CERN

Thermal behavior of TAXN and TCDXM D2 collimator mask, Finite element studies

Summer student internship

Stepans Sklariks
8-21-2015

1. FINAL REPORT

The objective of this project was to perform thermal loading simulations of TCDXM (D2 collimator mask) (see Figure 1) and TAXN so as to allow the preliminary evaluation of the suitability of the given parts for the upcoming high luminosity upgrade that is to be performed in LHC in the nearest future. These parts are special purpose absorbers that are needed to protect superconducting magnets from the collision product radiation obtained within the experiment to prevent the superconducting magnets from quenching. The absorbers also localize the induced activation to the absorbers and surrounding shielding. The suitability of the current parts is evaluated in terms of maximum temperature generated due to the heat deposition, which in turn should not surpass the allowable critical temperature defined for the given structure. Depending on the results obtained, some recommendations for the design of cooling system are provided. For the current analysis CAE package ANSYS 16.1 was used. The analysis was performed using heat deposition data that was provided by the use of fully integrated particle physics Monte Carlo simulation software package Fluka.

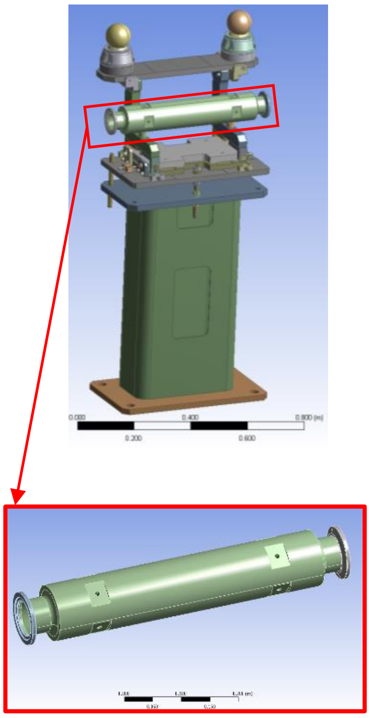

Figure 1: TCDXM D2 collimator mask geometry

1.1. TCDXM D2 COLLIMATOR MASK THERMAL ANALYSIS

For the TCDXM (D2 collimator mask) the analysis was performed in the following manner. For the objectives described a computational simulation model was generated (see Figure 3). Basic modelling parameters are as follows:

- The discretization is done by means of finite elements
- Volumetric parts are meshed by solid elements with tetragonal and quadratic shape functions;
- According to the design of TCDXM (D2 collimator mask) the material of the part is copper, thus an appropriate heat conductivity value of 401 W/(M*C) was chosen for further modelling

The applicable Mesh parameters are summarized in the Table 1. The density of the mesh can be seen in Figure 3.

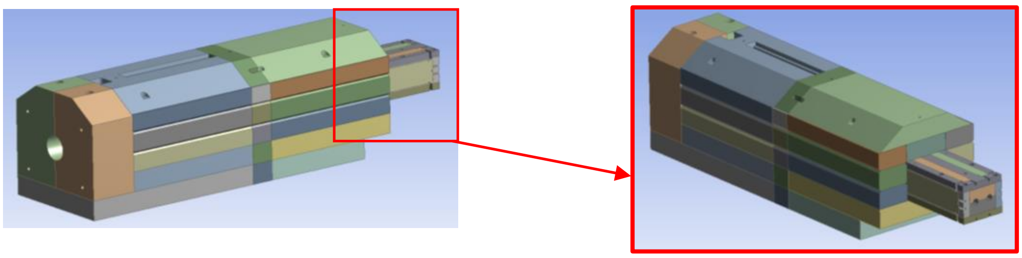

Figure 2 TAXN geometry

Table 1

Summary of mesh parameters applicable to thermal analysis performed on TCDXM D2 Collimator mask

Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	3.4907e-004 m
Statistics	
Nodes	42196
Elements	25203
Mesh Metric	None

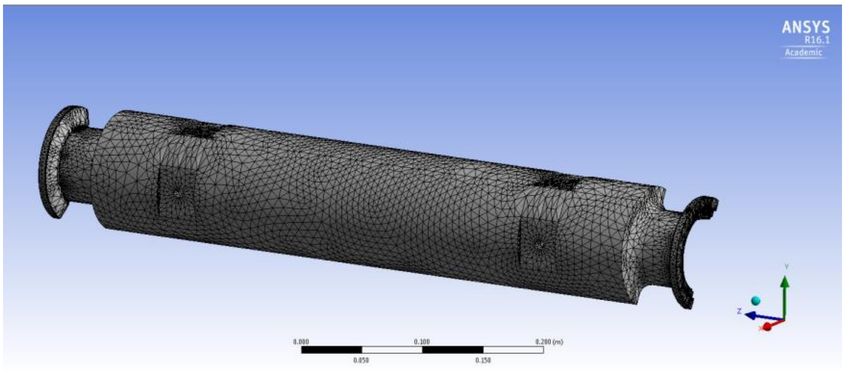

Figure 3: TCDXM D2 Mesh

Next, boundary conditions have been applied as follows:

- Heat deposited by the beam was modelled using Fluka data interpolated and defined as heat generation (see Figure 4). Heat generation data used in this scenario was taken from TAXS that was normalised at 5 L0 luminosity due to the absence of such data for the D2 collimator mask. The total power of the given part is much higher than it is required for the structure of the current study (~800 W for TAXS and 6.3 W for the collimator mask), thus the results obtained within the current study will illustrate a very pessimistic scenario and will have a very high safety margin.
- Convection was applied on the outer boundaries of the TCDXM D2 collimator mask as can be seen in Figure 5. The value for the convection used was 0.1 W/m^2. Such a value is appropriate according to the figure 4 in (Air Pressure Dependence of Natural-Convection, 2010) since the vacuum condition in the LHC is in the order of 10^{-6} mbar according to (CERN, 2015);
- Heat radiation was assumed and applied to the identical outer boundaries of TCDXM D2 mask as the ones that were chosen for convection (see Figure 6). According to the (Infrared services, 2000) emissivity value for commercial copper is 0.07, thus such a value was chosen and used for the current analysis.

Computational models in general contain simplifications and assumptions, which have to be considered for the interpretation of the results. Regarding the model of this project the following uncertainties apply:

- Material properties are fully isotropic;
- Contacts are perfect, fully bonded;
- Thermal expansion is not taken into account for contact surface calculation;

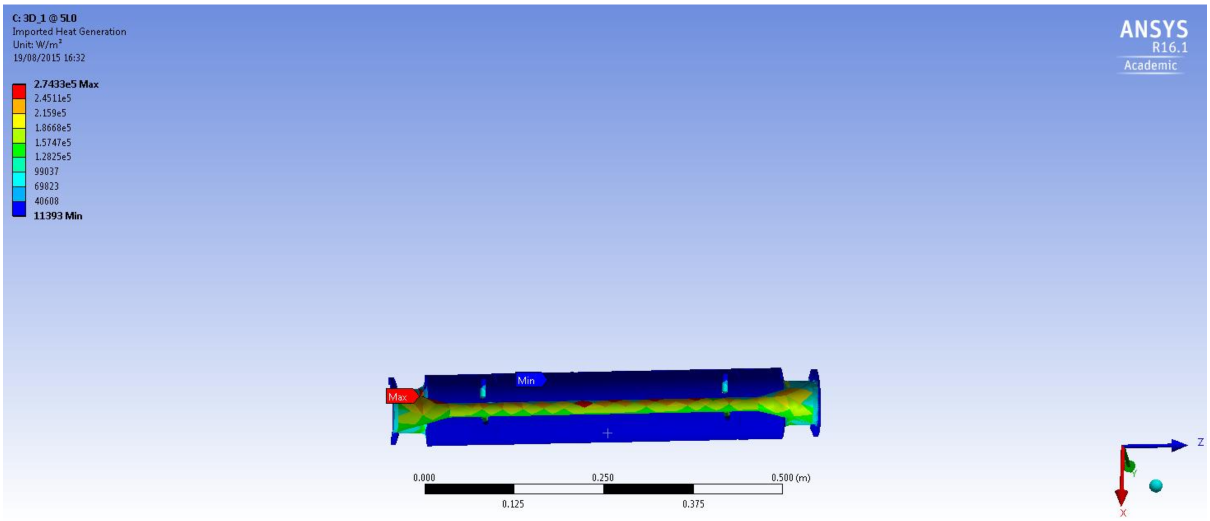

Figure 4 TCDXM Heat deposition at 250 W

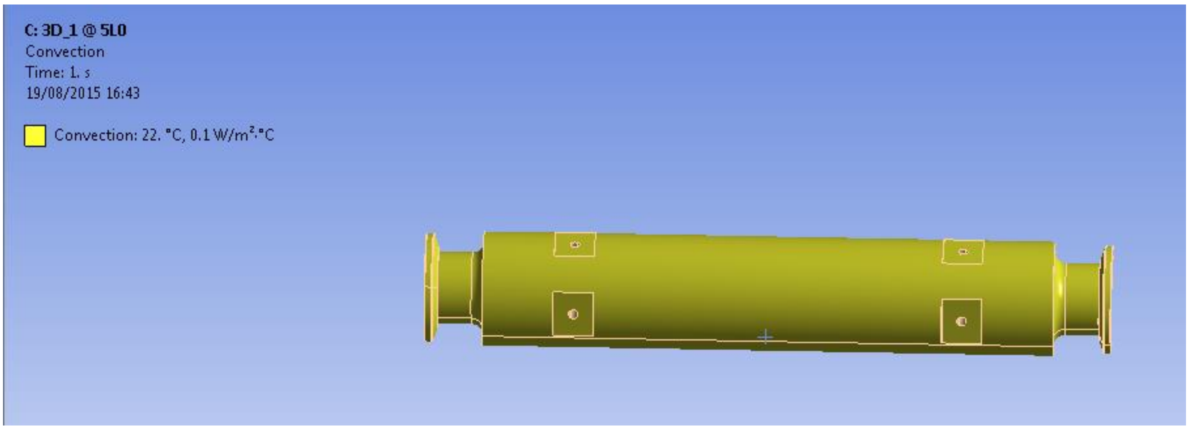

Figure 5 TCDXM D2 collimator mask outer convection.

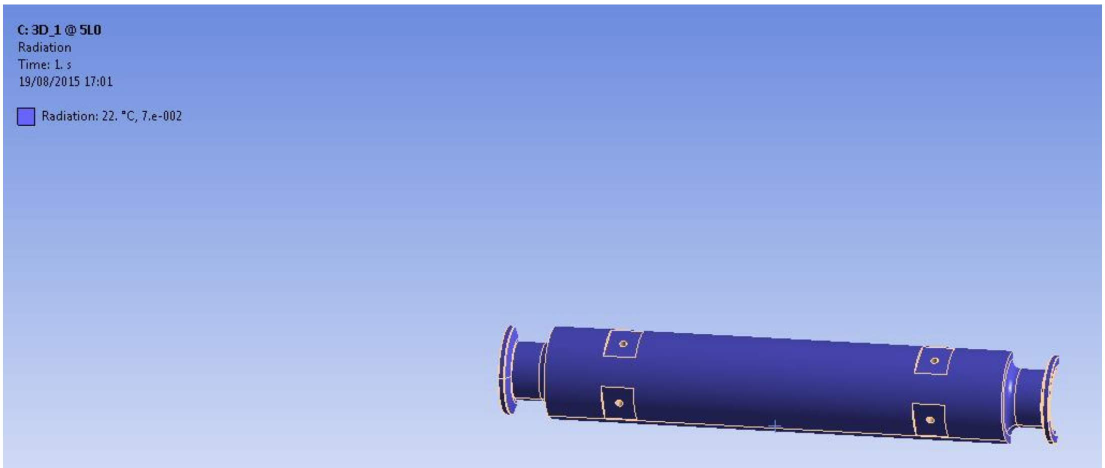

Figure 6 TCDXM D2 collimator mask emissivity faces

With the boundary conditions and assumptions described above the results that is illustrated in Figure 7 was obtained. For D2 collimator mask to conform to the applicable serviceability requirements, it was assumed that the maximum allowable temperature should not be higher than 100 °C. As it can be clearly seen form the results, the temperature variation within the structure is somewhat of ~470 °C till 472.2 °C. Such a level of heating of the structure is not acceptable, thus some possibilities of cooling were considered in the further steps of study.

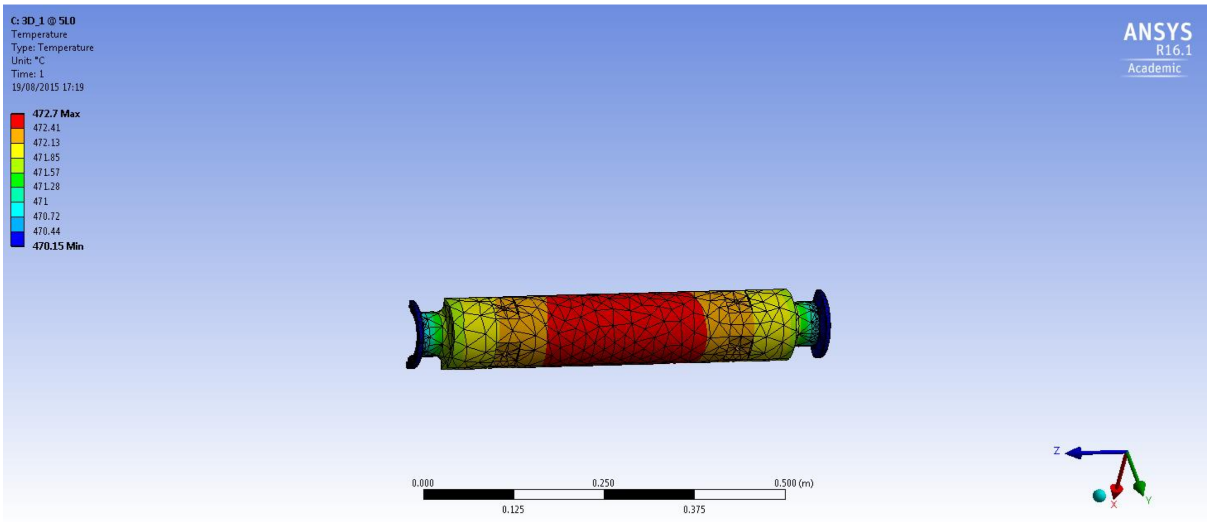

Figure 7 Temperature distribution within the structure of TCDXM D2 collimator mask

Firstly, a cooling collar with the variable width of 25…50 mm was assumed with the water channels going through the collar for the cooling purposes. The effect of the placement of such collar in the middle of the given structure was modelled with the convection value set to 300 w/m^2 on a specified region of the defined width that can be seen in Figure 8. All the other boundary conditions and assumptions are left identical as with the case of no cooling.

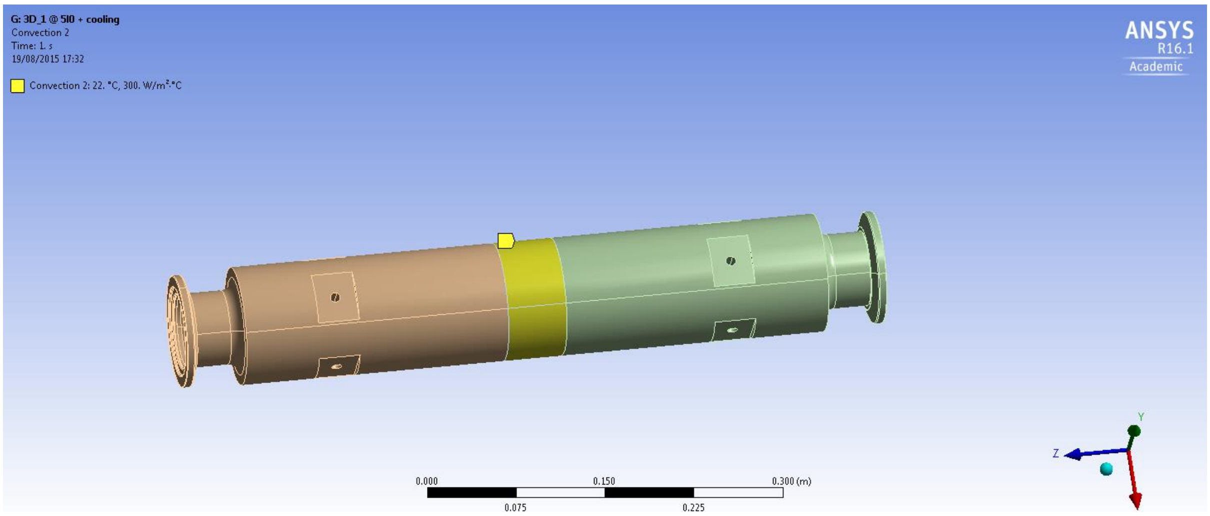

Figure 8 The definition of the defined width of convection region with the value of 300 w/m^2 for the purpose of imitating the effect of cooling collar

The graph of maximum temperature within the structure as a function of the width of the collar was obtained and can be viewed in Figure 9. The result for the width of collar set to 50 mm can be seen in Figure 10. Given that such a temperature still does not conform to the requirement of not exceeding the 100 °C with the maximum width of collar possible, a 2 collar cooling system was simulated (the configuration of such cooling system can be seen in Figure 11). The results of such simulation are given in Figure 12. From these results it can be stated that a system with effective placement of much smaller cooling collars is much more effective than a single collar cooling system, and that 2 collar cooling system can provide the necessary cooling conditions for the total structure to conform to the requirement of not exceeding the 100 °C boundary.

The total ansys interface simulation schematic for the D2 collimator mask is illustrated in Figure 13.

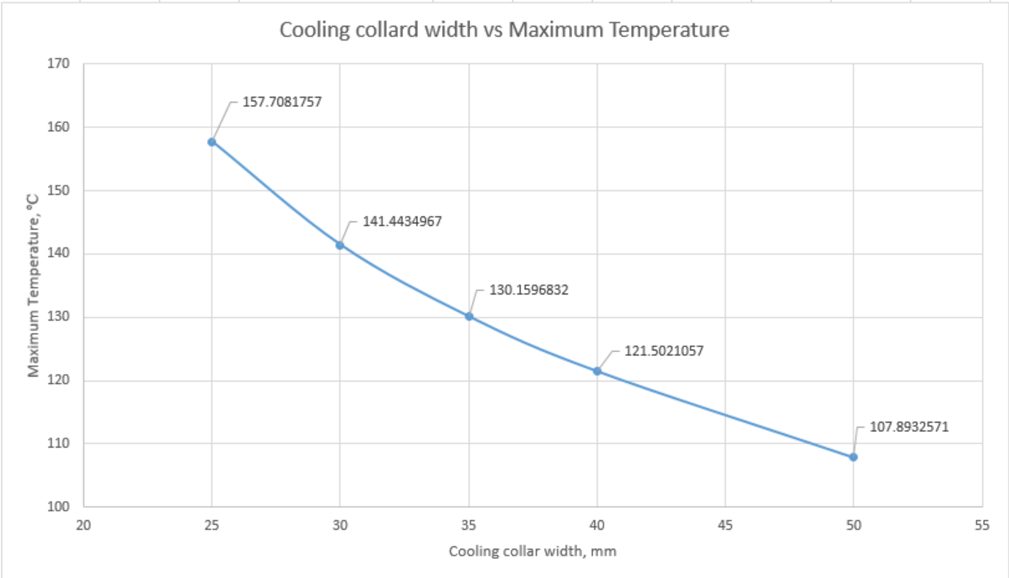

Figure 9 A graph illustrating maximum structure temperature variation with different single collar width values

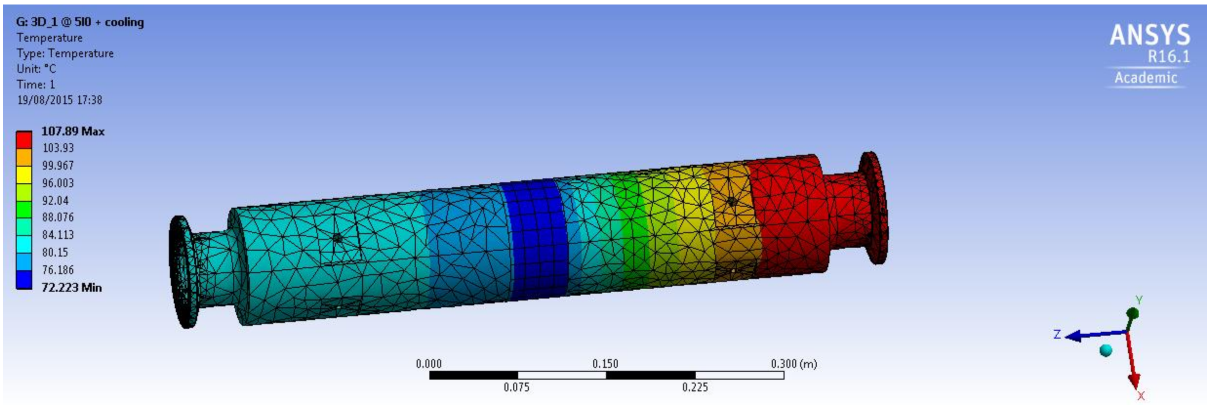

Figure 10 Temperature distribution within the structure of TCDXM D2 collimator mask with the imitated 50 mm wide cooling collar

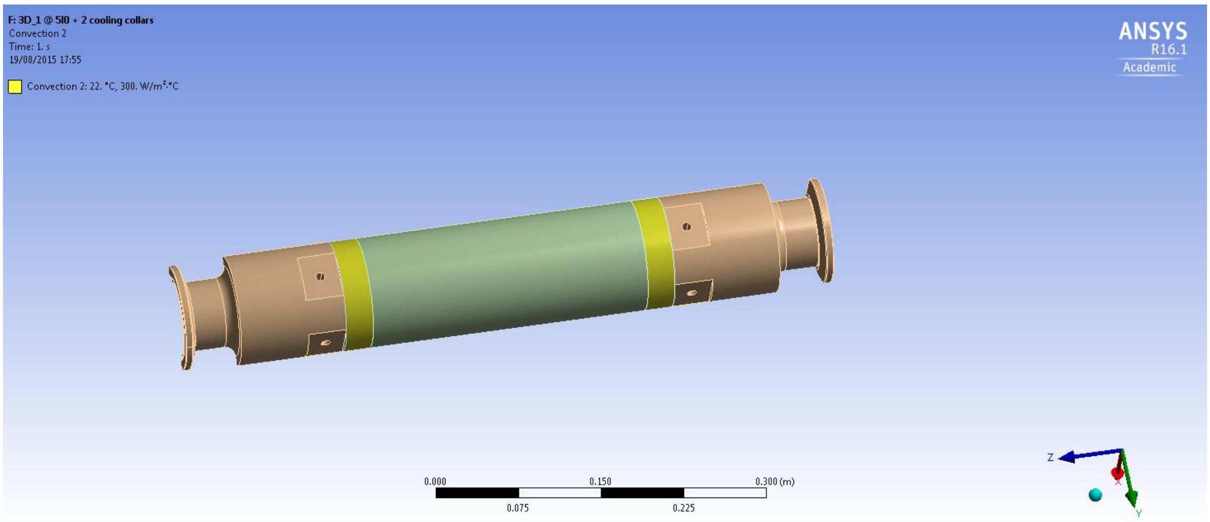

Figure 11 Two 10 mm collar cooling system definition of convection

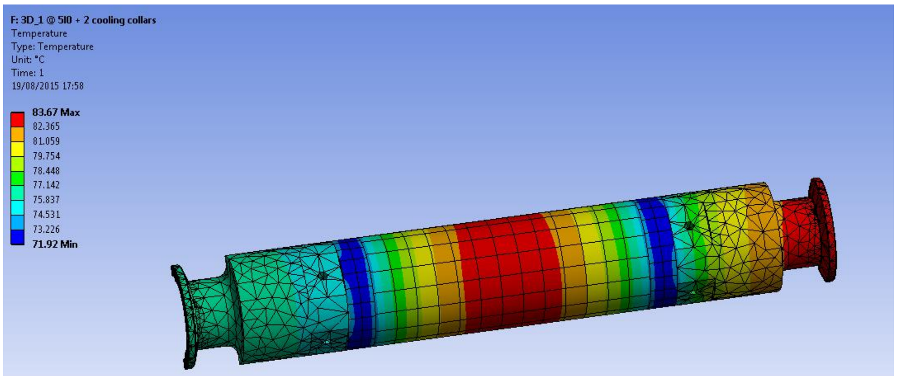

Figure 12 Temperature distribution within the structure of TCDXM D2 collimator mask with the imitated two 10 mm wide collars

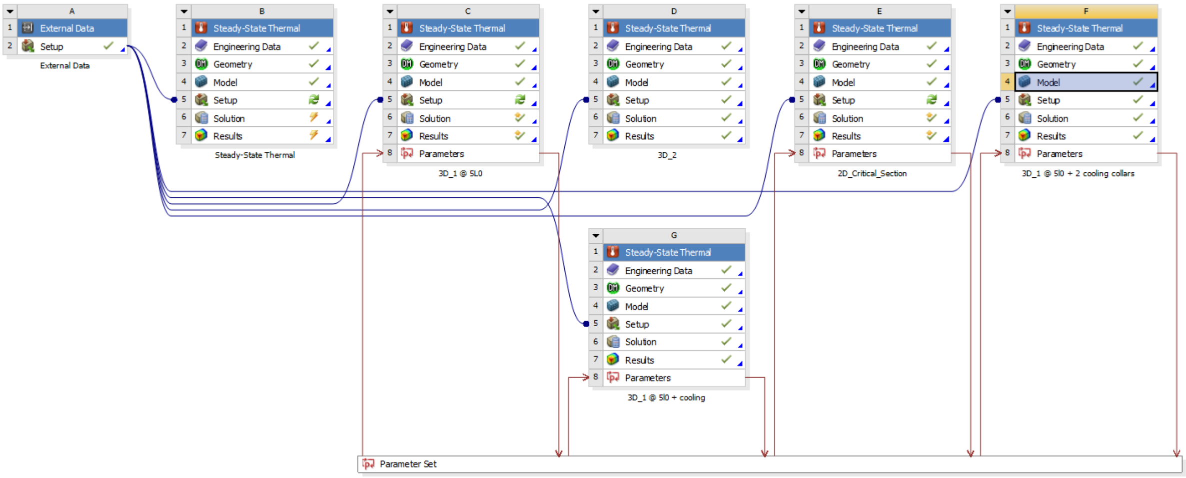

Figure 13 ANSYS interface simulation schematic of the performed simulations for the current study

1.2. TAXN THERMAL ANALYSIS

For the first and simplified set of studies a geometry with no shielding was considered (see Figure 14).

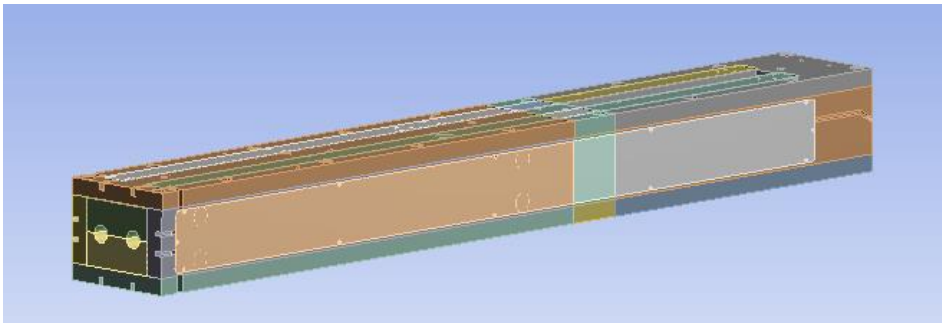

Figure 14 Simplified geometry of TAXN with no shielding

Heat deposition data source is the same as in previous study, but the data is provided only for the critical section of the particle beam. Critical section is the peak heat generation value of the longitudinal profile of the beam, which is illustrated in Figure 15. Such conditions require a following action to be made to successfully implement the given data for the study:

- A critical section must be constantly applied to a given width (given as X in Figure 15) of the structure within a certain interval of structure such that the total power corresponds to 1.8 kW.

The X can be found by applying a random value of heat generation width to the starting point of the critical section and evaluating the total power value as an output.

To initiate the execution of studies the following model parameters were chosen:

- discretization is done by means of finite elements

- Volumetric parts are meshed by solid elements with tetragonal and quadratic shape functions;
- TAXN simulations are performed assuming the core to be either copper or tungsten alloy (Inermet 180) with the conductivity values being 401 and 174 W/(M*C) accordingly; the first layer of shielding to be made from stainless steel with 15.1 W/(M*C) and the second layer of shielding to be structural steel with the thermal conductivity value being 60.5 W/(M*C).

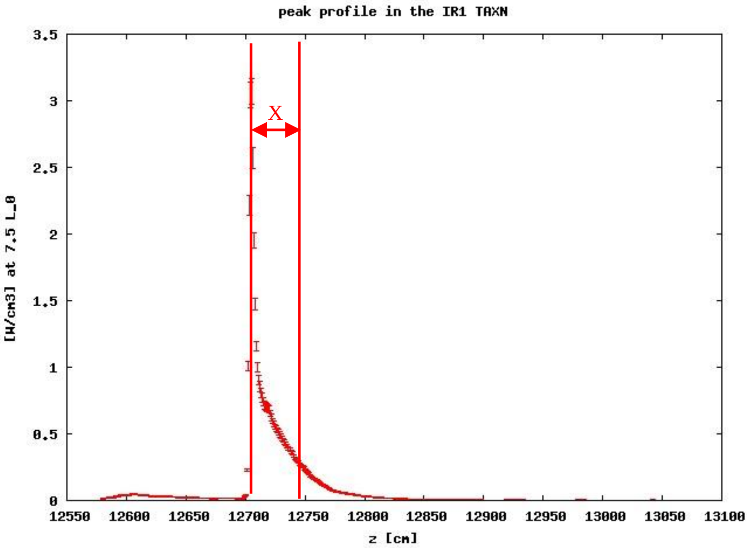

Figure 15 Peak profile of the TR1 TAXN

The applicable Mesh parameters are summarized in the Table 2. The density of the mesh can be seen in Figure 16.

Table 2

Summary of mesh parameters applicable to thermal analysis performed on TAXN

Defaults	
Physics Preference	Mechanical
Relevance	5
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	1.e-002 m
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Medium
Minimum Edge Length	3.2623e-004 m
Statistics	
Nodes	1270449
Elements	710966
Mesh Metric	None

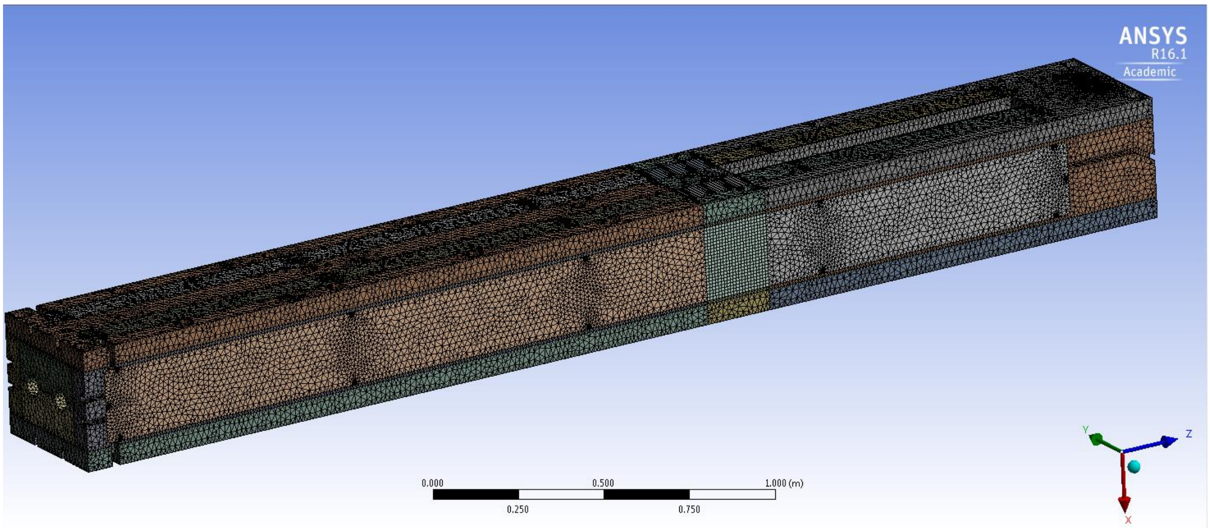

Figure 16 TAXN Mesh