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CFD PREDICTIONS OF WATER FLOW THROUGH IMPELLERS OF THE ALBA CENTRIFUGAL PUMPS AND THEIR ASPIRATION ZONE. AN INVESTIGATION OF FLUID DYNAMICS EFFECTS ON CAVITATION PROBLEMS

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Abstract

Currently, the ALBA refrigeration system pumps present cavitation when operating at their nominal regime. To alleviate this phenomenon temporarily until a definitive solution was found, the water flow was reduced to 67% of its nominal value. As this flow exchanges heat with the cooling water produced in an external cogeneration plant, modifying the working point of the pumps resulted in a reduction of the Accelerator cooling capacity. However, even at such low flow conditions, the flow has an anomalous oscillatory behaviour in the distributor of the aspiration zone, implying that the cause may be in a bad dimensioning of the manifold.

This paper presents a study of Computational Fluid Dynamics (CFD) applied to the aspiration zones of the pumps, to investigate the effects of fluid dynamics on cavitation problems and understand what may be happening in the system. The need for such research arises from the urge to recover the accelerator cooling capacity and the constant pursuit for the improvement of the system. The geometries for this study include the general manifold in the aspiration zone and a simplified model of the pump impeller. The simulations have been carried out with the ANSYS-FLUENT software.

Studies performed include considering the total water flow in nominal and under current operating conditions. In addition, the cases in which the flow is distributed through the manifold tubes in uniform and non-uniform ways have been treated separately. Pressure and velocity fields are analysed for various turbulence models. Finally, conclusions and recommendations to the problem are presented.

INTRODUCTION

During the last years, ALBA's operation has been affected by general thermal stability problems that prevent the correct performance of the system.

The cooling capacity of the facilities, which depends on the cold water supply from an external cogeneration plant (ST4), is affected by irregularities in the supplier's operation. The cogeneration plant changes its operating mode for a few hours each weekend, producing losses in the stability of the cold water supply (both in temperature and flow).

Moreover, from the ALBA side, the thermohydraulic system, described in [1], cannot move the required design flow in the heat exchange zone due to cavitation problems, which arise when the pump system (called P11) operates on design conditions. For this reason, the operating flow was reduced by 33% to protect the pumps from such phenomenon, worsening the heat transfer efficiency between ALBA and ST4 (see detailed description in [2]).

The thermal instability promoted by these factors affects the stability of the photons generated in the synchotron's ring and, therefore, the quality of the experiments performed by scientists.

Seeking to solve the local problem, this study focuses on investigating whether the cause of cavitation in P11 pumps is a bad configuration of the distribution panel in the suction zone or a bad dimensioning of the aspiration zone.

For this research, CFD (Computational Fluid Dynamics) systematic studies, global calculations and flow measurements are applied.

MAIN PUMPING SYSTEM: P11 PUMPS

Operation

P11 is the main pumping system of ALBA, composed by a couple of pumps which intersperse every 6 months their operation to avoid excessive wear or overload.

The pumps are fed by the hot water from the accelerator, after passing through filters and the three pipes connected to them (see Fig. 1). The flow is then redirected towards a group of heat exchangers before reaching the storage tank, where the water is cooled with the incoming flow from ST4.

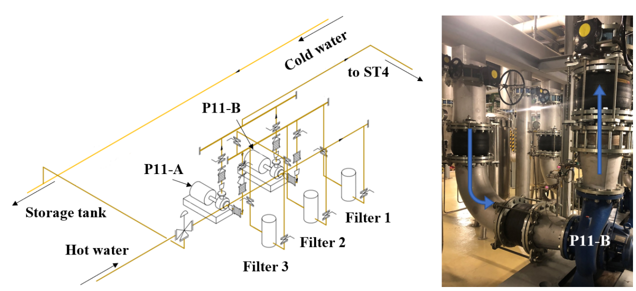

Figure 1: Schematic of the overall circuit studied (left) and photography of the P11 pumps (right).

Encountered Problems

Different problems have been detected in the P11 system during its operation in recent years:

- Reduced flow rate to avoid cavitation problems at nominal value.

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- Non-uniform geometry of the suction zone, distribution panel, which produces a flow imbalance detected with ultrasound reading.
- Oscillatory behaviour measured with ultrasound in the suction branches, which could be due the pump or the geometry of the suction zone.
- Anti-vibration effect of expansion sleeves cancelled when connecting pressure gauges with rigid tubes.
- Possible presence of foreign bodies as sponges trapped in the distribution zone from past experiences [3].

Cavitation

The NPSH required by the manufacturer is 2.42 m for 647 m^3/h. Under current operating conditions at 430 m^3/h, the pressure gauge reading in the suction zone is 1.6 bar, value over the NPSH limit taking 23 °C water conditions.

However, there are still exploding bubbles noises which indicate cavitation. Therefore, the conclusion that the NPSH complies may be questioned by a possible malfunction of the pressure gauge, and/or a high pressure gradient in the suction zone.

On the other hand, a poorly designed aspiration zone could promote high speeds and/or a complex, unstable distribution, which is also a source of cavitation. A situation expected to worsen with flow rate increases from 430 to the nominal value of 645 m^3/h.

A high-level CFD study has been conducted, as it is the only engineering tool that allows to confirm whether there are high pressure gradients and/or complex velocity distributions in the suction zone.

CFD MODEL

Geometry

The geometry used includes the general manifold in the aspiration zone and a simplified model of the pump impeller (see Fig. 2), as confidentiality prevents access to its drawings.

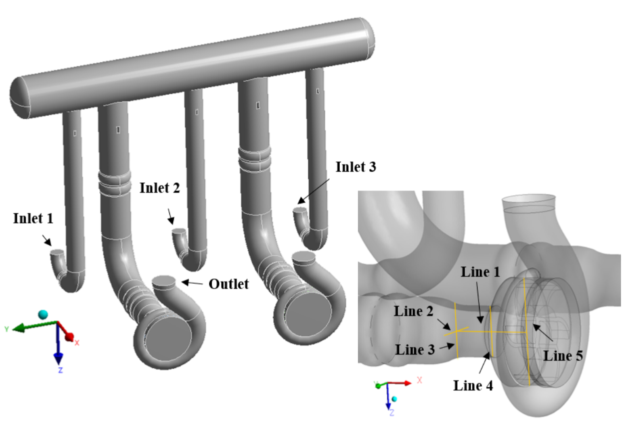

Figure 2: Boundary conditions and lines set to extract data from the 3D model of the system.

The mesh used has 3,570,085 elements. Moreover, an ideal setup of the pump together with a 6 m straight pipe was simulated with a mesh of 1,825,999 elements. For both cases, the lines depicted at Fig. 2 have been used to extract the data presented on the following section, being lines 2 and 3 at the current pressure gauge location.

Boundary Conditions

At the inlets, the velocities obtained from uniformly distributing the current and nominal flow rates (see Table 1) and the current non-uniform distribution (see Table 2) as measured by ultrasound were applied.

Table 1: Current and Nominal Flow Regimes

Case	Flow rate [m^3/h]	Angular velocity [rpm]
Current	430	1372
Nominal	645	1475

Table 2: Current Distribution of the Total Water Flow (referenced as **non-uniform conditions** hereinafter)

Inlet 1	Inlet 2	Inlet 3
36.441%	33.377%	30.182%

In the simulations, the movement of the pump blades has been implemented in the rotor area following the real behaviour of the system.

A zero value has been set as the reference pressure at the pump outlet. Water at 23 °C is considered, together with steady, isothermal and no-slip walls conditions.

RESULTS & DISCUSSION

Experimental Measurements

As part of the research, a hydraulic test on the system was performed, forcing a flow increment on the P11 from 430 to 585 m^3/h. As observed in Table 3, aspiration pressure tends to decrease up to 1.24 bar, a value which would leave the system far below the NPSH limitation given by the manufacturer. The precision of the pressure gauges remains to be investigated to confirm the validity of the measurements.

Table 3: Pump P11-B Aspiration Zone System's Total Flow and Average Pressure Measurements

Flow [m^3/h]	430	450	505	548	585
Pressure [bar]	1.59	1.55	1.45	1.35	1.24

Convergence Results

According to the reference variables defined in `ANSYS Workbench` as residuals, asymptotic results were obtained in all simulated cases for an average of 800 iterations with a trend below 10^{-2} in continuity, and 10^{-3} in the velocity field (see Fig. 3).

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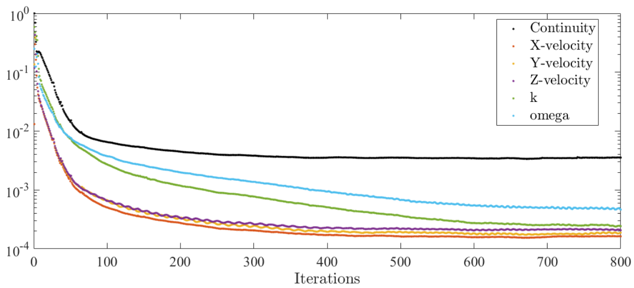

Figure 3: Residuals of continuity, velocity field, k and ω in a reference case (430 m^3/h, k-ω SST model at uniform conditions).

Laminar and Turbulent Models

In order to validate the conditions set, a study was initially carried out without the pump to later add its geometry together with its dynamics. For both situations at 430 m^3/h, a comparison of the velocity and pressure distributions obtained in the lines defined in Fig. 2 for different models was performed: laminar, k-ε, k-ω and k-ω SST.

The results show matching velocity distributions between models at all the lines considered (see Fig. 4). As for pressure, differences of maximum 4 % between turbulent models with equal trend distributions were obtained, allowing the use of the k-ω SST model in the rest of analysis. The laminar model is not valid as the flow's Reynolds value of 762,000 indicates for an average velocity of 3 m/s and water at 23 °C.

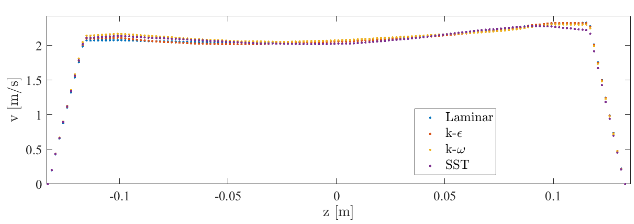

Figure 4: Comparison of velocity distributions at line 4. Case with uniform inlet distribution at 430 m^3/h.

Comparison of Flow Conditions

First, the uniform and non-uniform flow conditions were compared with the ideal setup results for each regime considered (see Table 1). As Fig. 5 clearly shows, the uniform and non-uniform velocity distributions are similar, differentiating from the ideal distribution in the centre of the pipe. Such behaviour is repeated with both flows. Figure 6 allows to appreciate the velocity distribution in the gauge section.

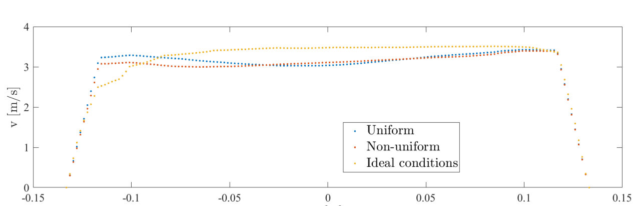

Figure 5: Velocity distributions at line 4 for 645 m^3/h.

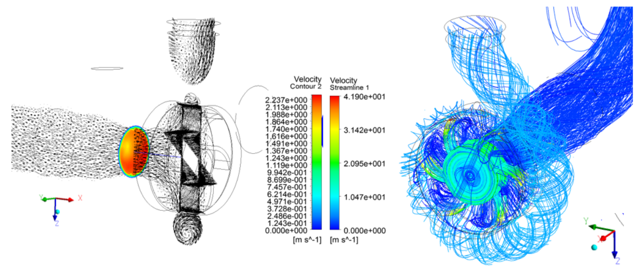

Figure 6: Flow at 430 m^3/h (a) left: velocity distribution at the gauge section; (b) right: streamlines around P11-B.

Regarding the pressures, an approximately constant distribution is obtained in all directions. The uniformity in the suction inlet tube allows to conclude that the readings of the pressure gauge installed in the area of lines 2 and 3 (see Fig. 2) is representative.

The main difference between regimes is given in the order of magnitude of the velocity as it can be observed in Fig. 7, going from a maximum of 2.12 to 3.2 m/s. However, such values fall above the limits established by the literature regarding adequate velocities in the suction zone of centrifugal pumps, becoming a problem to be solved [4, 5].

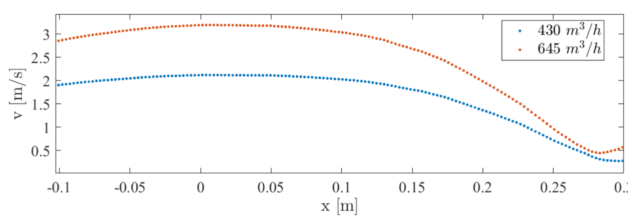

Figure 7: Velocity distributions at line 1 for both flow regimes. Case with uniform inlet distribution.

The study carried out has allowed to verify that the manometer readings are representative, although to work at nominal flow the pressure value in the suction zone should increase to comply with the NPSH limit. Moreover, the velocities reached by the fluid in the aspiration zone must be reduced to enter the recommended limits.

On the other hand, the existing rigid tubes must be changed to avoid vibrations transmission. Moreover, the manifold must be redesigned and the pumps must be changed or a third must be added to distribute the flow between two and keep another one as backup.

Finally, this research has been dedicated to the aspiration zone, but the impulsion zone immediately after the pump remains to be investigated.

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