Simulation of the JT-60SA supercritical helium cooling loops during magnet integrated commissioning using Simcryogenics

François Bonne[1], Louis Zani[2]

1 Univ. Grenoble Alpes, CEA, IRIG, DSBT, 38000 Grenoble, France, Gif-sur-Yvette, France

2 F4E, Broader fusion Development, 85748 Garching, Germany

JT-60SA cryo-magnetic system

Auxiliary cold box overview

The refrigeration of the magnetic system is organized around three superocritical helium loops. Loop 1 and Loop 2 are both working the same way. **Cold circulators** generate approximately **900 g/s** of supercritical helium flow, which is cooled to the bath temperature by **submerged heat exchangers**. This flows refrigerate magnets and their structures and return to the auxiliary cold box, where the heat absorbed from the magnet system is removed again by submerged heat exchangers.

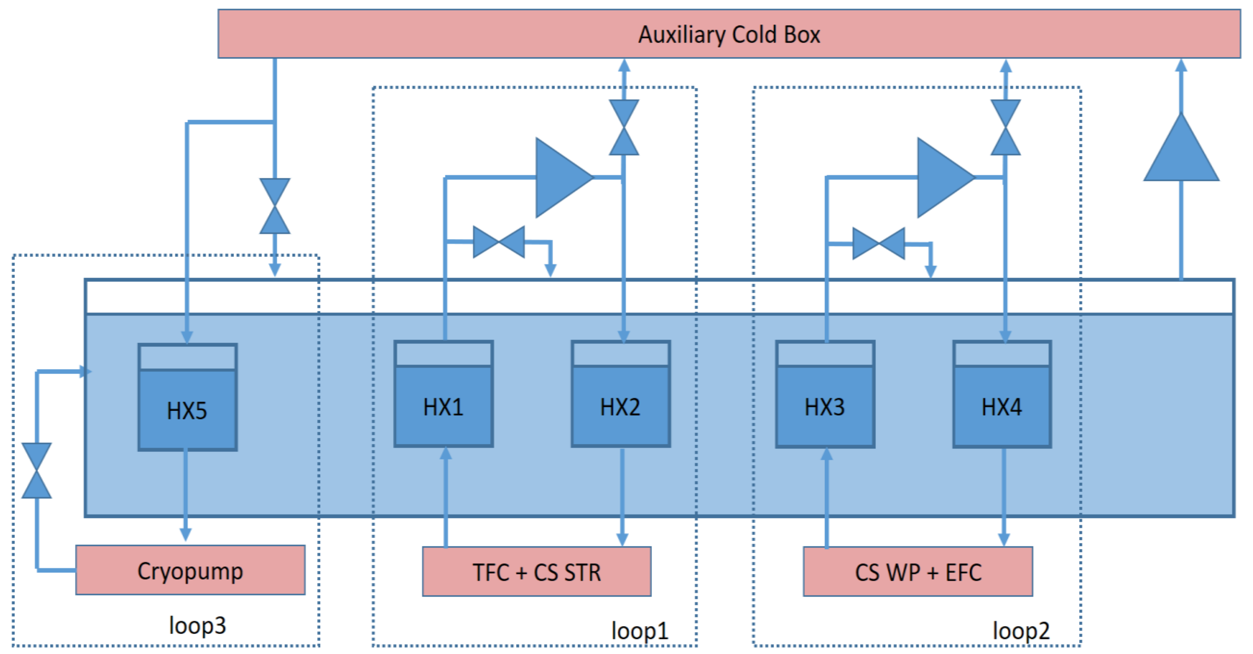

Fig 1 - Auxialiary Cold Box (ACB) overview Loop 1 and Loop 2 are dedicated to the refrigeration of magnets. Loop 3 is dedicated to the cryo-pumps. Pressure into loop1 and loop 2 can be adjusted by their respective charge and discharge valves

Loop 1 overwiew

The loop 1 is a supercritical helium closed loop that is dedicated to supply the **18 Toroidal Field Coils** (TFC) **Winding Pack** (WP) (one TFC WP is composed of **12 pancakes** (CICC) hydraulically in parallel) and the TFC / CS structures, as Fig. 2 sketches it. The total volume of supercritical helium contained into the loop 1 is around five cubic meters (for a mass inventory of around 700 kg). In the model, there is 82 meters of piping (separated into 4 pipes of different length in series, with decreasing cross-section as they approach the magnet) from HX1 to the TFC WP, 50 meters between the TFC WP and the TFC structure (4 pipes in series) and 115 meters from the TFC structure to the HX2 (4 pipes in series).

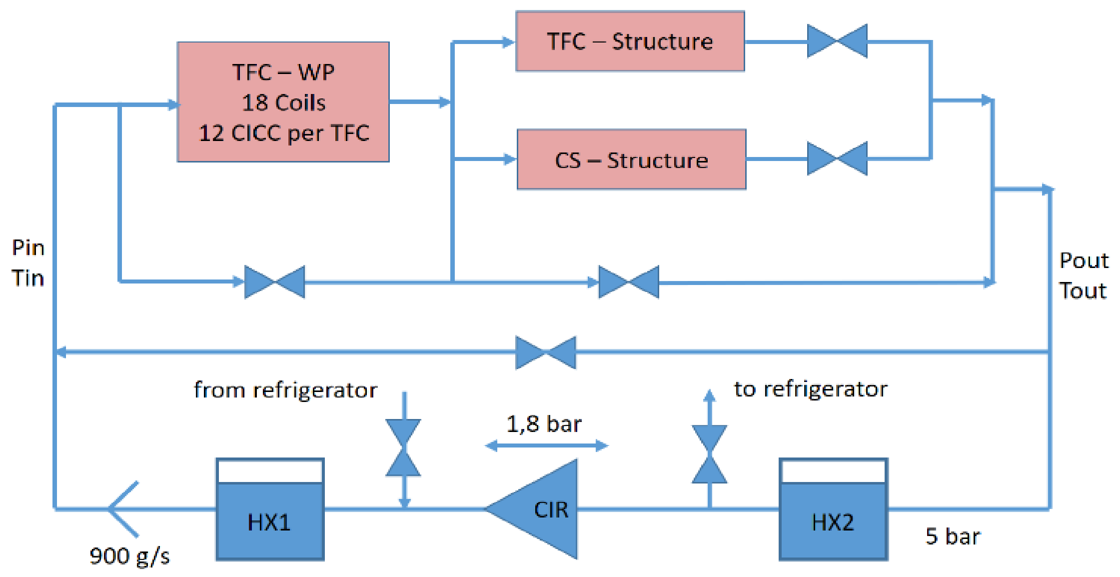

Fig 2 JT-60SA loop 1 overview, CIR stands for circulator, ensuring around 900 g/s supercritical helium flow rate. HX stands for heat exchanger, removing the heat generated by the circulator and coming from the magnets/structures. The heat exchangers are immerged into a liquid buffer helium bath at 4.3 K nominally. Valves allow some of the SHe flow to be bypassed.

Loop 2 overwiew

Loop 2 ensures the refrigeration of the **Central Solenoid** (CS) winding packs (WP) (their structure are refrigerated by Loop 1) and the **Equilibrium Field** (EF) coils. Each of the four CS magnets are composed of 56 pancakes. There are six EFCs, each differing in length and pancakes organization. Figure 3 provides an overview of Loop 2. The loop operates isochorically, but the pressure can be adjusted using the charge and discharge valves. Each of the ten lines in parallel is equipped with a **flowmeter, a temperature and a pressure sensor** at their end.

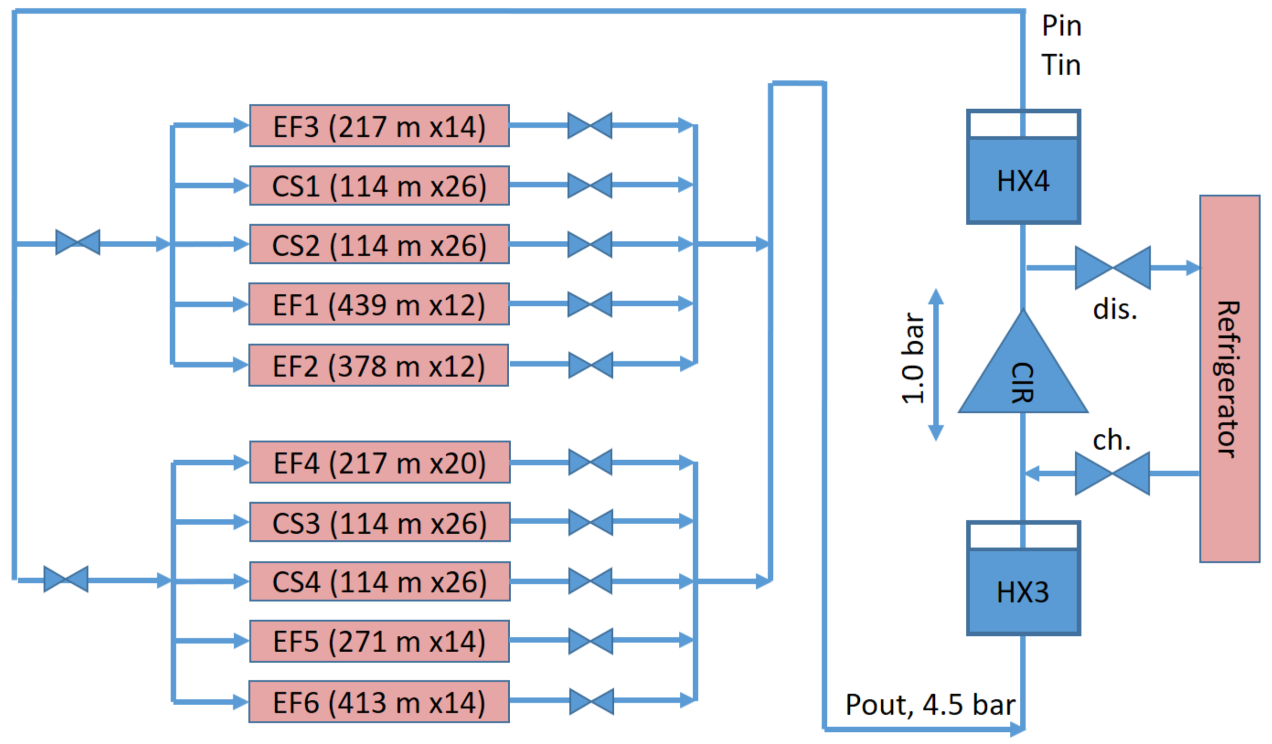

Fig 3 JT-60SA loop 2 overview, CIR stands for circulator, ensuring around 900 g/s supercritical helium flow rate. HX stands for heat exchanger, removing the heat generated by the circulator and that coming from the magnets. The heat exchangers are immerged into a liquid buffer helium bath at 4.3 K nominally. Each control valve at the outlet of each magnet allow the helium flow to be individually controlled.

CICC modelling

The hydraulic part of the magnets (**the Cable-In-Conduit Conductor, CICC**) is modelled with two pipes in parallel, respectively representing the central channel and the bundle, with different characteristics, in thermal contact with each other. They also exchange helium through the central channel's spiral gaps all along their length. The main CICCs characteristics implemented for the modelling of Loop 2 are gathered in Table 1 and 2 and figure 4 illustrates it. The pressure drop is calculated using the Darcy-Weisbach formula.

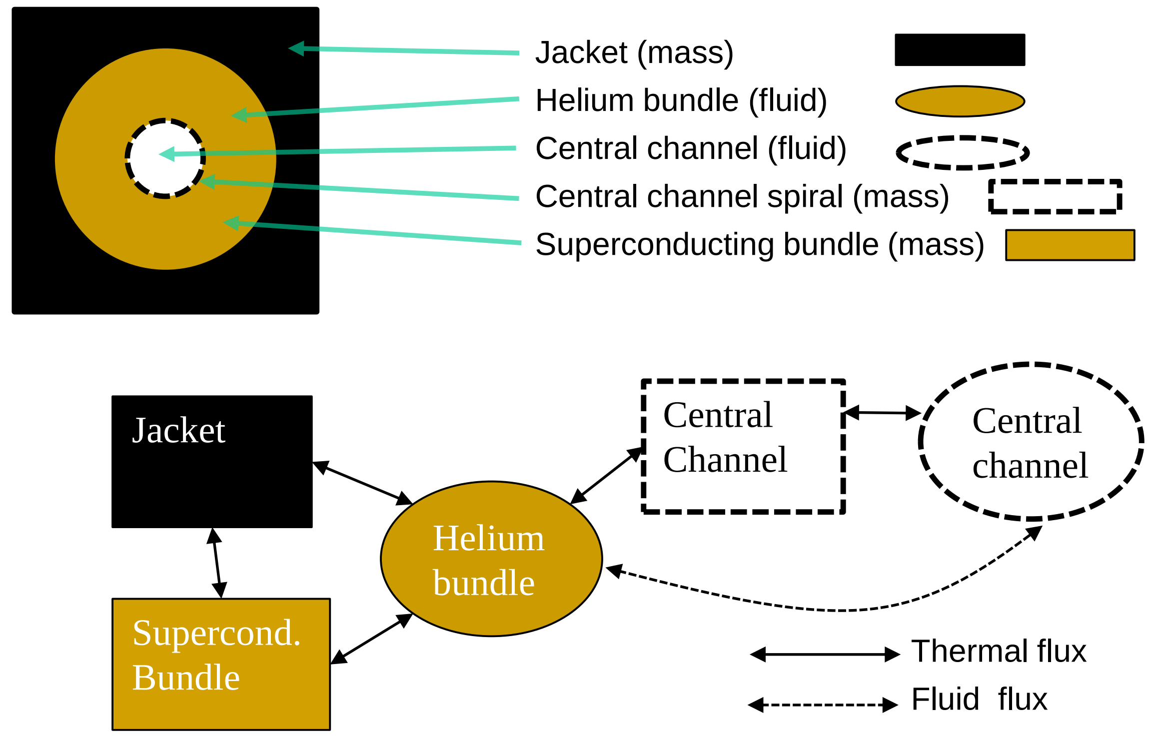

Fig 4. Illustration of the CICC modeling, with its 3 mass, 2 pipes and the interactions with one another.

The friction factor used are :

$$f_{spiral} = 0.42 * Re^{-0.1}$$

$$f_{bundle} = (0.0231 + 19.5 * Re^{-0.7953}) * void^{-0.742}$$

	EF3	CS1	CS2	EF1	EF2	EF4	CS3	CS4	EF5	EF6
Length (m)	217	114	114	439	378	217	114	114	271	413
channels in //	14	26	26	12	12	20	26	26	14	14
CICC Type	EF-H	CS		EF-L		EF-H	CS		EF-L	
Organisation	7 DP	6 OP + 1 QP		12 SP	12 SP	10 DP	6 OP + 1 QP		7 DP	14 SP

CICC Type	Inner size (mm)	Section (mm2)		Wetted perimeter (cm)		Nb of strands (total)	Strand diameter (mm)
		Bundle	CC	Bundle	CC		
EF-H	21.8x21.8	140	63.6	109.2	2.83	450	0.829
EF-L	19.1x19.1	102		80.8		324	
CS	21	96.1		79.0		324	0.82

Table 1 & 2. Hydraulic characteristics of CICCs (1). SP, DP, QP and OP stand for Single, Double, Quad and Octo pancakes. The total number of pancakes of the CS is 52 but the number of channels in parallel is 26. It is because the outlet of one pancake is connected to the inlet of one another.

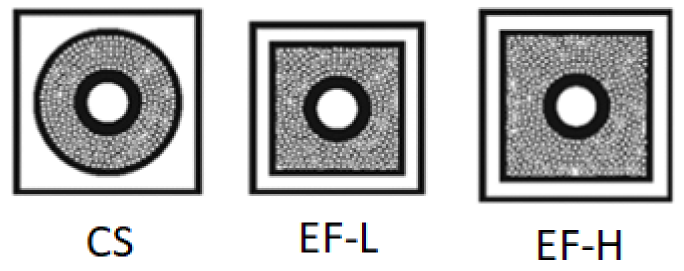

Fig 5. Illustration of the 3 different JT-60SA CICC cross section

Fig 6. Picture of a CICC

Comparison with experimental data

Stationary

A steady state comparison is made to check the consistency of the correlations used to calculated the pressure drop of the magnets. We choose to regulate the valves in simulation in order to generate the same pressure drop than in reality and to compare the resulting flowrate in the magnets, as well as their respective pressure drop. Pressures drops and flowrates are summarized in Table 3.

		EF3	CS1	CS2	EF1	EF2	EF4	CS3	CS4	EF5	EF6
Valve pressure drop (mbars)		699	594	380	41*	59*	619	776	525	610	223
Magnet Flowrate (g/s)	measured	45	110	155	53	66	92	116	168	60	64
	simulated	30	115	179	61	66	87	92	173	53	67
	diff.	15	5	24	8	0	8	24	5	7	3
Magnet pressure difference (mbars)	measured	86	190	404	743	725	293	136	387	301	688
	simulated	65	171	385	755	753	271	114	365	280	667
	diff.	21	21	19	12	28	22	22	22	21	21

Table 3. Comparison of flowrates and pressure drop of the magnets with respect to experimental data. The valve pressure drop is imposed in the simulation to reproduce the one from the experimental data.

Correlations used to simulate the relationship between pressure drop and flow rate for CICC provide comparable results.

Dynamical

The scenario involves two fast safety discharge (FSD) of Loop 1. During the Loop 1 FSD, the pressure and temperature of the thermal buffer increase, causing the pressure in Loop 2 to rise with the temperature of the thermal buffer. Since the behaviour of the thermal buffer is not modelled in this case, the experimental temperature of the bath is directly applied to the bath heat exchangers as an input. The variables of interest in this scenario are the inlet and outlet pressures in the loop.

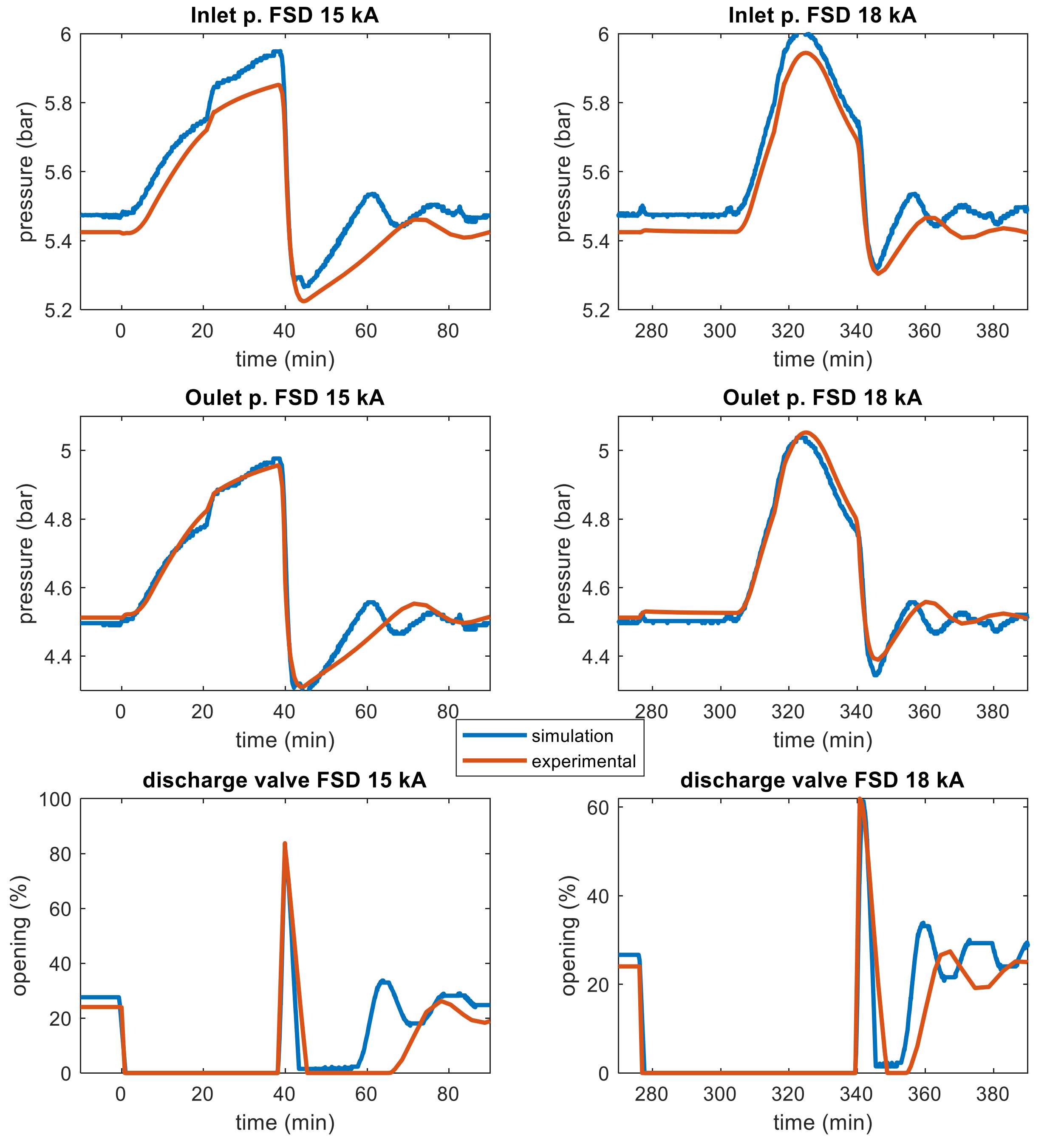

Fig 7. Inlet and outlet pressure of the Loop 2 magnets during the 15 kA and 18 kA FSD. The valve regulates the pressure except when is blocked at 0 (for example during FSD).

We can see that the pressure variation due to the bath temperature rise is captured by the model with some discrepancies. The next step of validation will be to simulate a fast safety discharge of one of the Loop 2 magnet.

Conclusion and future work

The supercritical helium Loops of the JT60-SA cryo-magnetic system has been modelled. Simulation has been performed and the modelling validity has been assessed with experimental data. The next step is to **gather the model that are existing** to create a comprehensive **simulator of the cryo-magnetic system**. This **global simulator** could help off-line to predict the machine behaviour or to train operators off-line, and it could be used on-line to monitor the system. Gathering the 3 models, Loop1, Loop 2 and thermal buffer is going to be our next focus

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research andTraining Programme (Grant Agreement No 101052200 - EUROfusion).