C3Po1F-01 [31]: An update of dynamic thermal-hydraulic simulations of the JT-60SA cryogenic system for preparing plasma operation

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ABSTRACT: The JT-60SA cryogenic system was commissioned in 2016 in closed loop, without the cryogenic users (superconducting magnets, current leads, thermal shields). The first plasma operation is expected in 2020. This paper updates the heat load profiles arriving at the refrigerator and its thermal buffer. The heat load profiles are calculated through thermal-hydraulic simulations of the magnets and the associated cryo-distribution, also named as supercritical helium loops. This update was performed by taking into account new data from the magnets (measured pressure drops, updated heat loads coming from the plasma), as well as a more accurate thermal model of the TF magnet. This paper compares the simulation results with those obtained for the TF coil loop with the Vincenta code in 2010. The latter were used for the cryogenic system acceptance tests. The new thermal-hydraulic model is performed by using Simcryogenics, the modeling tool dedicated to refrigeration and cryo-distribution developed by CEA. The differences between the two simulation results are highlighted and analyzed. These simulations provide the pulsed heat load profiles smoothed by the cryo-distribution and deposited into the thermal damper.

ASSUMPTIONS & UPDATES OF THE MODEL

- **Friction factor:**
  - Previous method: Nicollet-Katheder correlation: $f_D = (19.5/\mathrm{Re}^{0.7953} + 0.0231)/V_f^{0.742}$
  - Correlation from experimental data: $f_D = \alpha + \beta \times Re^{\gamma}$
  - Reduced mass flowrate of 3 g/s due to the higher-than-expected friction factor
- **Heat transfer coefficient:**
  - Previous method: constant values
  - Dittus-Boelter correlation: $Nu = 0.023 \times Re^{0.8} \times Pr^{0.4}$
- **Updated heat load : 14% contingency**

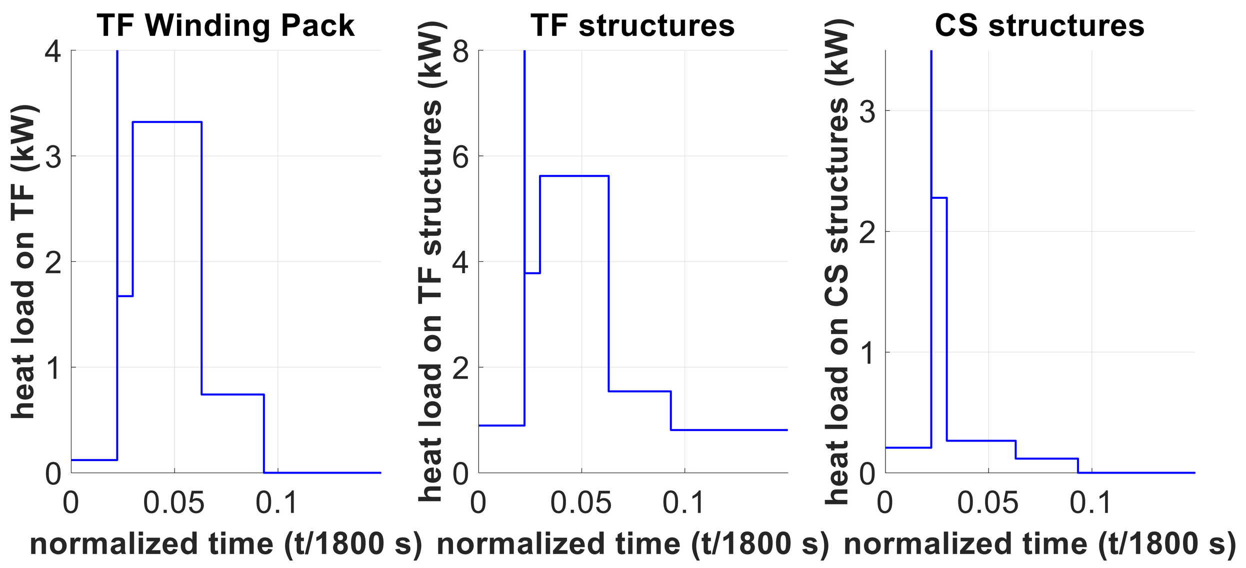

Fig.4: Updated heat load

- **Non-uniformly distributed heat load**

	Turn 1	Turn 2	Turn 3	Turn 4	Turn 5	Turn 6
Distribution	51%	21%	13%	7%	4%	4%

- **Inter-turn thermal coupling**
  - The CICC in one pancake is wound in 6 turns:

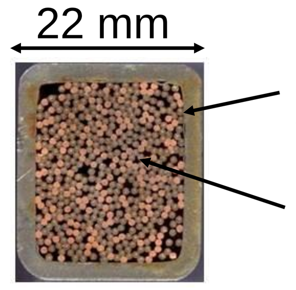

Fig. 5: Cross-section of the CICC (Courtesy of F4E)

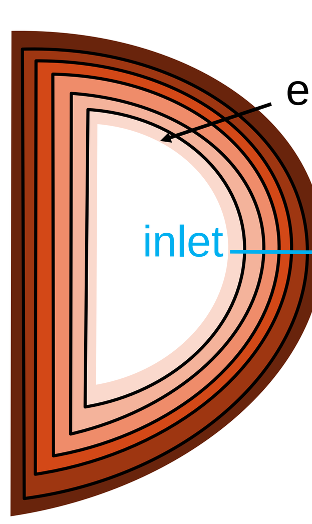

Fig.6: Simplified diagram of one pancake

- Calculation of thermal resistance:

$$R_{it} = 2 * e_{SS}/\lambda_{SS} + e_{GE}/\lambda_{GE}$$

SS: stainless steel / GE: glass-epoxy

- Thermal conductance $tc_{it} \approx 0.7\ W/(m.K)$ (per meter of CICC)

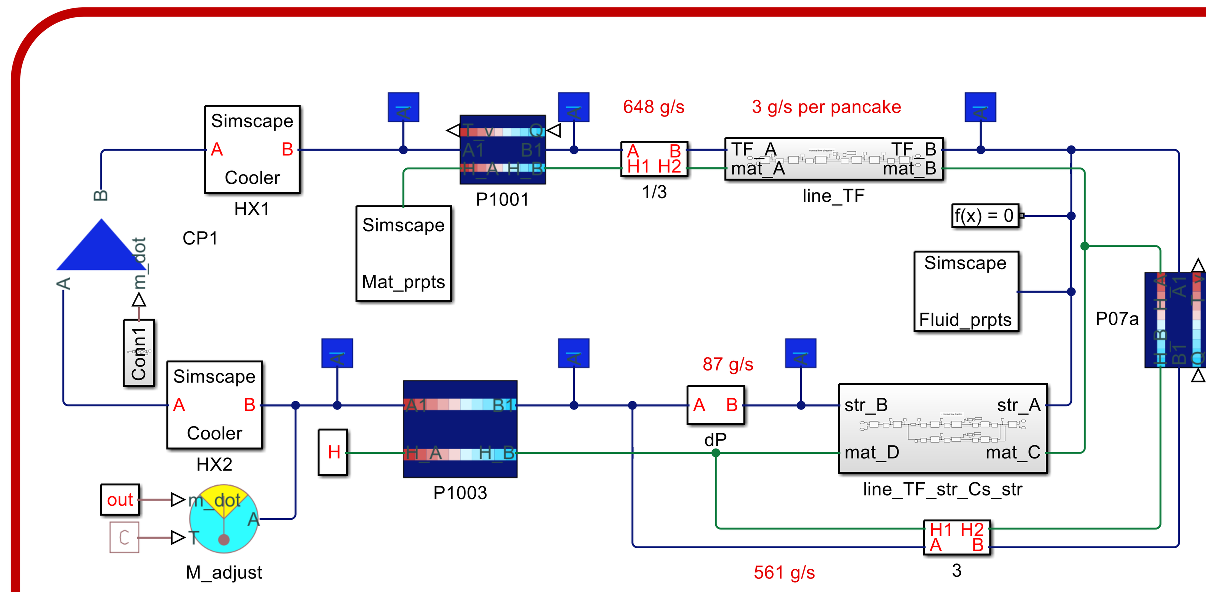

Fig.3: Schematic of the Simcryogenics model

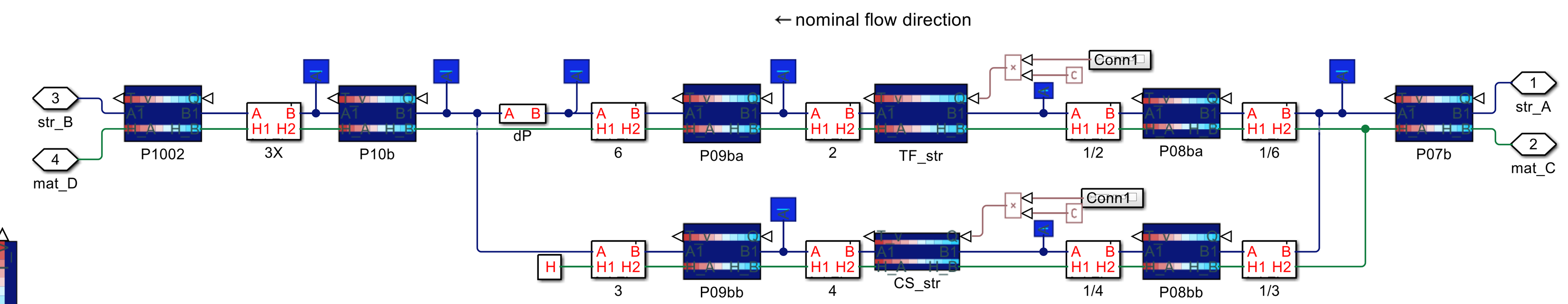

Fig.2: Schematic of the line containing the TF & CS structures

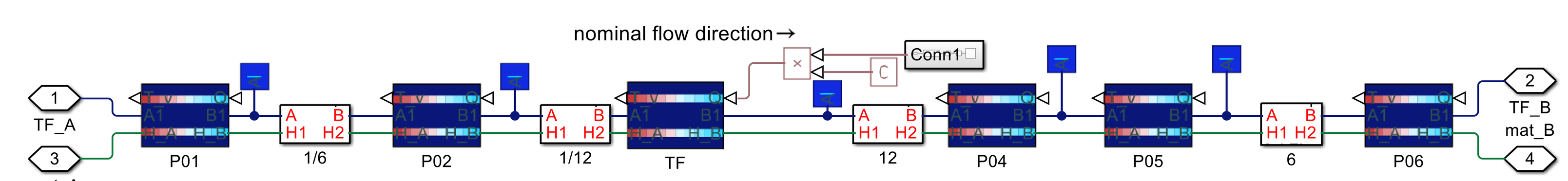

Fig.1: Schematic of the line containing the TF CICC

MODEL OF LOOP 1

- The loop1 is a **supercritical helium loop** designed to cool the 18 **TF coils** and the **TF & CS structures**
- The loop was modelled using the **Simcryogenics library for MATLAB/Simulink**
- 1D pipes were used to model the supply line, return line, TF CICC and TF & CS structures.
- Equivalent parallel channels were only modelled once and then multiplied.

RESULTS

Validation of the inter-turn model

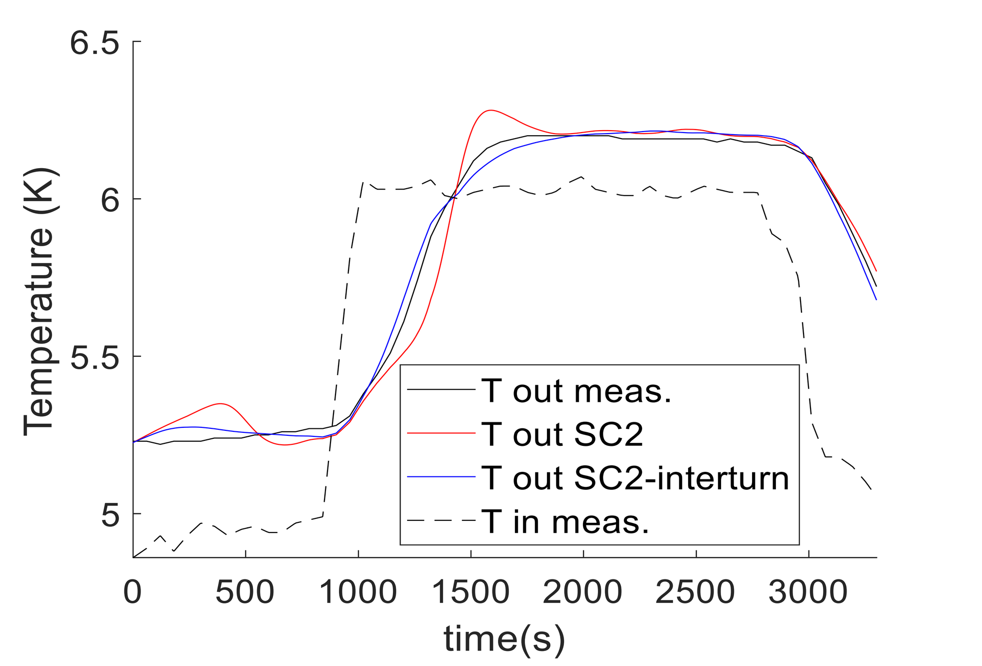

Fig.7: Profile of CICC outlet temperature

Test of TF coils in the Cold Test Facility (described by Abdel Maksoud et al, 2015)

Study of the CICC outlet temperature ($T_{TF,out}$) after a fast increase of inlet temperature

- Comparison between experiment & model
- **The model with inter-turn thermal coupling is more accurate**

Updated model without inter-turn thermal coupling

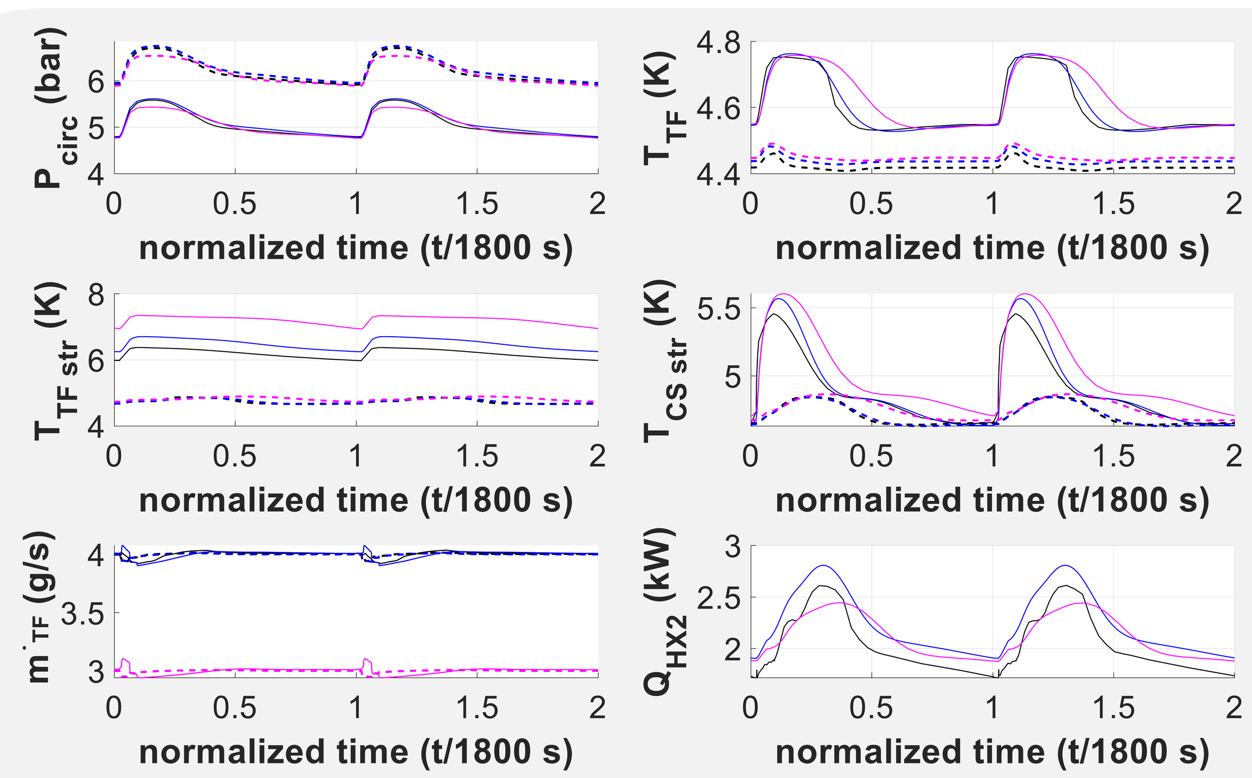

Fig. 8.a: Results after updating the heat load and the friction factor ($\dot{m}$=3g/s)

Updated model with inter-turn thermal coupling

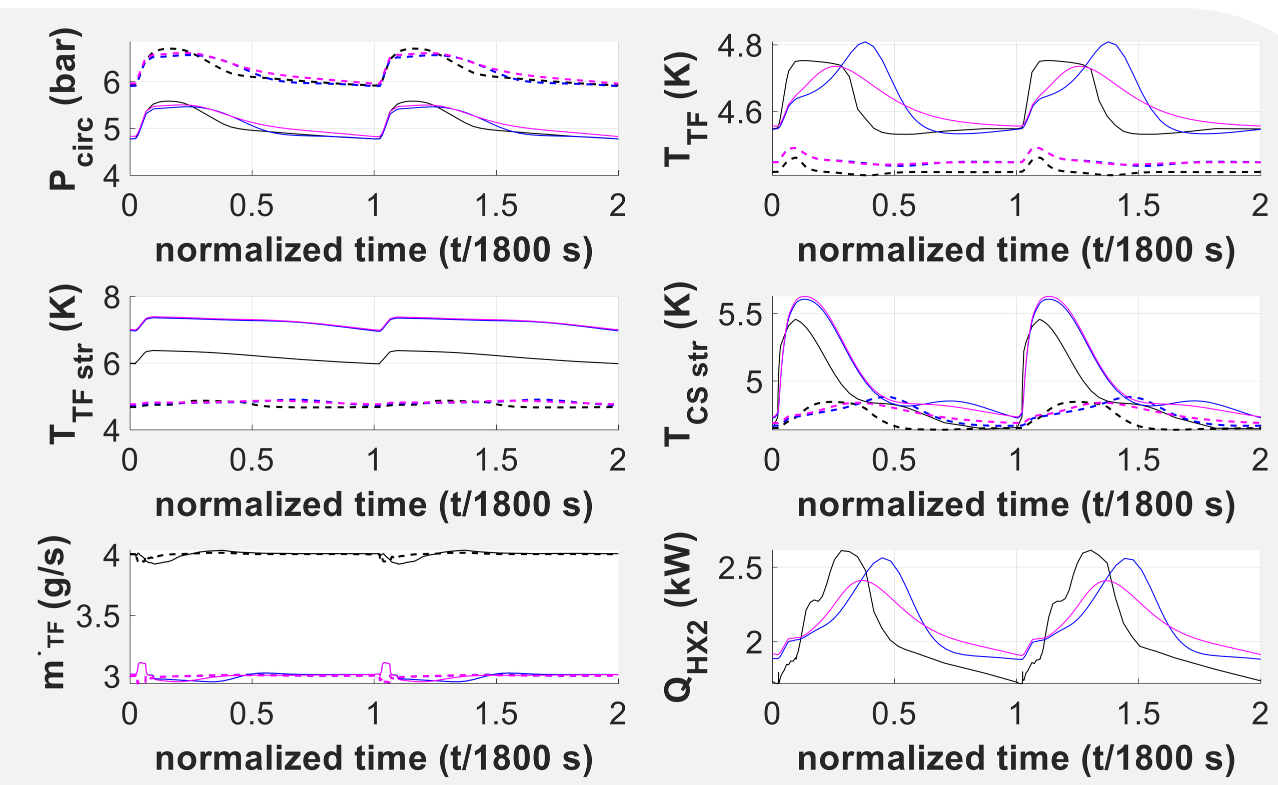

Fig. 8.b: Results after the updates shown in Fig. 8 and considering non-uniformly distributed heat load and inter-turn thermal coupling

Legend: Black: Vincenta model. Dashed line: inlet/solid line: outlet.

Blue: Simcryogenics model with updated heat load (1)
Magenta: (1) with updated heat load & friction factor ($\dot{m}$=3g/s) (2)

Blue: (2) with non-uniformly distributed heat load (3)
Magenta: (3) with inter-turn thermal coupling

Combined update of the heat load and the friction factor ($\dot{m}$=3g/s)

- Increase of the structure temperature
- Decrease of the power received by HX2 (Q_{HX2})
- Longer duration for $T_{TF,out}$ to reach its initial value after a cycle

Non-uniformly distributed heat load is a conservative assumption

- Increase of maximum $T_{TF,out}$ & Q_{HX2}

Smoothing effect of the inter-turn thermal coupling

- Longer duration for $T_{TF\ out}$ to reach its initial value after a pulse
- Decrease of maximum $T_{TF,out}$ & Q_{HX2}

CONCLUSION:

An **updated model of the TF & Structures loop** was built using **Simcryogenics** in order to take into account the latest information related to the manufacturing and testing of TF coils. The effect of the **inter-turn thermal coupling** was found to counterbalance the effect of the **non-uniformly distributed heat load**. The **updated profile of the heat load deposited in the thermal buffer** was **smoother** than that obtained in 2010. The modelling work performed using Simcryogenics can be used for preparing the plasma operation of JT-60SA in the coming years. Similar updates will be performed to simulate **CS & EF coils loop (loop 2)** in the future. The model can be **coupled with the cryogenic system model** and used for testing the **control strategies** related to pulse operation as well as investigating **cool down scenarios.**

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