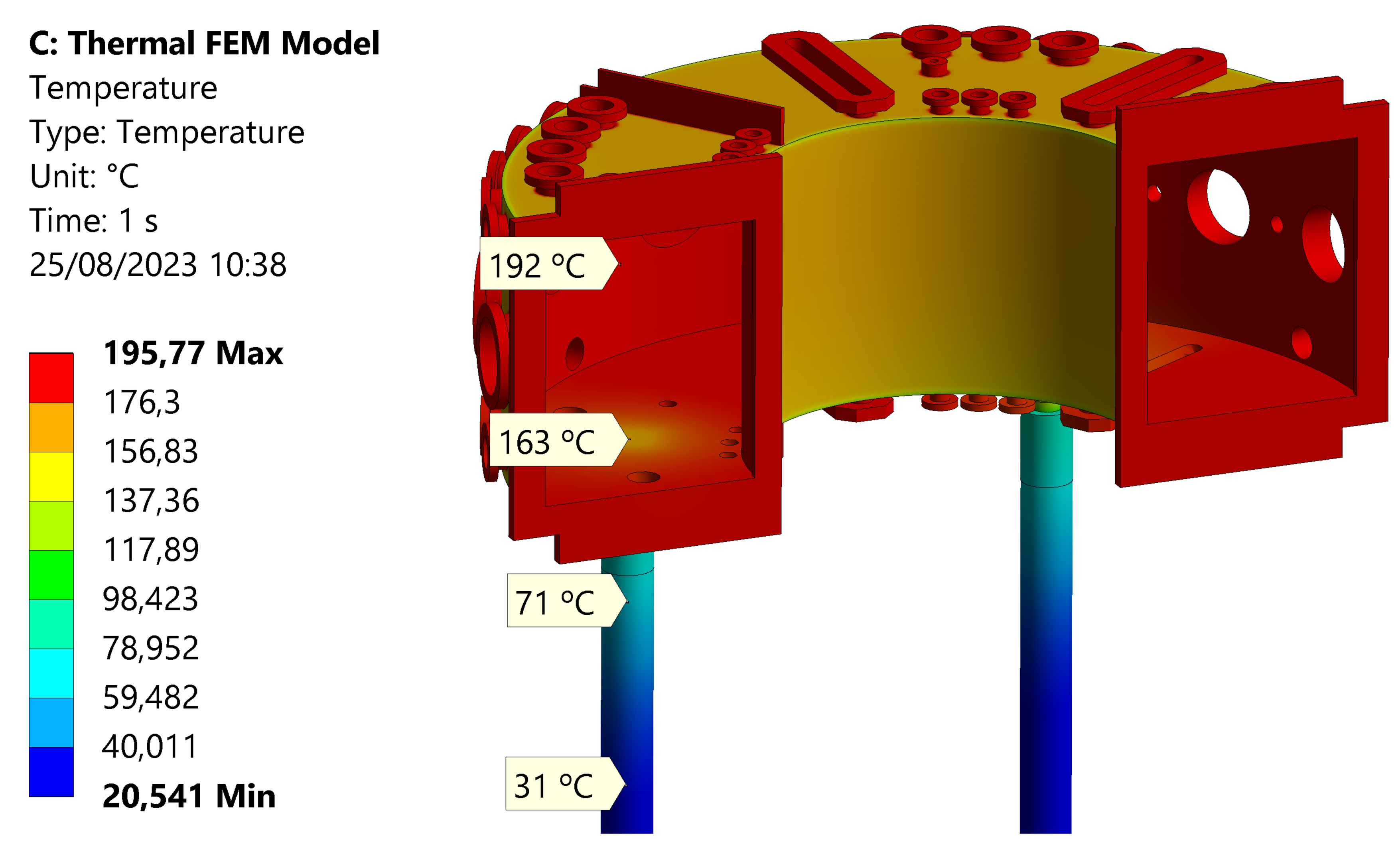

Fig. 2: Temperature distribution obtained for 3D model of vacuum vessel and support structures. Only half of the model is shown on this figure. A heat flux of 295 W/m^2 was applied on each toroidal wall of the vessel. Natural convection boundary condition was applied on the external walls of insulating blanket (shown in figure as orange) and support structures.

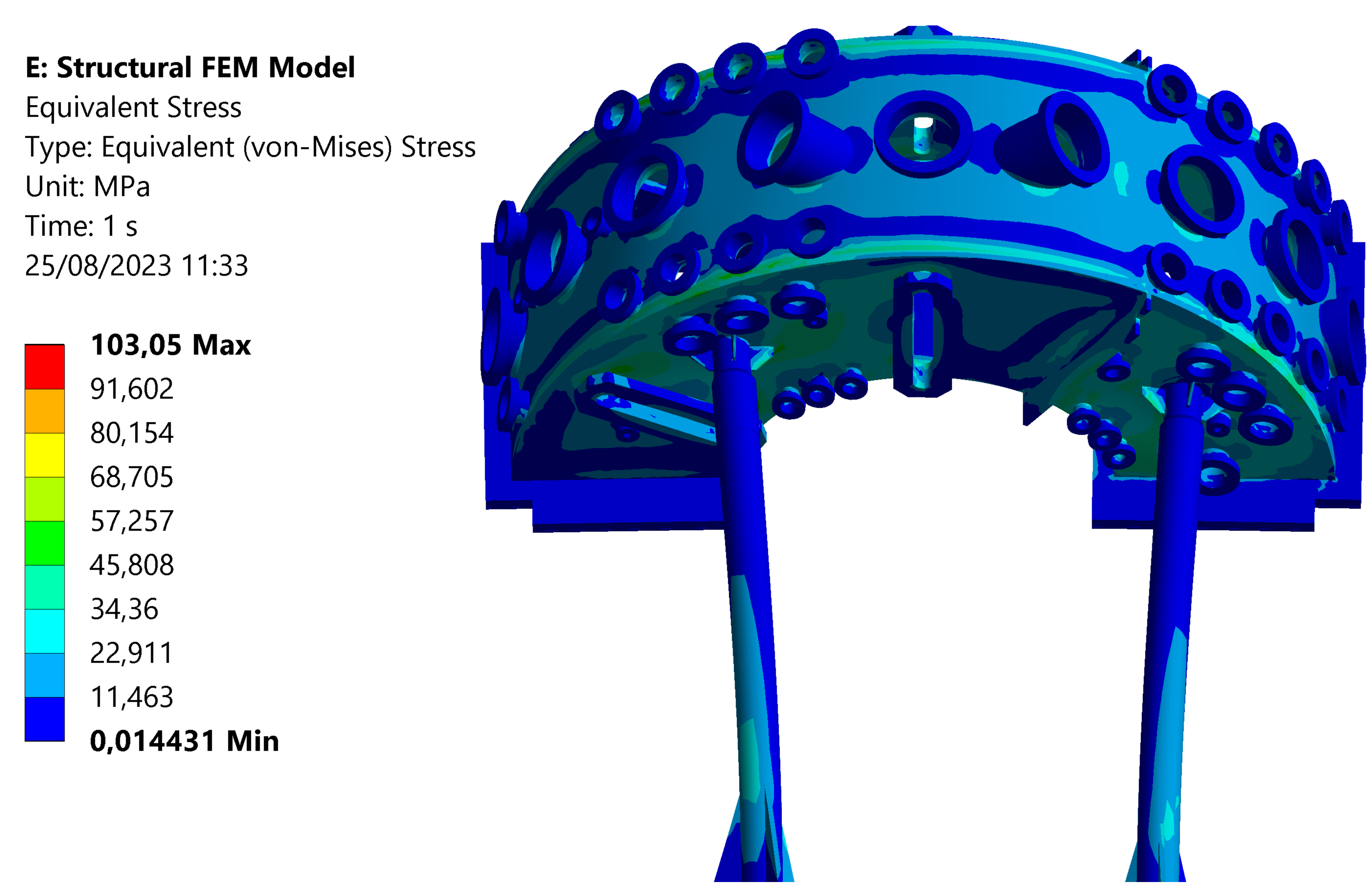

Fig. 3: Equivalent stress values obtained for 3D model of vacuum vessel (only half shown in figure). This model includes the effects of gravity, pressure difference – baking is performed while maintaining vacuum inside the vessel – and temperatures obtained from the previous model.

Conclusions

- Supports act as heat sinks; thermal insulation required.
- Thermal radiation has a strong impact on results; helps to reduce temperature differences across the vessel.
- Stresses below yield strength for 316L stainless steel.
- Thermal stresses are function of temperature gradient; transient analysis required.

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