# Dynamic simulation of the ITER helium cryogenic system under pulsed heat loads

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A numerical model of the ITER helium cryogenic system has been developed in order to perform dynamic simulations of the overall ITER cryogenic process during the magnet pulsed heat loads. The model includes one 25 kW @ 4.5 K refrigerator, the distribution system with the cryogenic transfer lines, the cold-compressor box and 4 Auxiliary Cold-Boxes. Different simulations were performed according to an ITER plasma scenario testing different control strategies. Simulation results show the importance of the process control in such a complex system in order to ensure good stability of the overall plant and to save energy.

## INTRODUCTION

ITER is an international project to build an experimental fusion reactor. The helium cryogenic system, which cools the superconducting magnets at 4.5K, is composed of three 25 kW refrigerators. It will be required to sustain significant variation in heat load during the plasma operation. Therefore, a model of the ITER helium cryogenic system is developed in order to better understand the system response to the dynamic heat loads, and to evaluate appropriate control strategies.

## MODELLING OF THE ITER HELIUM CRYOGENIC SYSTEM

The modelling uses EcosimPro and a CERN-developed cryogenic library, discussed in more detail in [1]. The model of the ITER helium cryogenic system is based on the Process Flow Diagram [2] and a conceptual design of a 25 kW refrigerator. The overall EcosimPro model shown in Figure 1 includes 4 main components: (1) a Compression Station (CS1), (2) a Cold Box (CB1), (3) the Cryoplant Termination Cold Box (CTCB) and (4) the Cryo Distribution (CD) which includes the 250m bridge between the cryoplant and the tokamak building, the Cold Compressor Box (CCB) and 4 Auxiliary Cold Boxes (ACB). The Cryo Pump (CP) ACB is not included in the model at this time, because no heat load boundary conditions are available for this subsystem, but its effect has been included in the modelling by including an additional 15% heat load. In addition, only one He refrigerator is modelled, for simplicity.

### Modelling of the Cryo Distribution (CD)

The CD model is shown in Figure 2, based on the ITER PFD schematic [2] and additional details provided in [3]. The transfer lines (C and D) are modelled with 1-D components (based on Euler equations) in order to account for the non-negligible temperature and pressure fluctuations along the 250m-length of the bridge.

The CCB model includes a cold-compressor and a heat exchanger (HX). Since the CCB pressure field is not yet known, the CERN LHC cold-compressor specification has been adapted.

Three ACBs (for the Structure (ST), Toroidal Field (TF), and Central Solenoid (CS)) are connected to the CCB and one ACB (PF) is directly connected to Line D with its own cold-compressor (CCPF), see Figure 2. Each ACB is composed of one phase separator and one helium input valve. Heat is applied to the phase separator in order to simulate a heat load in each ACB, as shown in Figure 2.

The CCB HX and both cold compressors as well as the applied heat loads have all been appropriately scaled (by 40%) to reflect the fact that only one of the three He refrigerators is modelled (=33%), the fact that the Cryo Pump ACB is neglected (+4%) and to add a small margin of error (+3%).

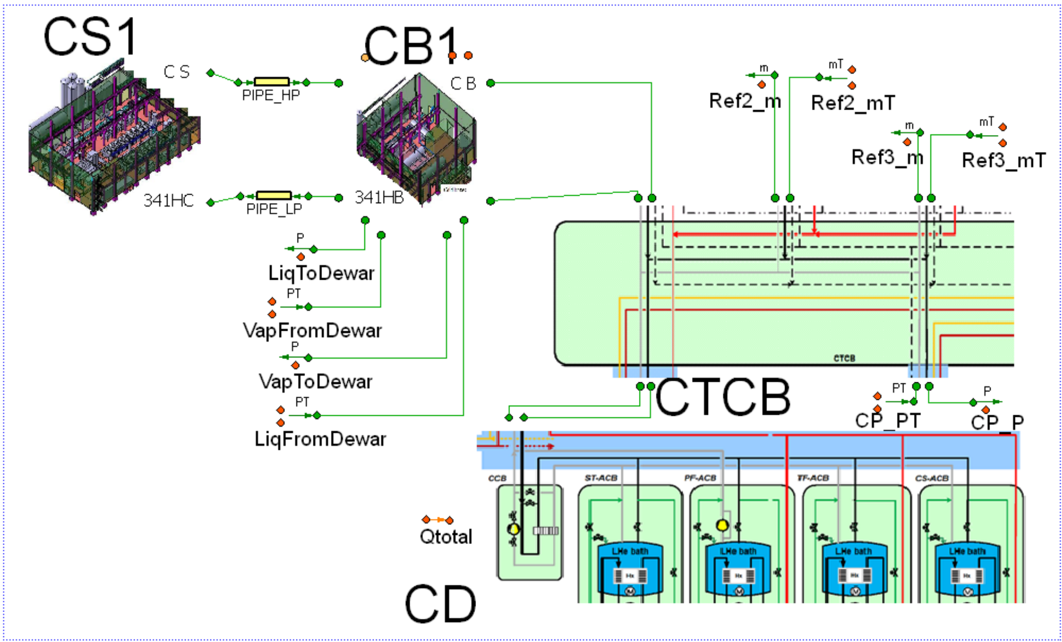

Figure 1  EcosimPro model of the ITER He cryogenic system (with 1 He refrigerator)

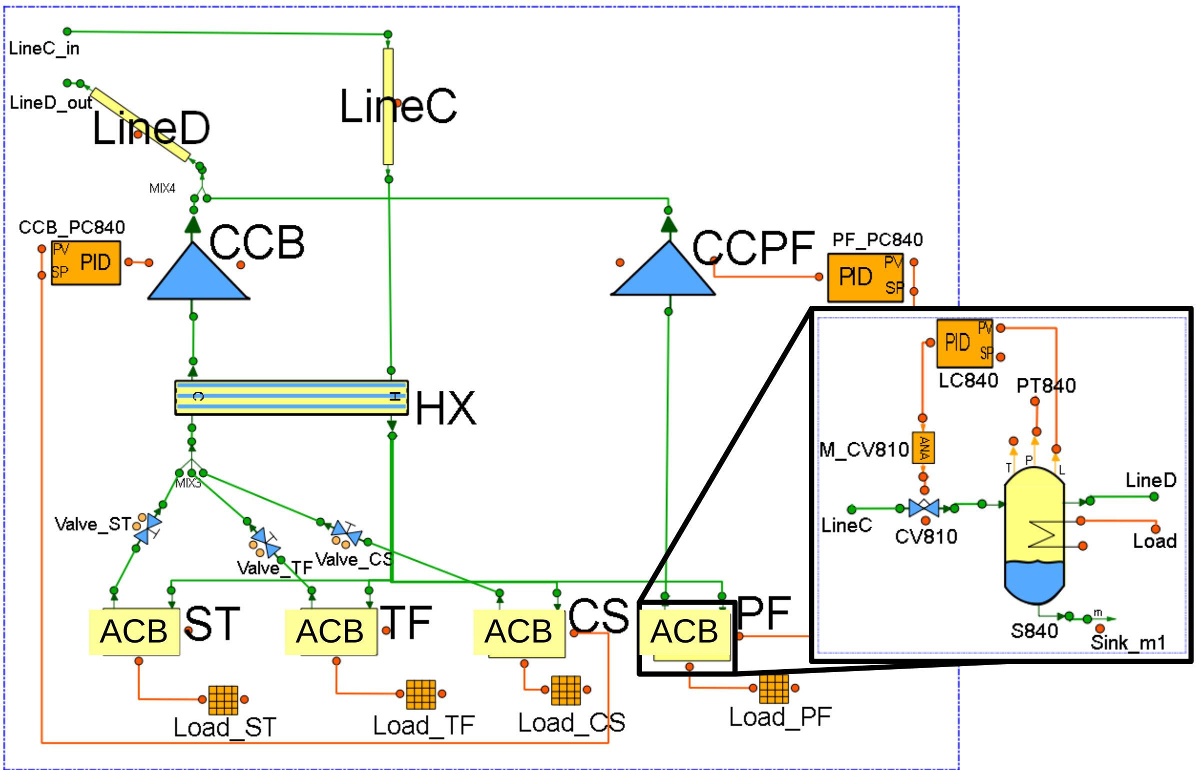

Figure 2  Cryo Distribution model, including CCB, CCPF and 4 ACBs.
NOTE: the dots just show the connections between individual model components.

BOUNDARY CONDITIONS

The following boundary conditions are applied to the model: (1) mass flow to High Temperature Superconductor (HTS) current leads [4], (2) liquid mass flow to Cryo Pumps, (3) heat load profiles applied to each ACB, see below, and (4) external LHe dewar pressure and temperature.

Plasma scenario (Heat Pulses in ACB)
Figure 3 shows 2 cycles of the worst case simulated heat loads applied to the ACBs for the CS, TF, ST and PF, respectively. These curves are based on VINCENTA simulation results [5].

Since the CD model shown in Figure 2 includes each ACB we can apply these loads directly to the appropriate ACB. The loads are applied in a periodic manner, in order to facilitate simulations of a series of pulses.

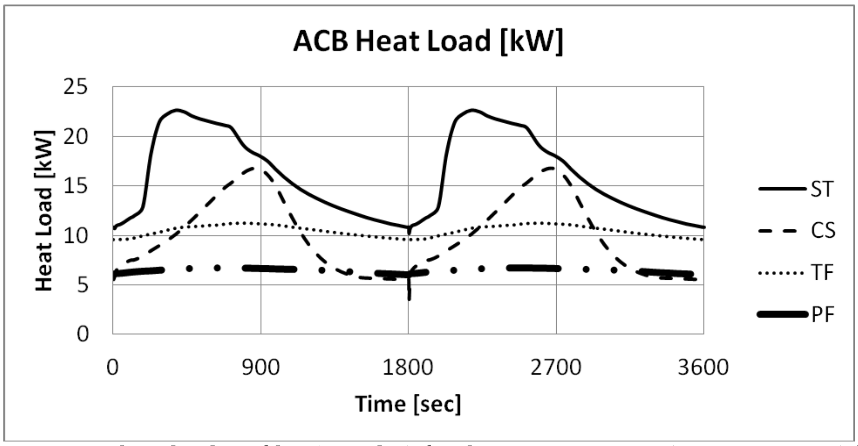

Figure 3 ACB heat load profiles (2 cycles) for the 4 ACB circuits (ST, CS, TF, PF) [5]

## CONTROL STRATEGIES

Different control strategies have been implemented in the cryoplant and in the CD to manage the variation of heat load. All feedback regulation loops are performed by Proportional-Integral (PI) controllers. During the pulses, the sequence is assumed to be known in advance (plasma burn or dwell (recovery)) and a boolean feed-forward signal is used in the control logic to switch between different control options.

Cryoplant
The key regulation loops in the cryoplant are summarized below.

- Two different approaches have been tested to control the High Pressure (HP): (1) control the HP at the maximum value, and (2) set the HP at the maximum value during burn and at a lower value during dwell to reduce power consumption.
- The turbine brake valve controls the turbine speed and the speed set-point varies according to the inlet temperature. The turbine inlet valve is controlled by 2 PI controllers to ensure good inlet pressure and outlet temperature regulation. Finally the turbine set points are varied as a function of the operation state (burn/dwell).
- The flow to the HTS current leads is controlled to the appropriate pressure and temperature conditions [4].
- The Joule-Thompson valve is controlled to regulate the supply pressure in Line C.
- The flow of liquid/gaseous helium to/from the external dewar is controlled by classic feedback regulation loops in order to maintain a level of 70% in the cold box phase separator.

Cryo Distribution (CD)
The Cold-Compressor in the CCB controls its suction pressure at 1 bar. The Cold-Compressor dedicated to the PF-ACB also controls its suction pressure at 1 bar. Finally, the input valve of each ACB controls the liquid level at 70%.

## SIMULATION RESULTS WITH DIFFERENT CONTROL STRATEGIES

The baseline simulation results for a sequence of 5 heat-load pulses are shown in the solid lines (legend #1: Baseline) in Figure 4. In order to reduce the power consumption, the HP control was modified with a floating set-point as a function of the operation state (burn/dwell), see dotted lines (legend #2: Floating HP). This resulted in a net loss of LHe mass in the dewar, so the turbine set point was raised, see dash-dot lines (legend #3: Floating HP+Raised Turbine SP). This resulted in a significant increase in compressor mass flow and power consumption. Therefore, the turbine set point was modified to a lower level, see dashed lines (legend #4: Floating HP+Lower Turbine SP), which resulted in an improvement in power consumption while maintaining the level of LHe in the dewar, with good overall system performance. This study demonstrates the importance of the process control on minimizing energy consumption, while maintaining overall system performance.

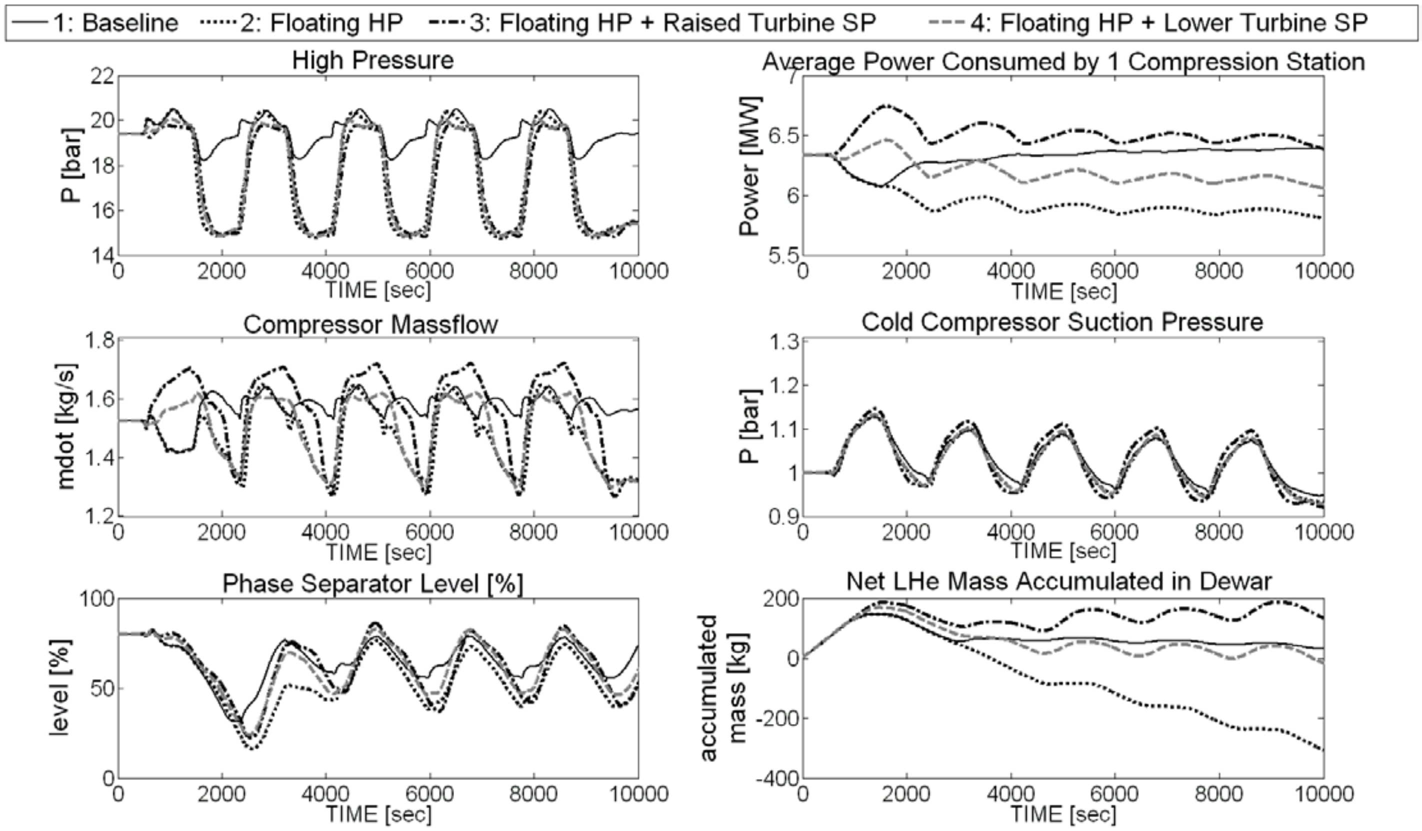

Figure 4 Simulation results for various control strategies

## CONCLUSIONS AND PERSPECTIVES

The dynamic simulation of the ITER helium cryogenic system has demonstrated the ability of the preliminary design to meet the operation requirements. This work will continue with the addition of two more He refrigerators, in order to understand the dynamics of the full system and the interaction between refrigerators. Finally, some additional control strategies will also be evaluated to reduce the amplitude of the pressure oscillations in the ACB.

## ITER DISCLAIMER

The views and opinions expressed herein do not necessarily reflect those of the ITER organization.

## REFERENCES


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