Numerical Simulation of the ALBA Synchrotron Light Source Cooling System Response for Failure Prevention

Xavier Escaler[1], Joan Casas[2], Carles Colldelram[2], Marcos Quispe[2], Montserrat Prieto[2]

[1] UPC, 08028 Barcelona, Spain

[2] ALBA-CELLS Synchrotron, 08290 Cerdanyola del Vallès, Spain

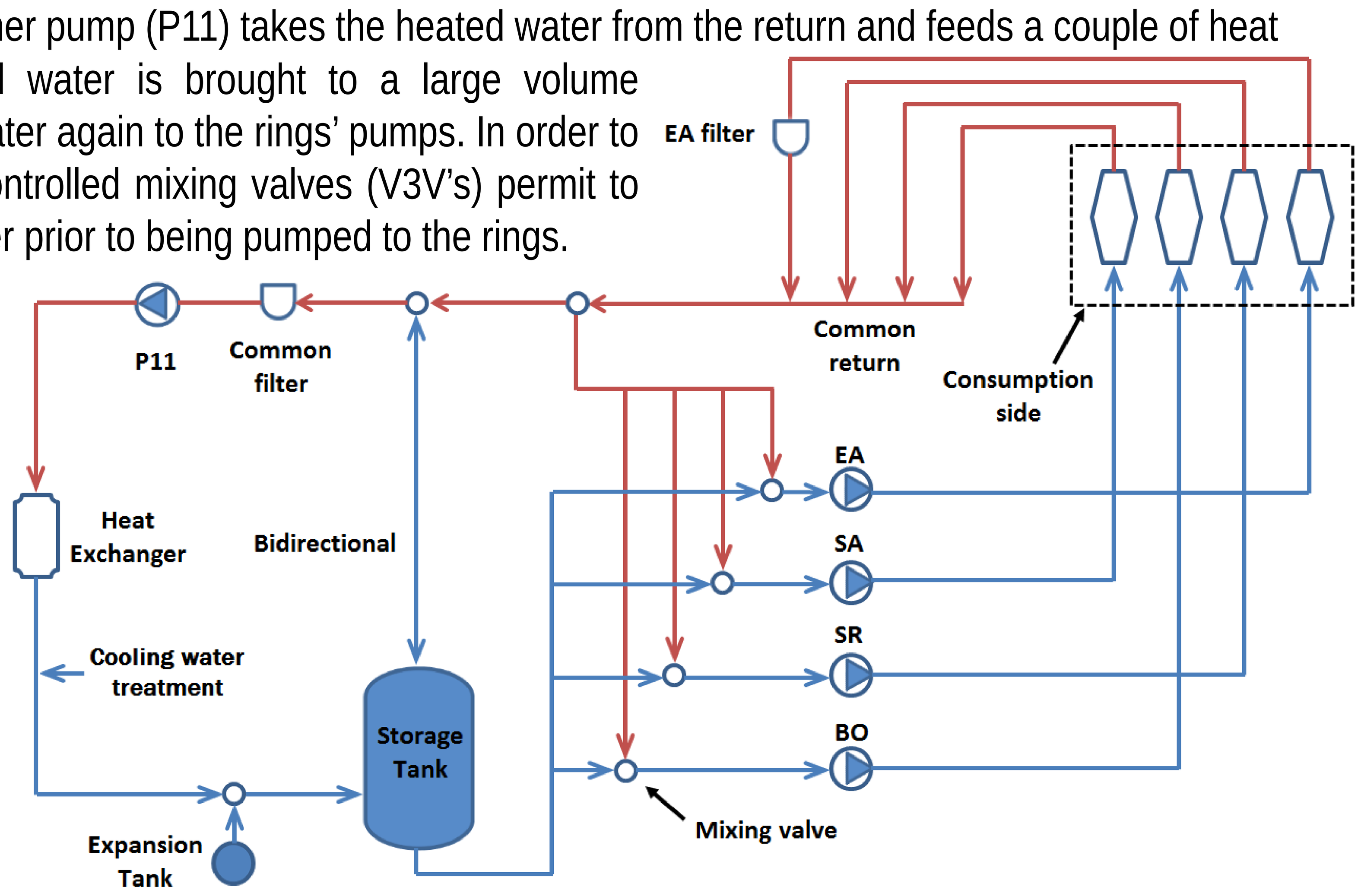
Abstract

The ALBA Synchrotron Light Source cooling system is designed with a common return pipe that interconnects the four consumption rings. Such configuration is believed to compromise its optimal operation. To understand its thermo-fluid dynamic behaviour, a detailed 1D model has been built comprising all the components such as the pipes, fittings, bends, valves, pumping stations, heat exchangers and so on, and the various regulation mechanisms. Preliminarily, the model results in steady state operating conditions have been compared with experimental measurements and the maximum deviations have been found below 13%. Then, a series of transient numerical simulations have been carried out to determine the system response. Specifically, effects of the blockage and leakage of a consumption line as well as the increase and decrease of heat duty for the tunnel rings have been investigated. As a result, the stability of the system has been evaluated and the operational limits have been estimated in front of hydraulic and thermal load variations. Moreover, particular behaviours have been identified which can be used to design monitoring and control strategies to prevent unexpected failures.

ALBA cooling system description

The ALBA cooling system is comprised by two main parts: the production and consumption sides. Four pumping stations named P07, P08, P09 and P10 feed the Experimental Area (EA), the Storage (SR), the Booster (BO) and the Service Area (SA) consumption rings, respectively (see attached Figure). Another pump (P11) takes the heated water from the return and feeds a couple of heat exchangers (EX07) that cool it. The cooled water is brought to a large volume accumulator from which a suction line takes water again to the rings' pumps. In order to regulate the water temperature, a series of controlled mixing valves (V3V's) permit to combine the cooled water with the heated water prior to being pumped to the rings.

Moreover, a pressure maintenance system with a compressor is mounted at the exit line of the heat exchangers before the accumulator. Finally, a pipe line connecting the accumulator with the common return line permits to compensate the lack/excess of flow to the cooling loop when the total flow rate changes in the rings' loops.



Numerical Model

- A complete model of the production side has been built up.
- Each consumption ring has been simplified to a heat exchanger component.

• Main regulation systems

- Modelled with PID elements:
  - Pump engine frequency converters (Ring delivery pressures)
  - Mixing valves (Mixed water temperature at 23 ºC)
  - EX07 Heat exchangers (Cooled water temperature at 21 ºC)

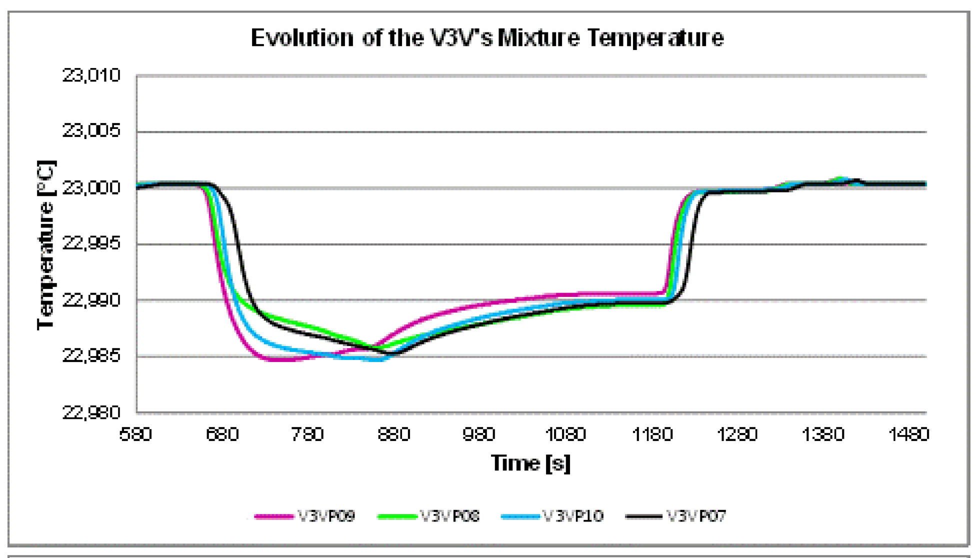
• Accuracy

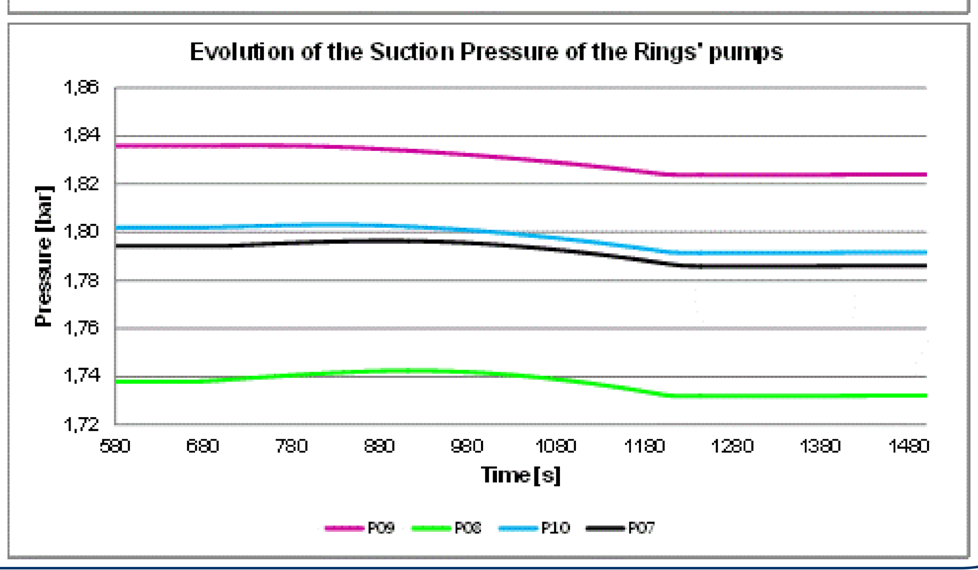
- Model goodness confirmed by maximum deviations in steady state around:
  - 6 % for the hydraulic variables
  - 13 % for thermal variables

Simulated Response

• Thermal load shut-down

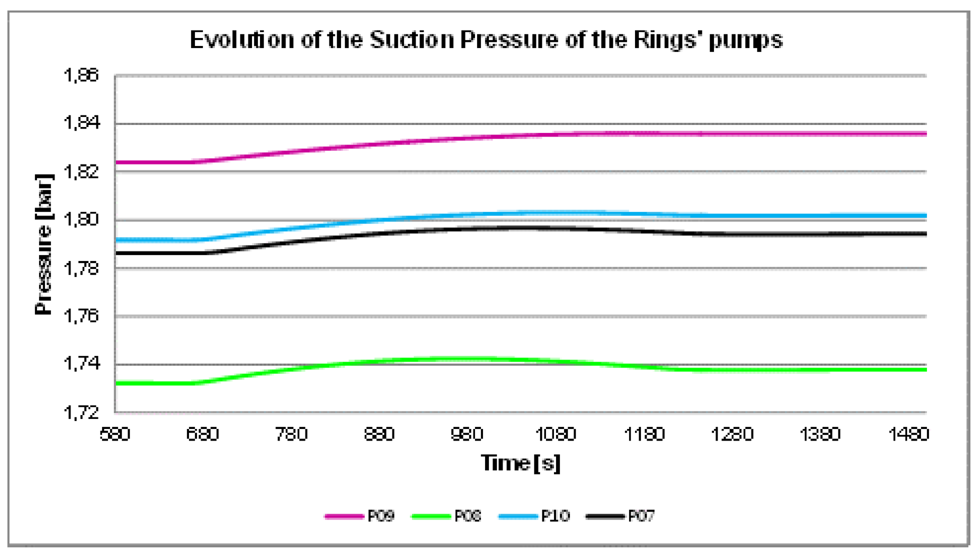
- Simulated maneuver:
  - SR's outlet temperature reduction from its nominal level of 25.6 ºC until 23.4 ºC (as if no heat duty demand existed).
- Results:
  - The common return design enhances the interaction between rings so that the transient, which affects large flow rate, propagates its effect to the rest of the rings.
  - Takes ≈ 80 s to affect progressively the mixed flow temperatures from the closest pumping station until the furthest one to the common return pipe.
  - V3V's reduce the cold flow and increase the hotter flow.
  - V3V's water temperature takes 540 s to stabilize.
  - Increase of flow from storage tank to P11 suction pipe.
  - Reduction of the suction pressure of all the pumping stations.





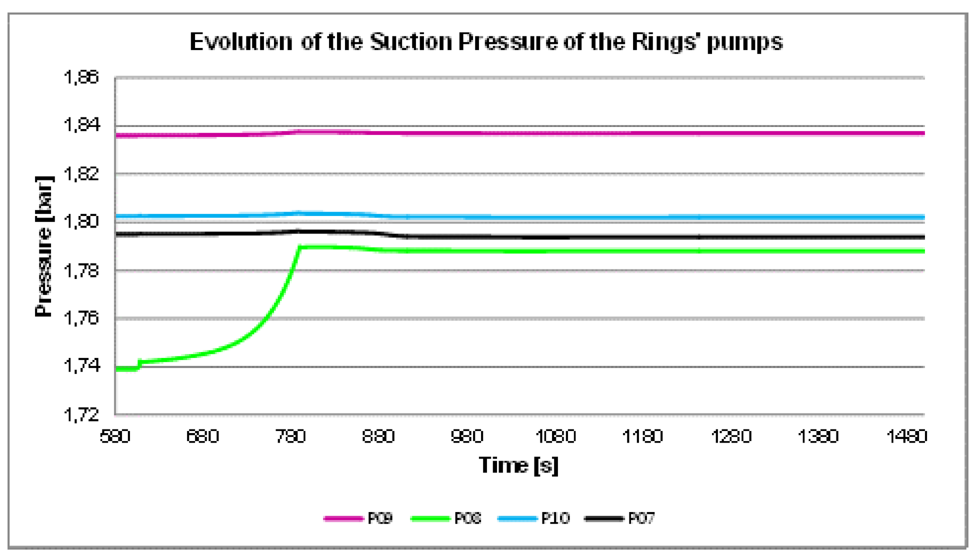
• Thermal load start-up

- Simulated maneuver:
  - SR's outlet temperature progressive increase during 540 s from 23.4 ºC at around 600 s to 25.5 ºC .
- Results:
  - V3V's increase the suction of cold water and decrease the suction from the return flow.
  - The flow through the bidirectional line is reduced.
  - At the end of the process, all of the pumping stations' suction pressures have increased significantly.



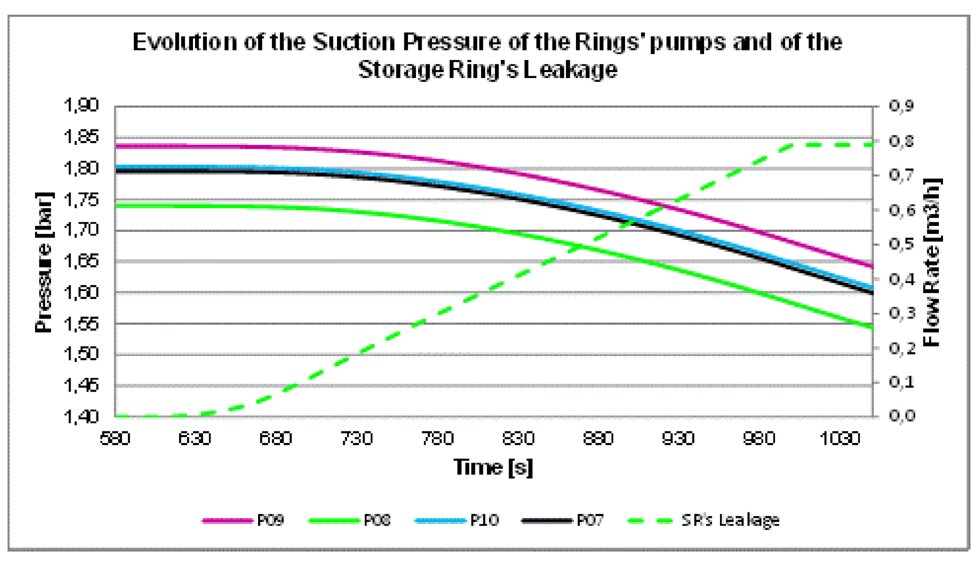
• Pipe blockage

- Simulated maneuver:
  - At constant heat duty, SR valve progressive closure provoking a flow rate reduction from its nominal value until a 20 % reduction.
- Results:
  - Immediate effect on hydraulic parameters:
    - ✓Significant increase of P08 suction pressure.
    - ✓V3V's close the tank flow.
    - ✓The flow from the tank towards P11 increases.
  - Delayed thermal response:
    - ✓Pump suction pressures and the flow rate at the bidirectional connection stabilize with a higher level than the initial one.



• Pipe leakage

- Simulated maneuver:
  - Leakage at the SR's inlet that increases steadily during 400 s to reach a continuous flow rate loss of 0.8 m³/h.
- Results:
  - Suction pressure of the pumping stations decrease.
  - Increase of the pump's rotational speed and ring's flow rate.
  - Leaked flow almost entirely provided by the expansion tank.
  - The remainder and the increase of the ring's flowrate is supplied by the storage tank through the V3V's.
  - The flow through the bidirectional line decreases.
  - When return's pressure reaches the value of 1.6 bar the expansion tank is unable to supply the leakage flow.



ALBA-CELLS | www.albasynchrotron.es | escaler@mf.upc.edu