

## Simulation Program for Cryogenic Plants at CERN

E. Melaaen, G. Owren\*, A. Wadahl and U. Wagner

LHC-Division, CERN, CH-1211 Geneva 23, Switzerland

\*Department of Refrigeration and Air Conditioning, NTNU, 7034 Trondheim, N

A steady-state simulation program for helium refrigeration plants has been developed. The objective was to have a tool available for analysis of existing plants in connection with the LEP project, but also for studying the requirements for future plants in the LHC project. The program can simulate individual components up to complete cycles, but it can also be used for closed-loop exchangers and expanders in a specified process. Each component is modeled by writing its energy balances, the equations are put into a unique matrix. Since refrigeration cycles are mainly closed-loop processes, the program solves the complete equation system simultaneously.

### INTRODUCTION

To reach the necessary beam energy in the Large Electron Positron collider, superconducting cavities operating at 4.5 K are installed. Four 12 kW @ 4.5 K are supplied by LINDE and L'AIR LIQUIDE, are installed for the task [1]. There is a need for a tool (CryoSim) for analyses and studies of existing refrigeration plants and the development of his work. The tool is now used to simulate existing plants and the evaluation of future cryoplants for the Large Hadron Collider (LHC) project.

### SCOPE AND CAPABILITIES OF CRYOSIM

CryoSim is a robust steady-state simulation program developed for cryogenic process simulations in general. Thermophysical properties for helium and other fluids available package HEPAK [2] are installed. Data from HEPAK are based on fundamental data. Since only helium data are implemented, the program has limitations for other fluids. Other fluids can be installed in the future.

CryoSim is especially developed for off-design calculations of existing plants. It is a useful tool for process calculations and optimization of helium liquefaction. It is useful for understanding and assessing the performance and efficiency for various cryogenic processes. The program can be used for thermodynamics studies and as a tool during specification of new plants.

The first version of CryoSim had some limitations since the turbine efficiency was assumed constant and independent of the operation conditions. In the same way the heat exchangers (UA) did not vary with the mass flow. This is improved, the turbine efficiency and heat-transfer coefficient varying with the flow rate are implemented. The program can be used for simulating situations with varying cooling power or at off-design conditions.

For a given process the flow-scheme has to be described in an input

and efficiencies are given here. In addition inlet and outlet stream connections between all components are specified. The second part of the about all the mass streams in the process. To specify a stream, flow rate or temperature have to be given. From the given data in the input file specified stream represents a boundary or an initial condition.

The following components are modelled and included in the program; b expander, flash drum, heater, heat exchanger, mixer, pipe, splitter, subco modelling each component is the same, and the structure of the program i component models. Heat exchangers are modelled in two different ways; method (called hx), while the second method is more rigorous (called rhx). the heat exchanger into a specified number of blocks, and each heat-exchan separately. With this method it is possible to get out a thermodynamic de heat exchanger (e.g. temperature profile). Also a control facility is ava used to update boundary conditions until specified set-points (e.g. temper

The program can calculate the flow sheet specified in the input fi simulation or design. In the simulation mode the process is solved as boundary conditions and specified component parameters. Design mode uses calculate the heat-transfer coefficient for heat exchangers and isentropic

The calculated results are stored in a specific output file. This file for mass and energy, exergy analyses, stream data (temperature, enthalpy flow rate and quality), component data (pressure drop, UA, efficiency information about iterations. Temperature profiles, pinch and NTU for heat

To work with CryoSim it is necessary to have some basic knowledge about available at UNIX ® (e.g. emacs). For the moment the program is only runn

Figure 1 shows an example of one process together with part of its ir regarded as the lower end of the cold box for one of the 12 kW plants at C file describes the main cluster of components here called EXAMPLE. The calculation mode is design or simulation. After this line starts a list cluster EXAMPLE. All components with their characterization are written in The first line for a component starts with an identification of the compo rhx) and an identification name. The information describing a component The example shows the structure of one heat exchanger and one expander m input file specifies information of each stream in the process. Every li boundary or initial condition for one stream.

## PROGRAM STRUCTURE

CryoSim is based on an object-oriented technique and written in the progr gives the program large flexibility. The equation system for each compone covering the equations for the whole plant. Since refrigeration cycles m the program solves the total number of equations as one large system (si Gauss-Jordan elimination method. The results is a robust program. The cc energy balances; therefore, the enthalpy for each stream is solved. The updated separately by following the streams from boundary conditions and f in the flow-scheme. For stream splitters and flash drums either split f specified in the input file. Similarly must the pressure drop inside each a component be specified in the input file. For a heat exchanger an op calculating the pressure drop dependent on the flow rate.

```

compound EXAMPLE
mode simulation
rhx HE1
  feeds mass str1 mass str5
  prods mass str2 mass str6
  param 1 10 1 -1
  pspec 1 0.1 0.05
  design 0 38000.0
  design 1 38000.0
end
expander T1
  feeds mass str2
  prods mass str3 work wb1
  pspec 1 4.5
  param 1 0.7
end
.
.
.
end
end
mass  str1  tp    7.17    6.36    524.0
mass  str2  tp    4.72    6.36    524.0
.
.
mass  str8  hp   11.12    1.20    524.0
mass  str9  tp    7.10    1.20    524.0
end

```

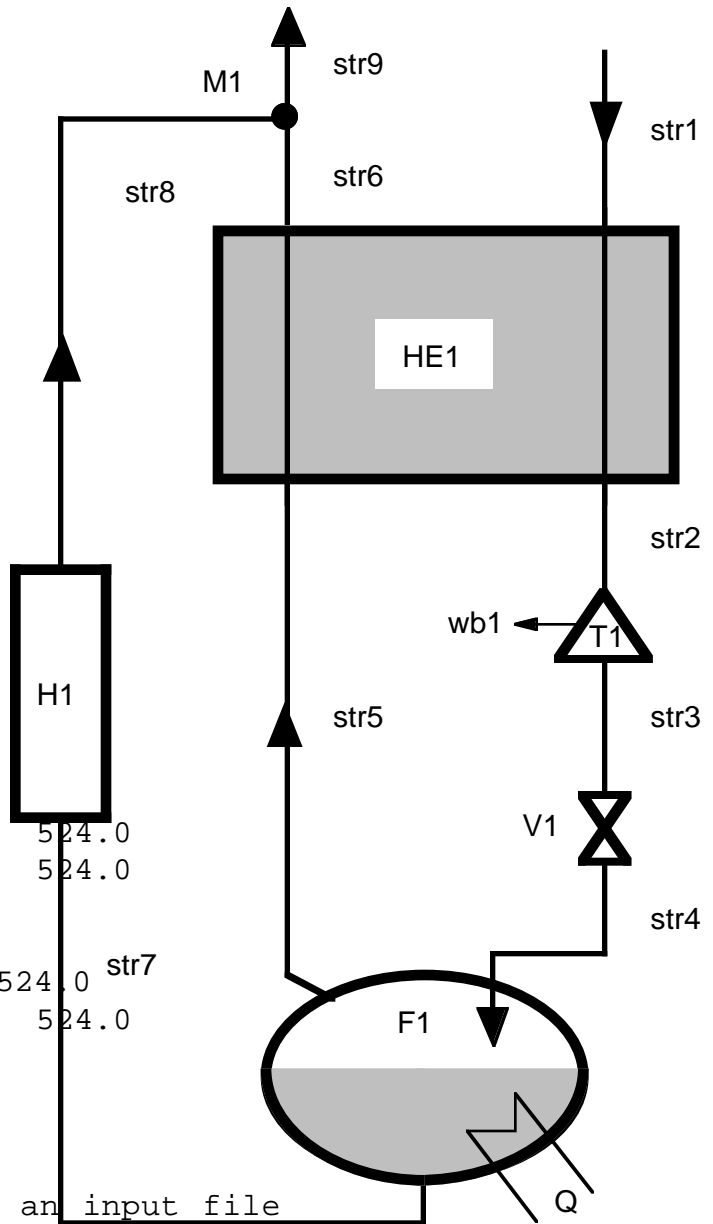


Figure 1 Shows the principle for an input file describing a given process [3]

The equations based on the energy balances are put into the matrix. The Gauss-Jordan method normally requires constant coefficients, but thermodynamic process has non-constant coefficients. An iteration procedure solving the system. For each iteration the coefficients are kept constant; coefficients are updated between each iteration. When the solution vector is reached after several iterations, the solution is reached.

Figure 2 shows the program structure. Each box represents one directory. All directories are compiled in a library. All libraries are compiled together; the result is the executable file sim. Directory CryoSim is organized into two subdirectories: steady and dynsim. steady represents the mathematical library with equation solvers, while cryodata represents the thermophysical properties. Basic contains the main structure of the program organization and storing of data. Two important structures defined in the program are streams and components. The two subdirectories steady and dynsim contain programs for steady-state and transient simulation, respectively. dynsim is under preparation and, to date, is not a paper. In the directory steady steady-state models of the components are implemented. The program compiled to the executable file sim. To run the program, sim must be executed from the directory steady.

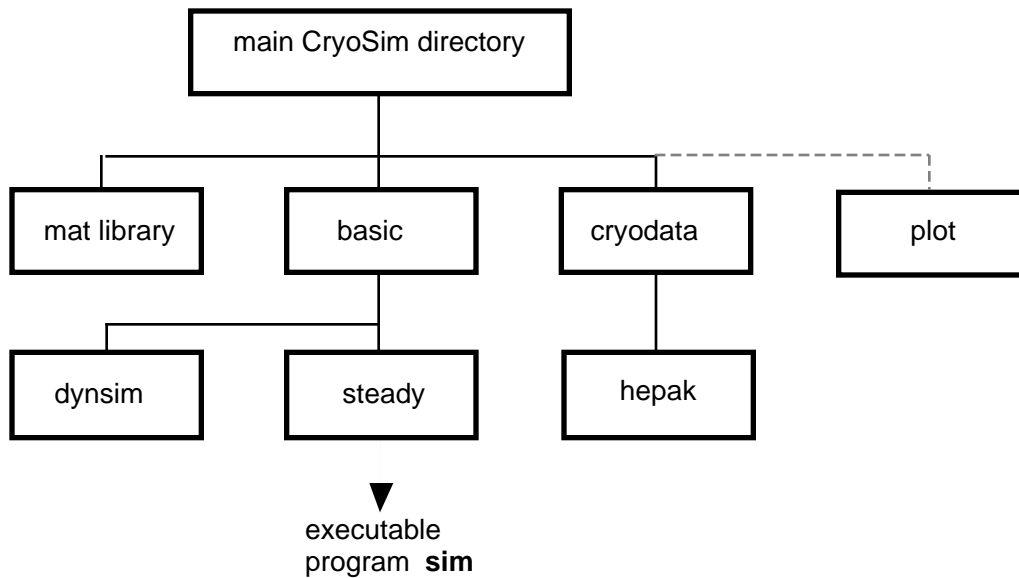


Figure 2 Shows the director structure of the program and links to other applications [

CryoSim partly tested out at CERN by comparing simulated results and measured data from running

plants. These studies show good validity for the program, but a closer study in the near future. Especially important is it to test the heat-exchanger design and off-design situation. A thorough description of the program and the validity of the models are given in [3-5].

## CONCLUSION

CryoSim is a robust calculation program for helium processes and cryoplastic simulation and for limited design cases. The program is useful during an evaluation of new processes. Since the total equation system is solved and adjusted to solve closed-loop processes as refrigeration cycles. The program has large flexibility and possibilities for further development. Current preliminary results show good validity [3-5].

## REFERENCES

- 1 Güsewell, D. et al., Cryogenics for the LEP200 Superconducting C Particle Accelerator Conference (PAC93), Washington D.C., 1993
- 2 Cryodata inc., User's Guide to HEPAK, Version 3.21, Colorado, January
- 3 Høye, G.K., A Simulation Program for Helium Cryoplants, Thesis, Norwegian Technology, Trondheim, 1994
- 4 Wadahl, A., CryoPlant Process Simulation Program, Thesis, Norwegian Technology, Trondheim, 1995
- 5 Melaaen, E., User's Guide to CryoSim and System Documentation for preparation, CERN, Geneva, 1996