CRYOLIB: a commercial library for modelling and simulation of cryogenic processes with EcosimPro

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A new commercial library called CRYOLIB is now available for the modelling and simulation software EcosimPro. This library comes from the collaboration between the company Empresarios Agrupados and the European Organization for Nuclear Research (CERN). This paper presents the different possibilities to model cryogenic processes using different types of coolant and its applications. This library has already been used for different purposes at CERN such as the control optimisation for helium refrigeration plants, the setup of virtual commissioning of control systems and the development of operator training platforms.

INTRODUCTION

The dynamic behaviours of cryogenic processes are becoming a key point in the main international projects dealing with cryogenics such as particle accelerators, tokamaks or stellarators. More and more, cryogenic systems have to be designed to fit different operation scenarios and ensure good cooling capacities during transients with reduced costs of investment and limited power consumption.

As cryogenic systems are very often unique with specific operation constraints due to the experiments, dynamic simulations are the only way to validate these systems during transients with their control systems and to guarantee behaviours in agreement with specifications.

The European Organization for Nuclear Research (CERN) developed in the last years a cryogenic library in the modelling software Ecosimpro in order to model and simulate the main CERN cryogenic systems such as those of the Large Hadron Collider (LHC) [1]. Based on this experience, CERN decided to perform a technology transfer to Empresarios Agrupados the company who developed EcosimPro in order to improve the cryogenic library and to commercialize it under the name CRYOLIB.

ECOSIMPRO

EcosimPro is a software able to model and simulate dynamic systems represented by differential-algebraic equations (DAE). It is also well adapted to manage different fluids with their thermodynamic properties and the tool provides an object-oriented non-causal approach for creating reusable component libraries. Models are solved by powerful symbolic and numerical methods capable of processing complex systems of DAE to perform dynamic simulation of large-scale systems in acceptable time scales.

Ecosimpro offers a convivial graphical user interface to build and parameterize complex models and allows users to visualize and modify source code of models. Hence, each equation, as for instance the calculation of a friction factor, is easily accessible and can be modified according to user requirements. In the same way, new component models can be easily derived from existing ones. Another interesting feature of Ecosimpro is the exportation of a model in a C++ class. It allows users to integrate their models in larger standalone applications which can be then connected to other systems as for instance a control system driving the model.

The typical workflow to perform a simulation is the following: First, the system to model is built in a graphical user interface by drag and drops of components from existing libraries and components are linked together according to the fluid flows. Second, each component is parameterized according to the system (e.g. Kv of a valve). Third, boundary conditions of the model have to be chosen. To do this, Ecosimpro proposes some boundaries in a wizard where users can modify them as desired (e.g. input pressure and temperature of an infinite helium source). User has then to specify values of boundary conditions during the simulation and setup a simulation scenario (e.g. Open a valve after 30s, start a regulation after 1 min, apply a load of 100W after 2 hr etc.). Finally, the simulation can be executed for a given time to plot and store simulation results. Note that this last step does not require any specific knowledge in numerical solvers.

CRYOLIB: A CRYOGENIC LIBRARY FOR ECOSIMPRO

Capabilities and main components

CRYOLIB has been developed to allow users to perform dynamic simulations of cryogenic processes such as helium refrigerators or liquefiers. The aim of the library is to facilitate the modelling of cryogenic systems by mean of a set of classic cryogenic equipments modelled in a 0-D or 1-D approach. The library offers the possibility to use different cryogenic fluids (helium, nitrogen, hydrogen, Argon and Xenon) and take into account the main fluid mechanics and thermodynamic phenomena driving cryogenic processes. Main material properties as stainless steel 304L or Aluminium T6 are also available on wide temperature ranges. Component models are essentially based on mass, momentum and energy balances performed between input and output ports. The library is constituted by around 45 components classified in five categories represented in Figure1:

- **Hydraulic components**: compute mass-flows as a function of pressure drops and the accumulation of mass in these components is neglected: Control valve, On/Off valve, screw compressor, turbine, cold compressor, pump.
- **Storage components**: compute an internal pressure as a function of input and output mass flows and have a thermal inertia: pipe, adsorber, tank, phase separator, phase separator integrating a heat exchanger in the bath, 1-D transfer line.
- **Heat Exchangers** (HX): perform an energetic balance between different 1-D streams (parallel flow or counter flow) and have a thermal inertia and a pressure drop.
- **Instrumentation**: basic analogical and digital cryogenic instrumentation: temperature sensor, pressure sensor, flow meter, level sensor, pressure switch, temperature switch, level switch.
- **Sources and Sinks**: Ideal sources and sinks to force boundary conditions: input pressure/temperature, input mass flow/temperature, output pressure, output mass flow.

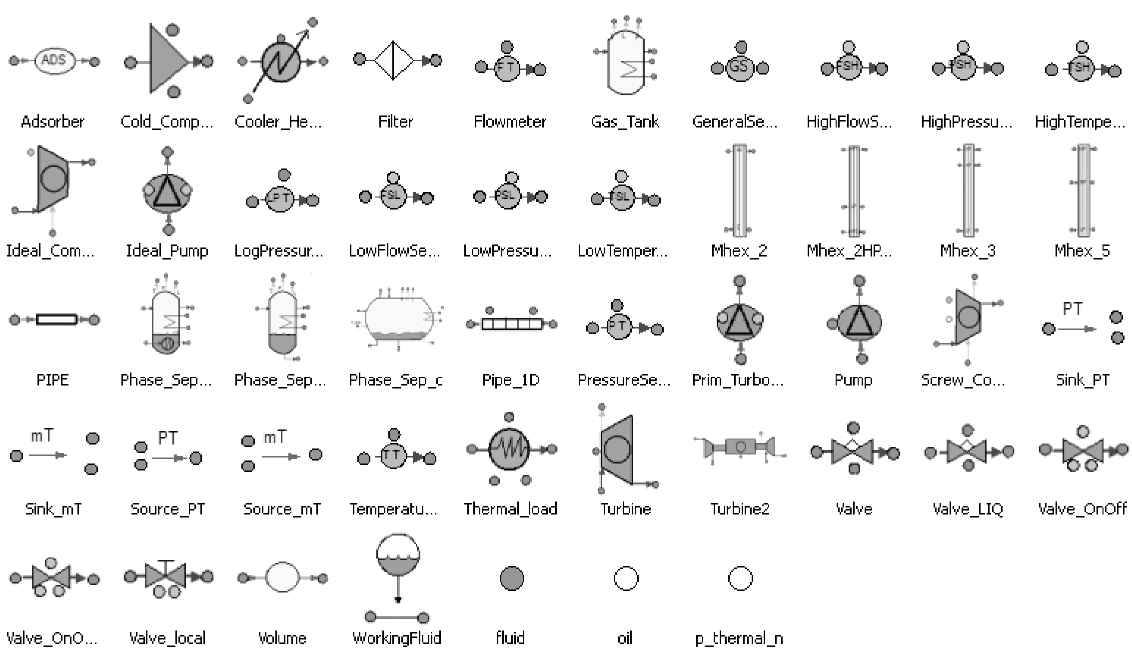

Figure 1 Palette of cryogenic components in CRYOLIB

Use case on a 300 W helium refrigerator

CRYOLIB is provided with a use case on a 300 W helium refrigerator at 4.5 K. The compression station is constituted by 1 compressor, several pipes and 5 valves. The cold-box is composed by 2 turbines, 4 heat exchangers, 8 valves and one phase separator, see Figure 2 where the cold-box schematic is represented under Ecosimpro. Note that the different regulation loops using PI controllers (Proportional-Integral) are also embedded inside the model in order to simulate the regulations.

Simulation results during a cool-down of the refrigerator and the dynamic responses face to a heat pulse of 200W are depicted in the Figure 3. The simulation of 20 hours of simulation took around 8 minutes on a desktop computer of 2.8 GHz for this model embedding 3 000 algebraic equations and 220 differential equations.

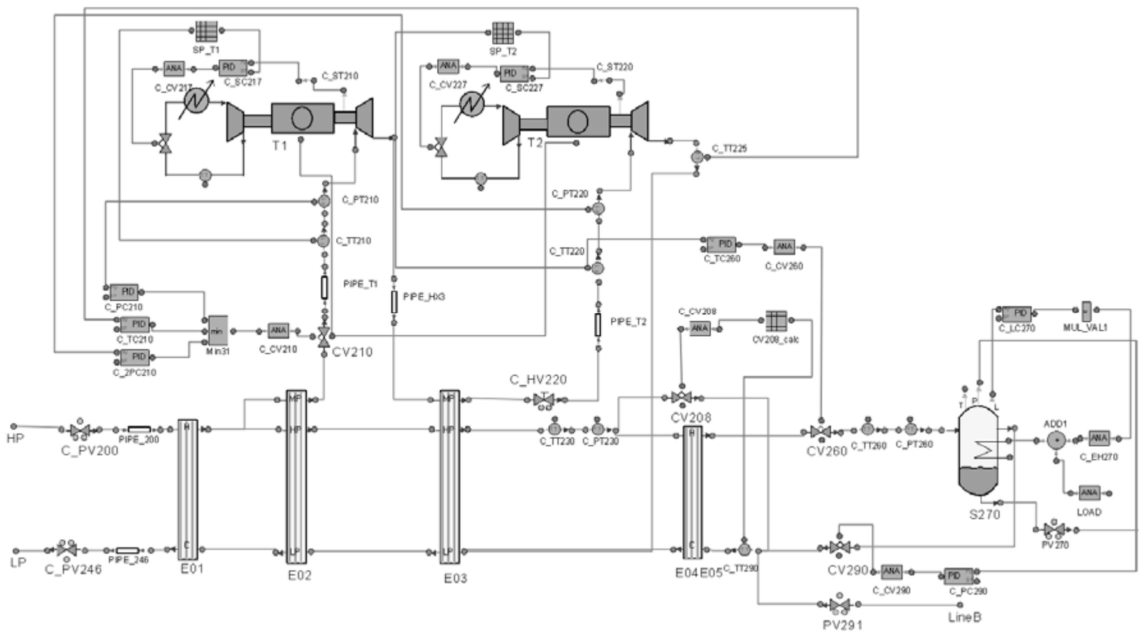

Figure 2 Ecosimpro schematic view of a 300W helium refrigerator using CRYOLIB

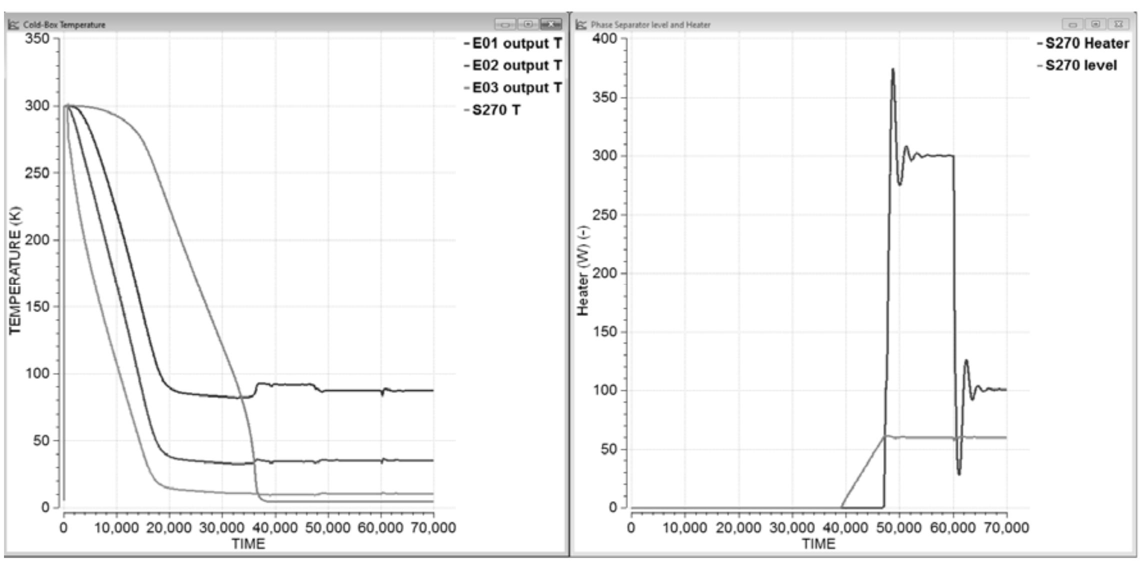

Figure 3 Simulation results of the refrigerator cool-down under the Ecosimpro interface

APPLICATIONS IN RESEARCH CENTERS

The CRYOLIB library is based on a cryogenic library initially developed at CERN which has been used to model and simulate main CERN cryogenic plants. The Linde 18kW refrigerators at 4.5 K and the Air-

Liquide 2.4 kW refrigeration units at 1.8 K used to cool down the LHC superconducting magnets have been simulated under EcosimPro successfully. One of the main results of these modelling works is the setup of an operator training centre in order to train the new cryogenic operators to the LHC installations. This model allows also CERN to test and validate new control strategies of cold-compressors [2] and to perform virtual commissioning of control systems before their implementation to minimize risks and accelerate commissioning phase during important control system upgrades [3].

From 2011, Ecosimpro is used to model the future cryogenic system of ITER (International Thermonuclear Experimental Reactor) in order to simulate the global behaviour of the different cryogenic subsystems during the important heat pulses applied on the tokamak superconducting magnets [4]. Ecosimpro shows in this application its capacity to manage large-scale cryogenic systems to validate and optimize control strategies and general engineering design during transients.

CEA (Commissariat à l'Energie Atomique) also began to use Ecosimpro in 2011 with the cryogenic library to simulate supercritical helium loop for the experimental facility HELIOS [5]. In this case, CEA reuses basic functionalities and components of the library, and derived new models from the cryogenic library to fit their specific requirements and simulate their cryogenic system.

CONCLUSION

CRYOLIB is an Ecosimpro library resulting of the collaboration between CERN and Empresarios Agrupados based on the modelling and simulation works performed during the last years at CERN. The library allows users to model and simulate dynamically small and large-scale cryogenic plants. One of the main advantages is that Ecosimpro gives the possibility to users to access and modify the source code of the components and to develop their own models using the power of the cryogenic library capabilities.

Moreover, simulations of cryogenic processes can help different working teams: First, simulations help *cryogenic engineers* to validate the design of cryogenic systems during transients. Second, the development of a dynamic model allows *control engineers* to tune the different regulation loops and to develop new control strategies to improve the stability or the energy consumption without disturbing the operation of real plants. Another interesting aspect for control teams is the ability to perform virtual commissioning of control systems linked to a model to minimize the real commissioning time and to reduce the subsequent risks. Finally, modelling complex cryogenic systems significantly helps *operation teams* by providing operator training platforms. Real-time simulators connected to a copy of the actual control systems can be used to train operators as if they were on the real plant with the same user interface without any risk. It can also be used to test operator reactions in the case of simulated failures which are infrequent occurrences on a real plant.

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