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Summer Student Report
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Thermo-Mechanical FE Simulation & Characterization of MoGr's Elastic Properties

Abstract

This report summarizes a two-month's internship within the EN-MME department, focusing on Finite Element simulations for the Collimation project and PSB H0/H- dump upgrade, and the progress done on the characterization of Molybdenum-Graphite elastic properties.

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1. INTRODUCTION

The following reports presents the work carried for two month within the EN-MME-EDS section as a summer student. A first part will detail the context and the results of thermo-mechanical finite element simulations. A second part will detail the process used for the characterization of MoGr Elastic Properties, a key-material for the HL-LHC collimator upgrade.

2. THERMO-MECHANICAL FE SIMULATIONS

Each of the following studies, carried out under ANSYS, has been issued in three independent detailed reports, two of which were published on EDMS.

2.1 Fatigue study of BPM cable for the TCSP collimator - *EDMS n°1403669*

2.1.1 Scope

Finite elements calculations were performed to evaluate the behaviour of BPM cables embedded in a TCSP collimator, checking if the position of supports leads to acceptable equivalent stress and deformations during exercise.

As the jaws of the collimators move often during operations these cables are subject to repeated stress. A fatigue analysis was performed to evaluate the resistance of cables after several working cycles (opening and closing of the two jaws).

2.1.2 Results

The support positions of BPM cables ensure a vertical displacement **lower than 2 mm** during the jaw movement (see Figure 1). This result ensures that there will be **no friction between the cable and its surrounding**, and that it will not alter the vacuum environment, during the entire operation of the TCSP collimator.

With the medium stress almost negligible, the alternate stress is the key parameter for the fatigue analysis. The calculated equivalent stress is 80 MPa, half of the fatigue limit stress for a 10^6 cycles life, therefore **no fatigue problems** are identified by this analysis. No additional creep-induced deformations are expected.

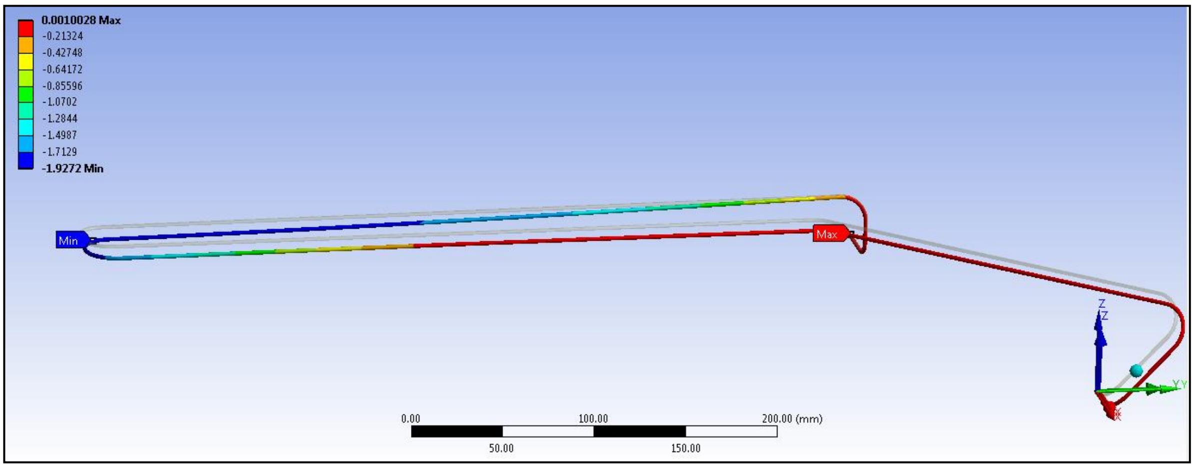

Figure 1 — TCSP: BPM cable 1 maximum vertical deformation ~ 1.93 mm

2.2 Brazing of the BBLRC wire for the TCTW collimator - *EDMS n°1405114*

2.2.1 Scope

This study reports the analyses performed to simulate the brazing of the BBLRC wire in the TCTW collimator, in order to evaluate the temperature increase in the surrounding flange and sockets during the process.

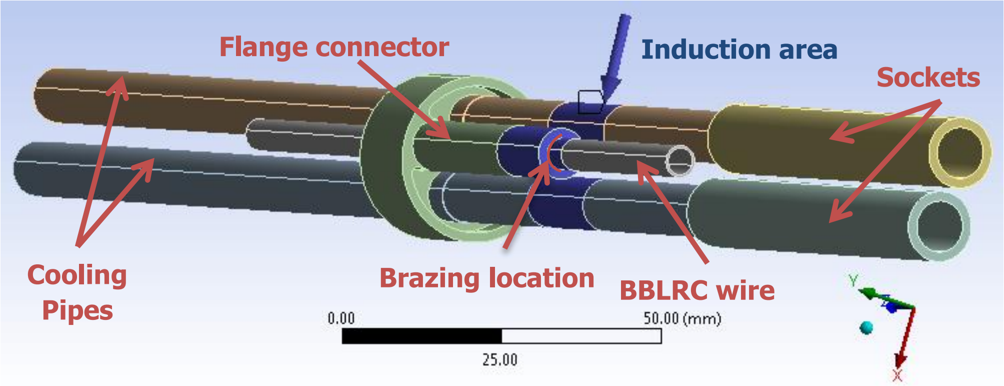

Figure 2: Modelled Brazed assembly for the thermal study

Finite elements calculations were performed to validate the 5 cm length of the connector: this length must guarantee that the heat generated by electromagnetic induction, while brazing the BBLRC wire, which propagates by thermal conduction to the opposite side of the flange, is low enough to avoid re-melting the connections pipes/flange and pipe/socket already brazed together. The quality of these different connections is critical to ensure the leak-tightness of the collimator's vacuum chamber. A thermal analysis was performed to evaluate the temperature in the different components during the brazing process.

2.2.2 Results

The brazing heat flux was estimated to 0.07 W/mm^2, increasing over 2 min, in order to reach the brazing temperature of 881°C and hold it for 10s.

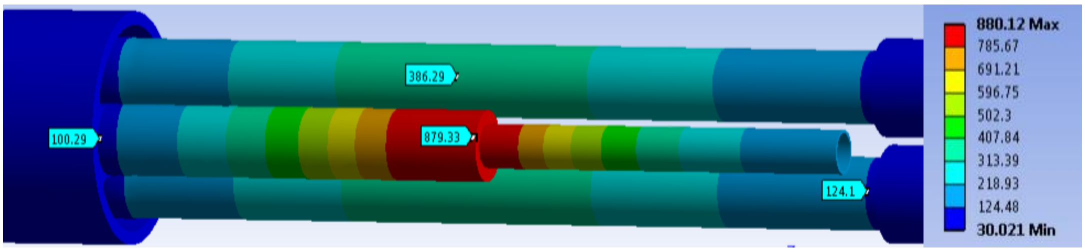

Figure 3: Temperature distribution after heating

The **length of the connector**, designed in order to decrease the temperature near the areas brazed during the first brazing cycle under vacuum, has been **validated**.

- The flange connector is long enough to avoid alteration of the first brazing location. The temperature remains under 190°C.

- Maximum temperature reached in Cu-Ni cooling pipes: 390°C and 304L sockets: 146°C.

- If heat radiation to ambient is taken into account, as more energy is required to compensate this phenomenon, the final temperatures reached are: Flange 172°C, cooling pipes 453°C, and socket 161°C.

2.3 PSB Injection – H0/H- Beam Dump – Thermal contact conductance

2.3.1 Scope

This study reports the analyses performed to determine the thermal contact conductance between the H0/H- Dumps and water-cooled chamber, located in the PSB Injection region.

As the LINAC4 H- beam is injected into the PSB, a foil strips these H- ions from their electrons to produce H+. As this process is not 100% efficient, the remaining H- and H0 need to be dumped. As they interact with the Ti64 dump material, they heat it. As the chamber and the surrounding magnets need to be maintained at low temperature, the cooling of the dump must be efficient. In order to determine the efficiency of the whole cooling, the thermal contact conductance between the dump and the chamber must be known.

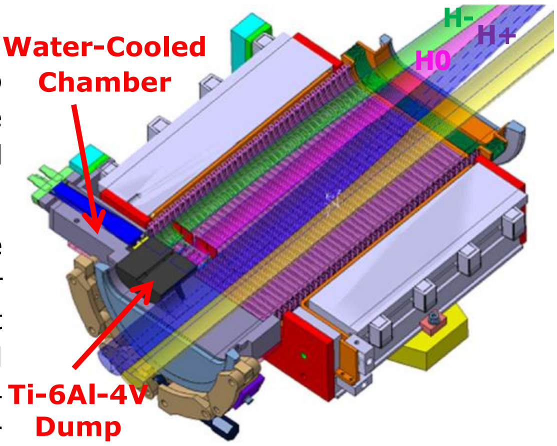

Figure 4: Localization of the H0/H- Dump in the PSB injection region

2.3.2 Results

A mechanical study has been carried in order to determine the contact pressure between the dump and its supporting water-cooled cavity (in grey and black in Figure 4), set by two M6 screws, tightened to 6400 N each. This study enables the calculation of the thermal conductance of the contact. The value was then implemented in a steady-state thermal analysis to check the dump final temperature, while receiving 14.2W of the beam energy (foil inefficiency of 2%).

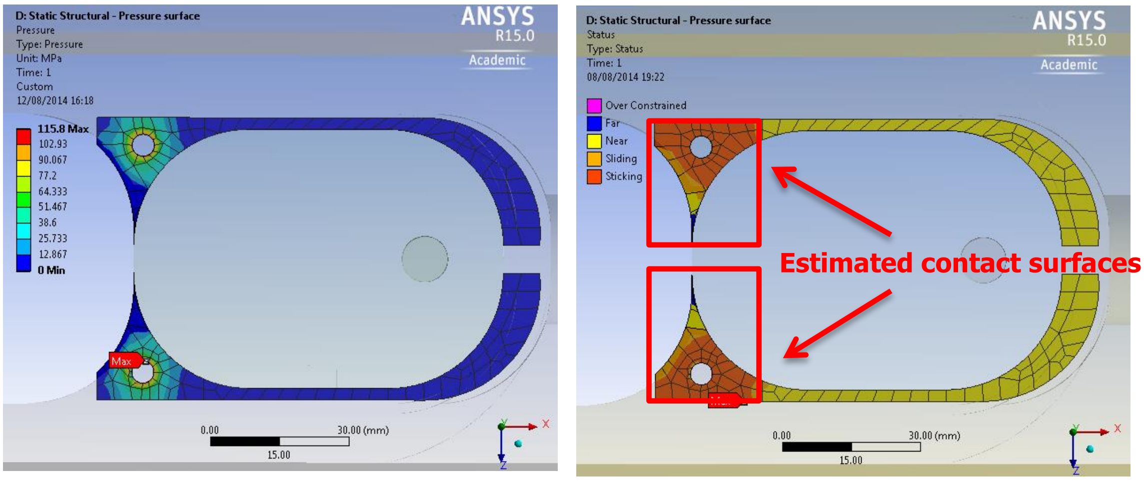

Figure 5: Static analysis - Pressure and estimated Dump/Chamber contact surface

With a calculated contact pressure of 37 MPa on the average of an estimated contact surface, the resulting **thermal conductance** is calculated to **4300 W/m².K**, value which is higher than the minimum contact conductance (2500 W/m².K) required by design. With a water cooling convective coefficient of 4500 W/m².K, the overall dump-to-cooling **effective convection coefficient** reached is thus **2200 W/m².K**, also higher than the minimum design value.

3. CHARACTERIZATION OF MoGr's ELASTIC PROPERTIES

The Molybdenum-Graphite composite is one of the most promising materials developed at CERN, in view of a possible use in the new collimators for the HL-LHC upgrade. Set to interact with the beam, in the collimator's jaws, this material has many outstanding properties such as its high electrical and thermal conductivity. But as this is a non-isotropic material, the characterization of its mechanical properties is not easy.

The definition of the compliance matrix, that governs the elastic behaviour of the material, requires 5 constants for the transverse isotropic model: $Ex{=}Ey$ (Young's Modulus In plane of the composite fibres), Ez (Transverse), Gxy, Gt (Shear modulus) and ν_t (transverse Poisson ratio), ν_{xy} defined as $\nu_{xy} = \frac{Ex}{2.Gxy} - 1$.

$$\begin{bmatrix} \frac{1}{Ex} & -\frac{\nu_{xy}}{Ez} & -\frac{\nu_t}{Ez} & 0 & 0 & 0 \\ -\frac{\nu_{xy}}{Ex} & \frac{1}{Ey} & -\frac{\nu_t}{Ez} & 0 & 0 & 0 \\ -\frac{\nu_{tt}}{Ex} & -\frac{\nu_{tt}}{Ex} & \frac{1}{Ez} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{Gt} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{Gt} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{Gxy} \end{bmatrix}$$

In order to know the first four parameters and define the diagonal, the resonance vibration method can be used. Since the vibrating frequencies of a beam mostly depend on the first four parameters, while the influence of the transversal Poisson's ratio is negligible, the four of them can be calculated with only two samples: one longitudinal to the fibres, one transverse. But if the sample dimensions would not fit the formula's criterion, the calculated moduli could deviate from the real values. Using the found parameters, as an input, a modal analysis could then be carried, with a careful parameter optimization (E, G) in order to match the experimental vibrating frequencies observed.

Ex = Ey	Ez	Gxy	Gt	νxy	νt
75 GPa	8 GPa	32 GPa	4.6 GPa	0.172	0.1

Table 1: MoGr's Elastic Parameters - Transverse isotropic model

The remaining νt parameter, influencing the transverse component of the compliance matrix is left to define. As the Stiffness matrix (inverse of the compliance matrix) components are all influenced by the νt value, the determination of only one of its components would permit the calculation of νt. As these components can be calculated from the ultrasonic wave propagation speed in different directions, and the density by the formula: $C_{33} = \rho.V_{33}{}^2$, νt can be known. C_{33} being more accurately known, as $V_{33}$is more accurately measured (wave propagation in the transverse direction).

4. CONCLUSIONS

Thermo-mechanical simulations have been carried on various set of physical problems.

A characterization process for transverse isotropic material has been defined and used in order to determine Molybdenum-Graphite elastic properties, using resonance vibration method coupled with modal analysis under ANSYS and ultrasonic wave propagation speed measurements.