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INVESTIGATION OF THERMAL INSTABILITIES IN THE ALBA COOLING SYSTEM, BASED ON NUMERICAL SIMULATIONS AND EXPERIMENTAL MEASUREMENTS

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Abstract

This paper presents an investigation into the thermal instability problems that currently affect the ALBA Cooling System. During these periods of instabilities, which occur for a few hours every week of operation, there are deviations up to +1.5 ºC, concerning the nominal temperature of 23 ± 0.2 ºC in the four rings of ALBA: Service Area, Booster, Storage and Experimental Hall. This problem has a direct impact on the quality of the beam of the Accelerator. Previous studies have preliminarily concluded that the causes of this problem are due to (1) thermohydraulic anomalies in the operation of the external cogeneration plant, which supplies cold water to ALBA, and (2) cavitation problems in the pumping system (the water mass flow has been reduced to 67% of its nominal value to temporarily mitigate the cavitation). In order to confirm these hypotheses and propose solutions to the problem, an investigation has been developed making use of one-dimensional thermo-hydraulic simulations, performing Computational Fluid Dynamic (CFD) studies, statistical evaluations of data taken from our control system, and systematic flow measurements in critical areas, with ultrasonic flowmeters. As a result of this research, a set of solutions and recommendations are finally proposed to solve this problem.

BACKGROUND

ALBA is a third-generation synchrotron light source facility located in Cerdanyola del Vallès, Spain, with more than eleven years of operation and eight operating beamlines. Over the last years, the water-cooling system of ALBA has been under thermal instability problems, which affect the control of the inlet temperature in its four main rings: Service Area (SA), Booster (BO), Storage (SR) and Experimental Hall (EH).

These anomalies appear during changes in the operating modes of the external cogeneration plant, called ST4, which supplies cold water to ALBA. An increment of the ST4 water temperature rises the in-tank temperature of D02, which is a high-capacity tank of 40 m^3 [1].

Otherwise, the volumetric flow circulating through the ALBA's circuit, where heat is exchanged with ST4, is reduced from the design value of 645 m^3/h to 430 m^3/h, to mitigate unexpected cavitation problems that affect the performance of the principal recirculation pump in ALBA, called P11. One possible cause of this cavitation problem is an inappropriate sizing of the manifold located in the suction zone of the P11 pumps.

This is an utmost magnitude issue, insofar there is a direct linkage between the electron beam stability and the thermal stability of the water-cooling circuit. Moreover, this behaviour restricts ALBA's expansion capability in terms of machine current: whereas its design current is 400 mA, ALBA operates at 250 mA. Furthermore, this would affect the growth plan of ALBA II [2].

ALBA'S THERMOHYDRAULIC CIRCUIT

The ALBA's thermohydraulic cooling system in nominal conditions is described in a simplified scheme in Fig. 1. The circuit begins with the hot deionized water returning from the machine headed to the P11 pump, which should move 645 m^3/h at 26.8 ºC after a filtering process. The water circulates through E01 heat exchangers, where heat is partially exchanged with the Cooling Towers. In real operation, all the flow circulates through E01B and steers to heat exchangers E07, where each exchanger takes 156 m^3/h and transfers 1815 kW of heat to ST4 water, aiming to decrease the water temperature to 22 ºC. After that, the water is stored in tank D02.

The circuit ends with the 3-way valve and the P7-P10 pumps, which allow the impulsion of the water from D02 to the machine. The function of the bidirectional tube is to maintain the hydraulic balance in the system.

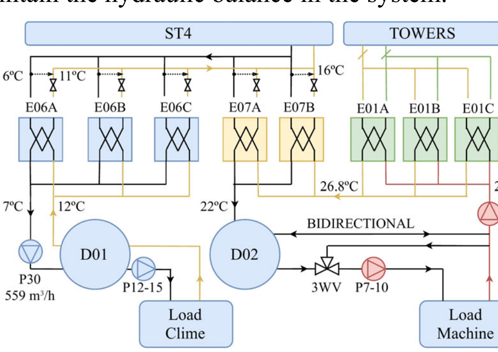

Figure 1: Simplified scheme of the ALBA's thermohydraulic cooling system.

The HVAC applications use water from the D01 tank employing P12-P15 pumps. The water from D01 is cooled with the E06 heat exchangers, each one taking 187 m^3/h and transferring 1080 kW of heat to ST4 water. Once cooled, the flow returns to D01 circulating through the P30 pumps, which move 559 m^3/h. Two-way mixing valves and differential pressure valves regulate the flow that circulates through E06 and E07 exchangers.

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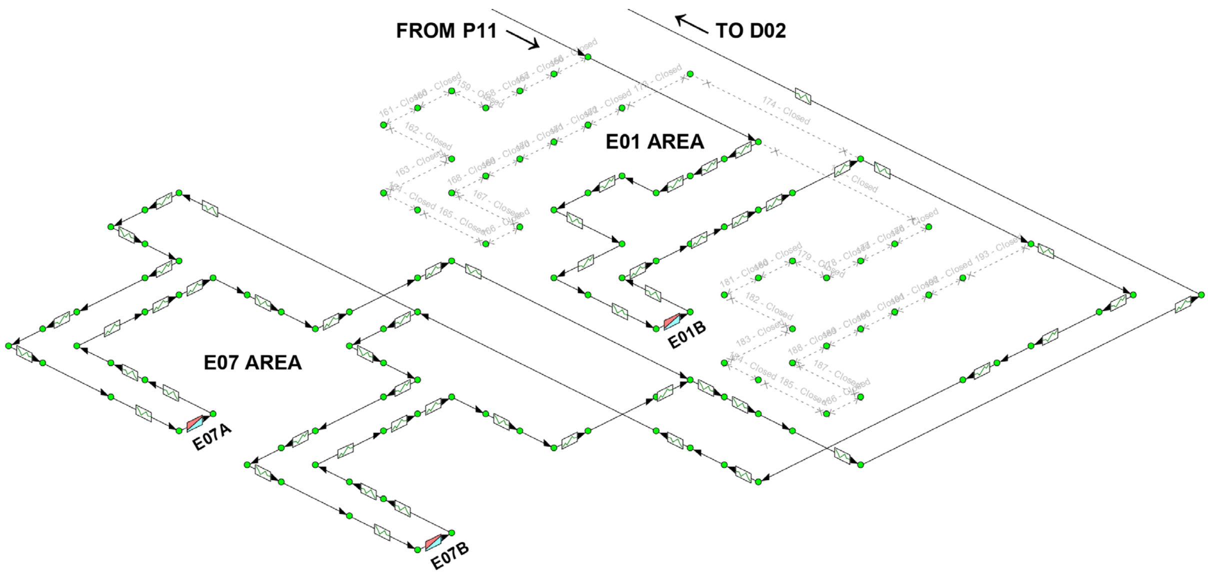

Figure 3: Fragment of the geometry modelled with Pipe Flow Expert, including E01 and E07 heat exchangers zones.

Thermal Instabilities

The thermal instabilities tend to appear in the first hours of the morning, causing a maximum increase of 1.5 ºC above the inlet temperature (23 ± 0.2 ºC) of the four main rings. For each week, it has been quantified that these instabilities have a total duration of 10 hours.

Figure 2 shows the thermal instabilities in the morning of the 28th of April of 2021. The continuous lines correspond to polynomial regressions of the points, while the scattering corresponds to real data extracted from historical records. For this example, the mean amplitudes of the rings EH, SR, BO, and SA are 0.59ºC, 0.05ºC, 0.57ºC, and 0.70ºC, respectively.

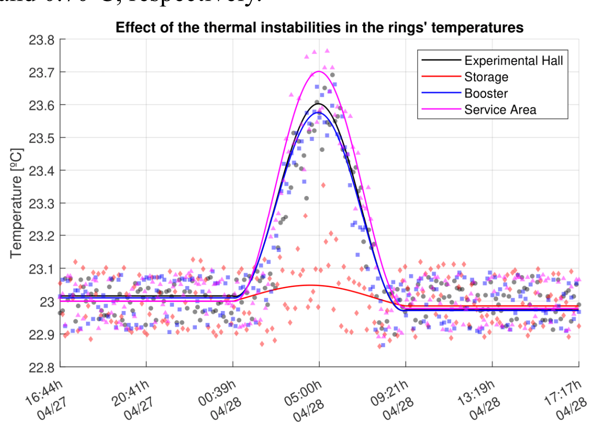

Figure 2: Inlet temperature of the EA, SR, BO and SA rings. Date 28th of April of 2021.

EXPERIMENTAL STUDIES AND THERMAL HYDRAULIC SIMULATIONS

One-Dimensional Simulations

The hydraulic behaviour of the circuit is studied by the use of one-dimensional simulations implemented in the software Pipe Flow Expert (PFE) [3]. Figure 3 shows the part of the hydraulic circuit corresponding to areas E01 and E07. The simulation describes the mass flow and pressure distributions along the circuit. Based on the one-dimensional model, the existence of an irregular flow distribution has been detected in the three branches of the manifold in the suction zone of the pump P11.

The thermal performance of the circuit has been simulated employing a self-made Matlab code, based on the hydraulic results given by PFE and solving energy balance equations over the circuit. The E07 heat power has been statistically modelled with more than 500,000 values from historical records. The results have been compared with real data, obtaining errors of less than 2%.

CFD Calculations

In particular, the E07 exchanger zone has been studied with three-dimensional CFD simulations due to its great importance in the heat exchange.

The SimsScale software [4] has been used for the simulations. For the model, a laminar flow condition with more than 4,5M elements is considered for both ST4 and ALBA flows. In regard to the pressure distribution of ST4 water in the E07 inlet, an example of this simulation is shown in Fig. 4.

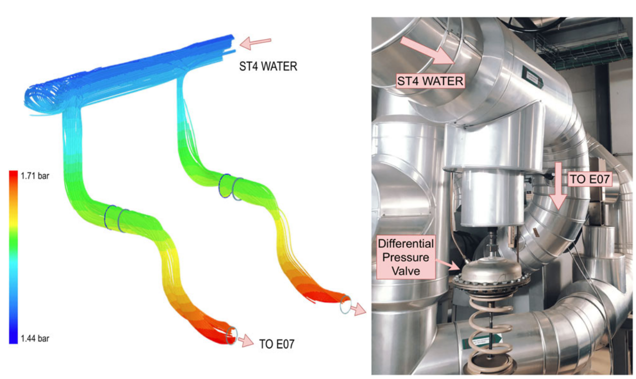

Figure 4: CFD of the ST4 water circuit. Details of pressure distribution in E07 inlet.

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These simulations permitted to obtain a detailed description of the temperature, pressure and mass flow distribution in the pipes close to E07. Integrating on the different branches, it is observed that, due to the geometry of the pipes, 48.65% of the secondary flow is distributed by E07A and 51.35% by E07B. These CFD results differ from the experimental ones, 44% and 56%, obtained employing ultrasonic flowmeter equipment. The causes of these differences are attributed to (1) low precision measurements due to the lack of space when installing the ultrasonic equipment and (2) geometric limits imposed in the CFD model.

CONCLUSIONS AND RECOMMENDATIONS

A) In the current operating conditions, it is not possible to increase the ST4 mass flow in the E07 circuit due to a full opening condition of the two-way mixing valves. It is recommended to increase the setpoint of the differential pressure valves, located on the ST4 circuit of E06 and E07, from 0.5 bar to 1.5 bar. By changing this, a reduction in the opening condition of the two-way mixing valves from 100% to a new working regime between 50% and 70% is expected.

B) Lack of instrumentation for the pressure and mass flow measurements has been evidenced in the E06 and E07 zones. It is strongly recommended the installation of ultrasonic flowmeters located in the pipes of the ST4 circuit, pressure sensors near the differential pressure valves, and an intensive calibration of the temperature sensors along the circuit.

C) The one-dimensional model detected an irregular distribution of the flow in the suction zone of the P11 pump, which has been confirmed by the use of ultrasonic equipment measurements. Moreover, the flow has an oscillatory behaviour, with an average oscillation amplitude of ± 2.7 m^3/h in this zone, which is counterproductive in connection to the occurrence of cavitation problems. A deeper investigation into the fluid dynamics in the aspiration zone of the P11 is strongly recommended in order to dim or remove the mentioned anomalies [5].

D) The Matlab simulation concludes that, by maintaining the current mass flow condition of the ST4 water and recovering the nominal mass flow in the ALBA's circuit (from 430 to 645 m^3/h), it would not be possible to improve the tank temperature condition. This is described in Fig. 5, which compares the D02 tank temperature against the return water temperature at the nominal ST4 working regime. As it is possible to see, an increase of the P11 volumetric flow (Q_{P11}) would only increase the in-tank temperature. This hypothesis has been confirmed with several experimental tests, by changing the duty point of the P11. Although a favourable thermal effect has not been observed, increasing the mass flow rate in the P11 pump is recommended in order to increase the mass flow in the bidirectional tube, currently low.

E) Simulations show that the temperature variation in the tank, relative to the variation of ST4 temperature, would be reduced by more than 50% when recovering the nominal mass flow conditions in the ALBA's circuit. Thus, temperature deviations in the rings due to the thermal instabilities, currently up to 1.50 ºC, would be mitigated to 0.75 ºC.

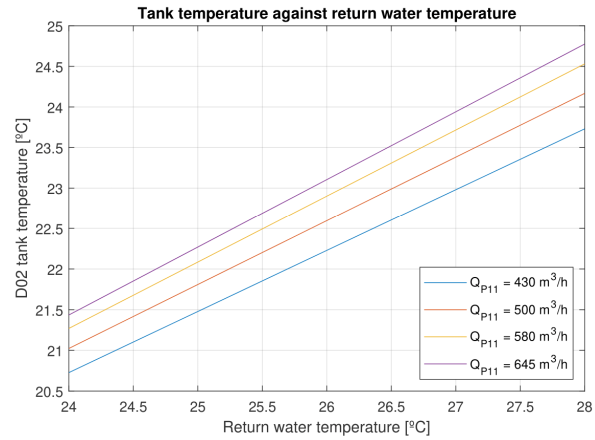

Figure 5: D02 temperature against return water temperature at ST4 nominal conditions.

F) Putting together the ultrasonic measurements with the results of the simulations, it is estimated that to achieve a desired stable temperature of 21ºC in-tank, 25 m^3/ h of additional cold water are needed in each E07 for the current regime, and 65 m^3/h for the nominal regime.

G) According to the thermal calculations, there are no significant changes in the D02 tank temperature between summer and winter. Table 1 shows the tank's temperature increment between summer and winter (ΔT_{D02}), taking into account the heat transfer throughout the entire circuit for an extreme scenario, with an outdoor temperature of 14ºC in winter and 28ºC in summer. The results are given for different volumetric flow conditions of the P11 pump.

The low values show that it is not necessary to insulate the pipes of the system since it would not have a relevant effect on the temperature of the tank.

Table 1: Estimation of the D02 Temperature Increment Between Winter and Summer

Q_{P11} [m^3/h]	380	430	500	580	645
ΔT_{D02} [°C]	0.096	0.087	0.076	0.067	0.061

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