Simulation Environment

AIR CHILLER CYCLE

This case study demonstrates the transient operation of a two-stage Air Cycle Chiller. The chiller consists of a closed cycle in which dry air is circulated via a set of centrifugal compressors and expanded through a turbine to provide cooling at very low temperatures. A typical application is in crust-freezing of pre-baked foods.

FOOD INDUSTRY

CHALLENGE:

This case study demonstrates the transient operation of a two-stage Air Cycle Chiller. The chiller consists of a closed cycle in which dry air is circulated via a set of centrifugal compressors and expanded through a turbine to provide cooling at very low temperatures. A typical application is in crust freezing of pre-baked foods.

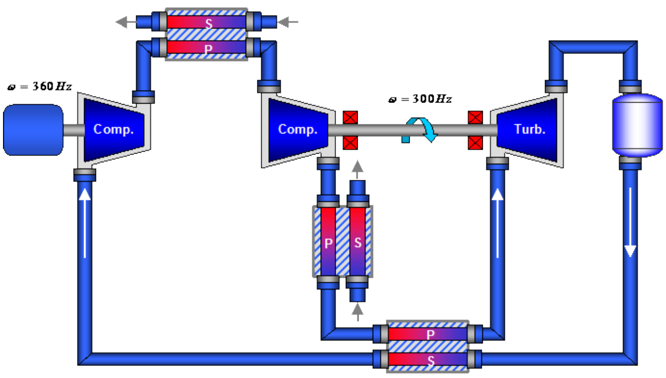
The objective of the simulation is to model the integrated transient operation of the system together with the controller. This is required, amongst other things, to check that the compressor never runs the risk of surging.

BENEFITS:

- Transient/Dynamic simulation of the system.
- Integration of a PID controller.
- Ensure compressor operating points are within limits to prevent surge.

SOLUTION:

The transient simulation of the two-stage air cycle chiller integrated with the PID controller shows that the temperature can be controlled effectively by varying the shaft speed of the low pressure compressor. It also shows how the operating points of the low pressure compressor and turbine changes in response to the operation of the system. The compressor operating point is sufficiently far away from the compressor surge line at all times during the transient.



The transient simulation of the two-stage air cycle chiller integrated with the PID controller shows that the temperature can be controlled effectively by varying the shaft speed of the low pressure compressor.

TRANSIENT SIMULATION OF A TWO-STAGE AIR CYCLE CHILLER

SYSTEM DESCRIPTION

The cooling chamber (on the extreme right of the schematic) is operated at a temperature of -50°C and an absolute pressure of 100 kPa. Air is extracted from the chamber at a rate of approximately 1 kg/s through the secondary side of the recuperator heat exchanger (at the bottom) where it is heated to 30°C after which it enters the low pressure compressor. The compressor is driven by an electric motor via a variable speed drive. The air leaves the compressor at around 95°C and 176 kPa and enters a water-cooled heat exchanger. The air is cooled down to 40°C after which it enters the high pressure compressor. The high pressure compressor is driven by the turbine via a free-running shaft. The air leaves the high pressure compressor at approximately 80°C and 245 kPa and enters a second water-cooled heat exchanger. The high pressure gas at -40°C is then expanded through the turbine to a pressure of just above 100 kPa and a temperature of -80°C, before it re-enters the cooling chamber.

The operating temperature of the cycle is regulated by varying the shaft speed of the low-pressure compressor via a PID controller.

The cooling is operated at a temperature of -50°C and an absolute pressure of 100 kPa.

OBJECTIVE OF SIMULATION

The objective of the simulation is to model the integrated transient operation of the system together with the controller. This is required, amongst other things, to check that the compressor never runs the risk of surging.

FLOWNEX MODEL

The Flownex model of the system is shown in Figure 2.

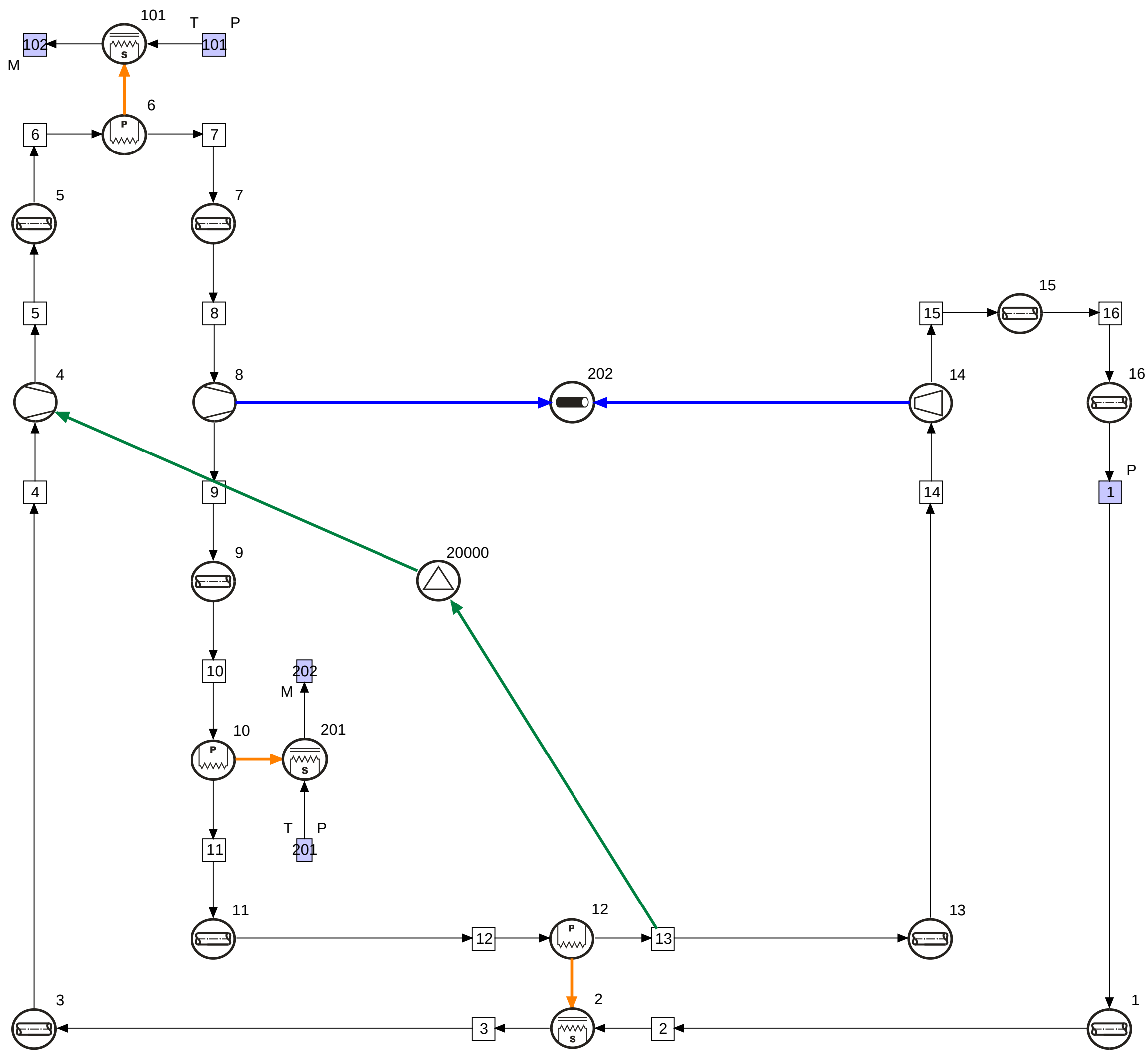


Figure 1: Flownex network of the direct two-shaft closed inter-cooled recuperated Brayton cycle PBMR power plant.

Node 1 represents the inlet to the system from the cooling chamber. This is followed by a pipe (element 1), the secondary side of the recuperator heat exchanger, another pipe, the low-pressure compressor, pipe, heat exchanger, pipe, high-pressure compressor, pipe, heat exchanger, pipe, the primary side of the recuperator, pipe, the turbine, another pipe and finally the cooling chamber, represented by yet another pipe element. The design heat load of 31.42 kPa is specified within pipe element 16.

The PID controller (element 20000) senses the temperature at the outlet of the primary side of the recuperator and attempts to control it at a set-point of -40°C by varying the speed of the low-pressure compressor. The free-running shaft that connects the high-pressure compressor to the turbine is represented by element 202.

DESCRIPTION OF SIMULATION

The simulation starts at steady-state with the shaft speed of the low-pressure compressor fixed at 21,600 rpm. The resultant temperature at the outlet of the recuperator is only -32.8°C instead of the desired -40°C. As soon as the transient starts, the controller is switched on. This should result in the controller speeding up the low-pressure compressor in order to lower the temperature. After 30 seconds the heat load in the cooling chamber is increased to 40 kW and after another 30 seconds it is decreased to 20 kW, with the controller and shaft speed responding accordingly every time. Note the response of the free-running shaft as well as the locus plots of the compressor and turbine operating points on the non-dimensional performance maps.

The simulation starts at steady-state with the shaft speed of the low-pressure compressor fixed at 21,600 rpm. The resultant temperature at the outlet of the recuperator is only -32.8°C

RESULTS

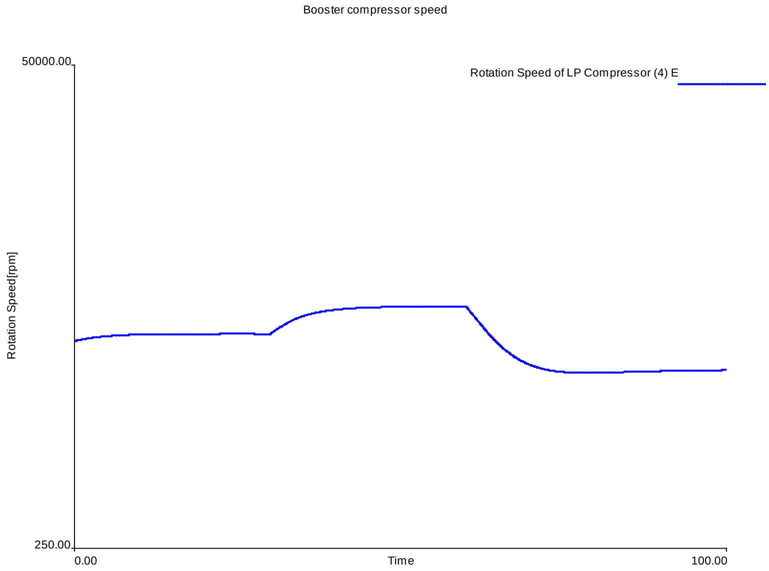


Figure 2: Low-pressure compressor shaft speed.

Figure 3 shows how the low-pressure compressor shaft speed is initially increased in an effort to lower the controlled temperature. At 30 seconds it is increased again to cater for the increased heat load and at 60 seconds it is reduced in response to the lower heat load.

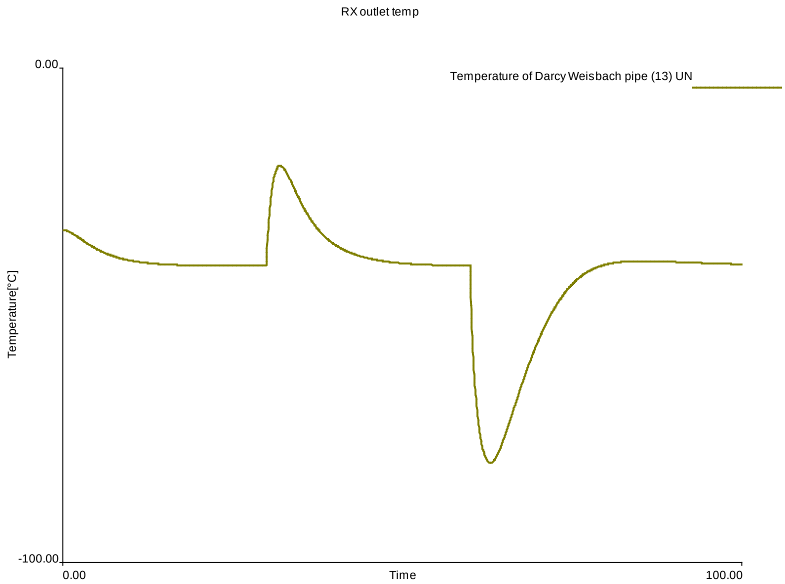


Figure 3: Temperature at the outlet of the recuperator primary side.

Figure 4 shows the resultant controlled temperature.

Figure 3 shows how the low-pressure compressor shaft speed is initially increased in an effort to lower the controlled temperature.

CONCLUSION

The transient simulation of the two-stage air cycle chiller integrated with the PID controller shows that the temperature can be controlled effectively by varying the shaft speed of the low pressure compressor. It also shows how the operating points of the low pressure compressor and turbine changes in response to the operation of the system. The compressor operating point is sufficiently far away from the compressor surge line at all times during the transient.