C3Po1A-09 [16]: Simcryogenics: a Library to Simulate and Optimize Cryoplant and Cryodistribution Dynamics

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ABSTRACT

In many fields of engineering, conception and operation teams need to perform simulations in order to design systems fulfilling the user requirements and to operate the systems efficiently. To simulate a cryogenic plant and its distribution to the end-users, a large number of commercial or homemade tools are nowadays available. However, there is a lack of available solutions for quick dynamic simulations for both control with model-based design and design optimization through parametric studies. This article presents the Simcryogenics library that has been developed at the CEA Cryogenic Engineering Department for several years. This library aims at generating model-based control schemes for cryogenic plants that are subject to high disturbances (such as the pulsed heat loads in fusion reactors or particle accelerators). The library is based on Simscape, the modelling language extension of the Matlab/Simulink software suite, which is very flexible and well documented. This paper introduces how Simcryogenics works, how to use it, and it provides examples of applications such as the modelling of warm compression stations and cold boxes, the simulation of the cooling of superconducting magnets and RF cavities, the generation of control schemes, the debugging and validation of the process logic control.

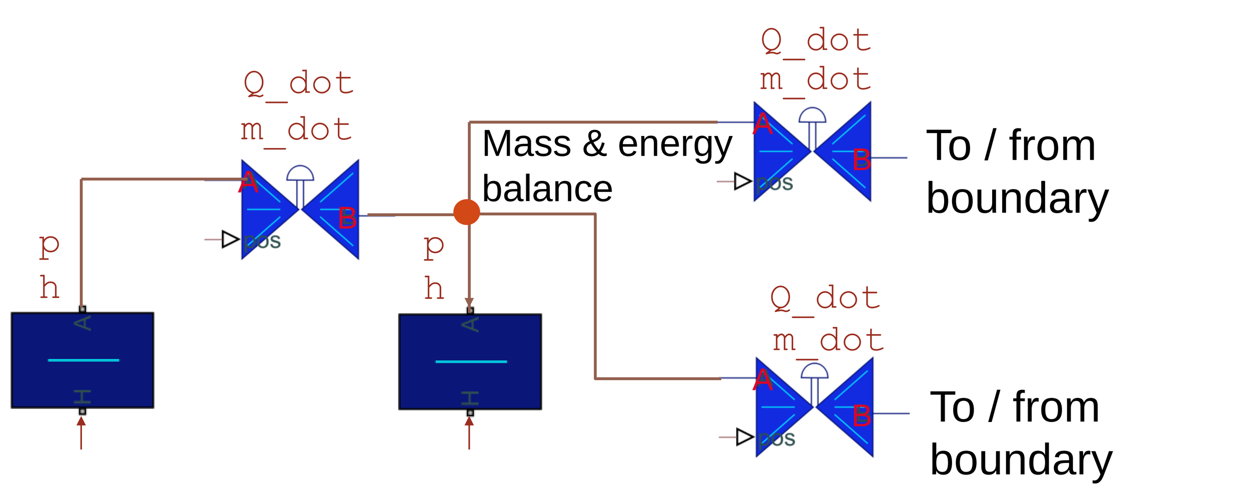
HOW SIMCRYOGENICS WORKS

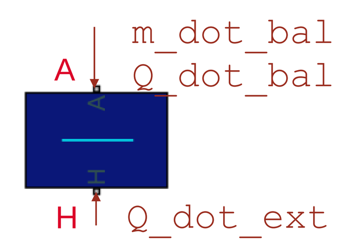
Customized library of components

- Use of the **Simscape** language, the modelling language of **MATLAB/Simulink**
- Library of **1D & 0D components** such as pipes, heat exchangers, phase separators, pumps, turbines, valves
- Include a **fluid domain** (helium, nitrogen, …) and a **material domain** (use data from Hepak, Coolprop, NIST)

Calculations of equations for dynamic modelling

- Mass & energy balance on each node
- Alternating components imposing pressure & specific enthalpy and those imposing mass flowrate & enthalpy flow
- Differential equations for mass & energy balance in the components that imposes pressure & specific enthalpy





Mass balance

$$\dot{\rho} \times Vol = \dot{m}_{balance}$$

Energy balance

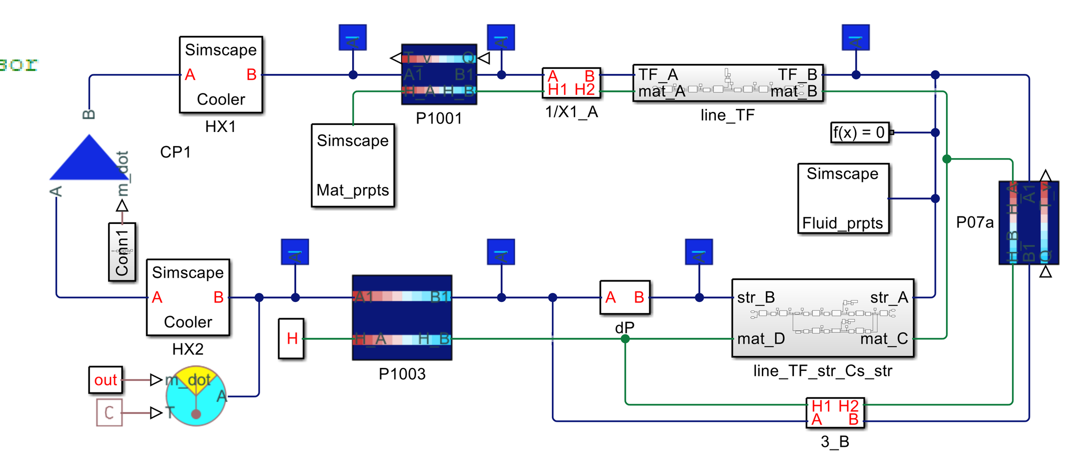
$$(\dot{\rho} \times u + \rho \times \dot{u}) \times Vol = \dot{Q}_{ext} + \dot{Q}_{balance}$$

HOW TO USE SIMCRYOGENICS

Creation of components (optional) ⟹ **Creation of the model on Simulink** ⟹ **Dynamic simulation** ⟹ **Analysis of the results**

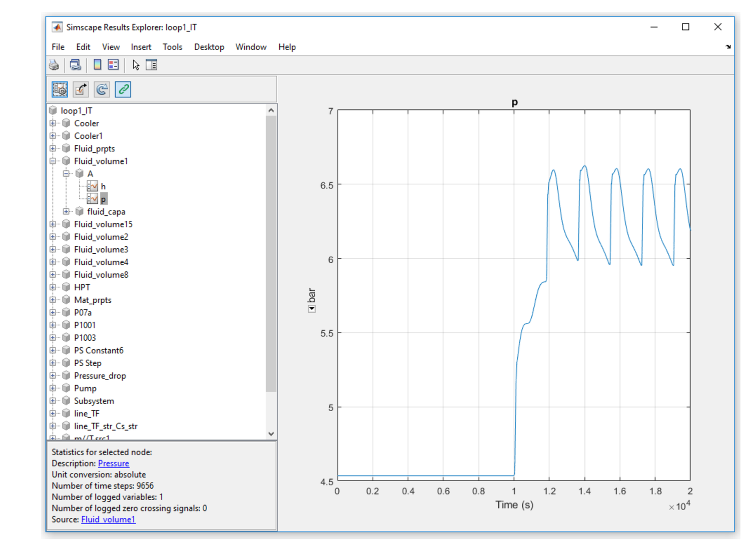
```
component HPT
% HPT
% this component models an enthalpy and/or pressure sensor
%The unit of the output enthalpy is [J/kg]
%The unit of the output pressure is [bar]

% Version 1.0 au 18/01/2019.

    nodes
        A=Simcryogenics.fluid; %A:Right
    end

    outputs
        h    = {1  , 'J/kg'}; % h:Left
        P    = {1  , 'bar'}; % P:Left
    end
```

New components can be coded from existing components or from scratch



Simcryogenics model of JT-60SA loop 1

A model is created by dragging & dropping the components directly from the library and connecting them

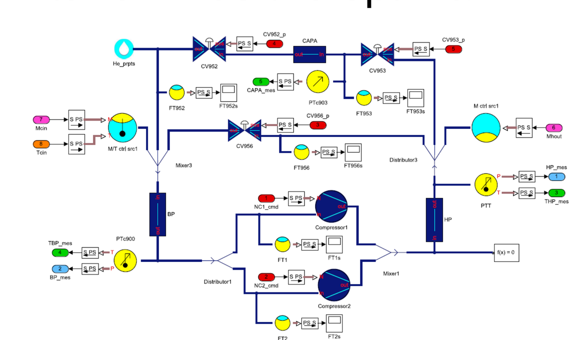


After simulation, every variable is available to the user

CONTROL SCHEMES

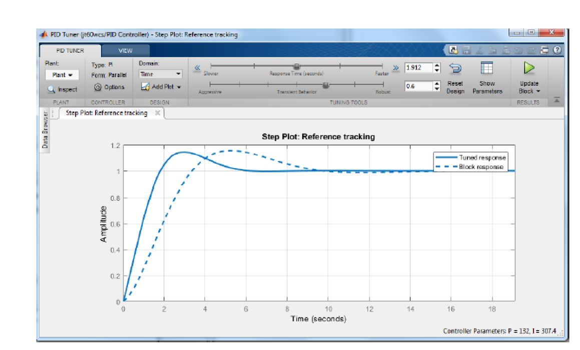
Simcryogenics can be used to derive or validate control schemes : **PI or multivariable**.

To derive a control scheme using Simcryogenics, MATLAB linearizes the model, and a PID tuner finds the optimal PID parameters in order to match the time response criteria.



Warm compression station model

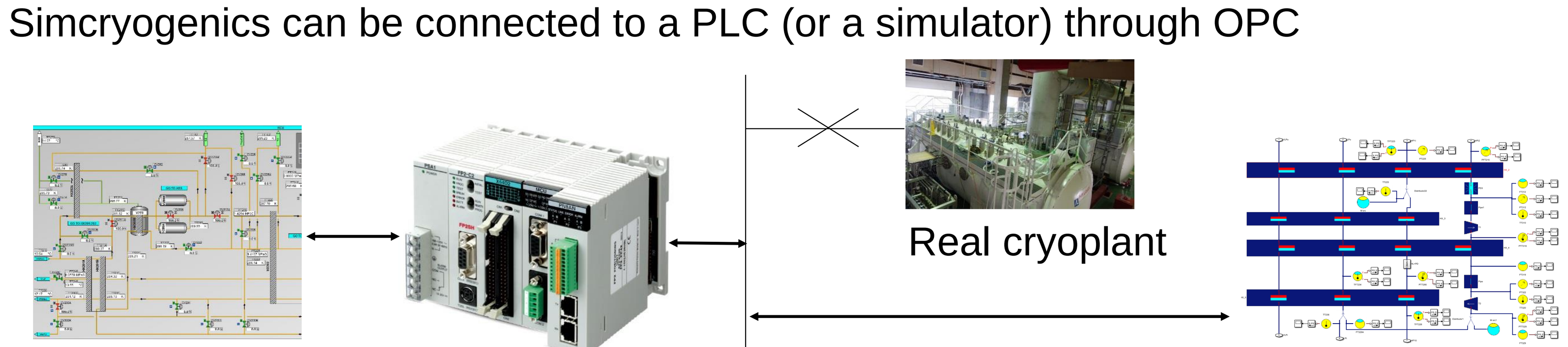
linearization →



PID tuning according to the specified time response

PLC debug and operator training

Simcryogenics can be connected to a PLC (or a simulator) through OPC



CONCLUSION

Simcryogenics is a **multi-purpose simulation library** developed by CEA/dSBT based on **MATLAB/Simulink/Simscape**

- Simulation of steady-state and dynamic operation of cryogenic systems
- **Parameter optimization** (flowrates, temperatures, …)
- **Model-based controller tuning** (PI / PID, or advanced controllers)
- **PLC code debugging** and virtual sensors
- **Operators training** on simulators

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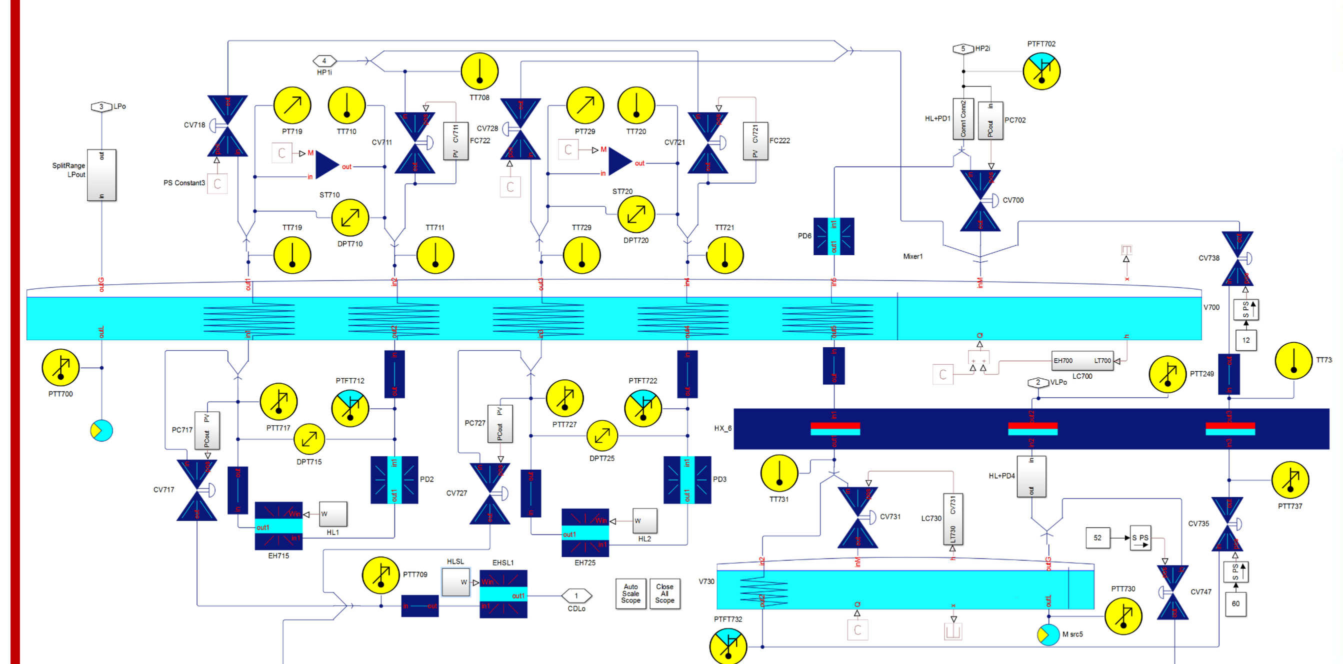
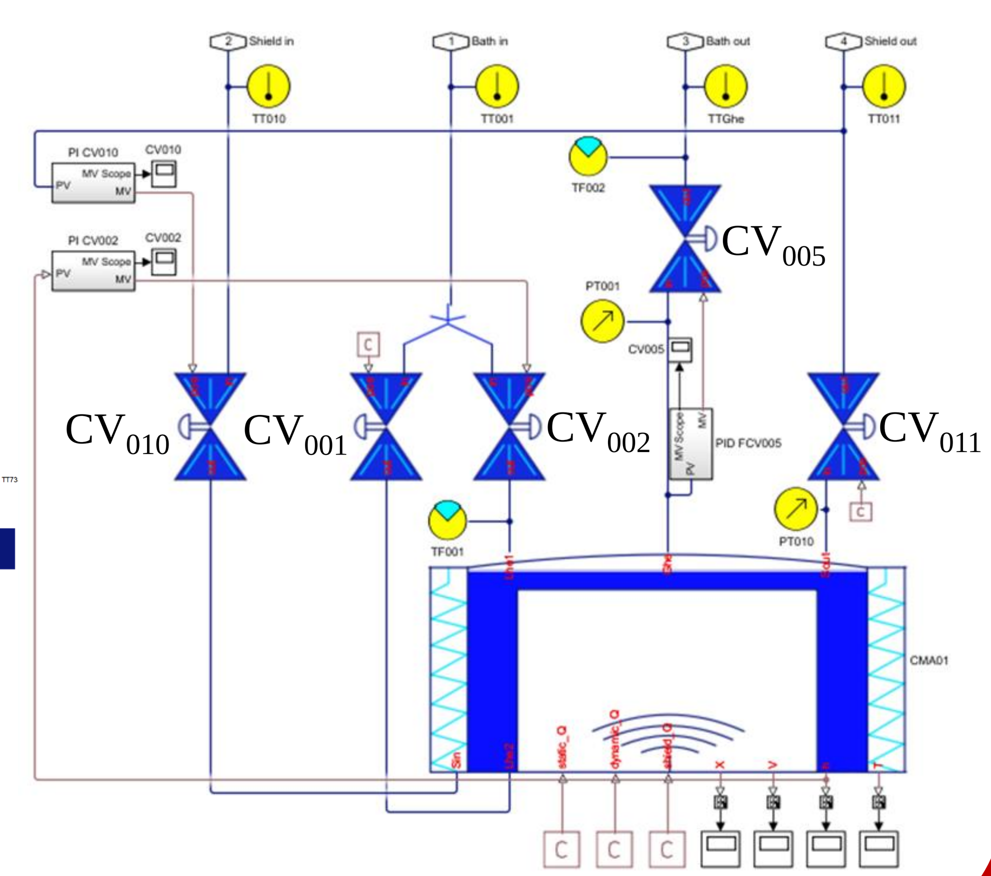
EXAMPLE OF APPLICATIONS

- **Warm compression station** (see the **poster C3Po1A-08 [17]:** Control of Warm Compression Stations Using On-line Model Predictive Control (MPC): Experimental Results)
- **Cooling of superconducting magnets** (see the **poster C3Po1F-01 [31]:** An update of dynamic thermal-hydraulic simulations of the JT-60SA Cryogenic system for preparing plasma operation)
- **Cold boxes**, *e.g.* JT-60SA Auxiliary Cold Box (ACB)
- **RF cavities**, , *e.g.* SPIRAL2 cryomodules



Simcryogenics model of JT-60SA ACB



Simcryogenics model of SPIRAL2 cryomodules