THERMO-FLUID NUMERICAL SIMULATION OF THE CROTCH ABSORBERS' COOLING PINHOLES FOR ALBA STORAGE RING

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Abstract

The ALBA Synchrotron Light Facility crotch absorbers, that remove the unused storage ring radiation, incorporate an internal cooling system composed by a number of parallel pinholes and by the corresponding stainless steel inner tubes inserted into each of them. Water flows in the resulting annular sections to evacuate the total heat power. Around each inner tube, a spiral wire is fixed along the whole length with a given pitch height in order to enhance the convection heat transfer. The influence of several design parameters on the absorber thermo-fluid behaviour has been evaluated by means of the CFD software ANSYS CFX®. In particular, the wall heat transfer coefficients and the pressure losses through a single pinhole have been evaluated for a range of different flow rates and pitch heights. Moreover, some modifications of the end wall geometry have been simulated as well as the effect of reversing the flow direction inside the channels. Finally, the critical crotch absorber type 3 has also been simulated and the limiting pitch height-flow rate combinations have been found based on the available driving pressure of the cooling system.

INTRODUCTION

Most of the synchrotron radiation generated by the bending magnets in the Storage Ring (around 95%) is absorbed in the crotch absorbers. An important challenge in the engineering of the crotch absorbers is the ability to withstand the temperature and thermal stress induced by the high heat load in the component materials within the accepted safety limits. For the critical crotch absorbers the peak linear and surface power densities at normal incidence are about 64.4 W/mm and 246.2 W/mm^2 respectively, and the maximum total power is about 6.78 kW as presented in [1].

Due to this thermal load, the crotch absorber must be carefully designed to guarantee longevity and good performance. A flow of water at 23 °C circulates inside the absorber through a series of pinholes to cool it. Hence extensive Computational Fluid Dynamics (CFD) work has been conducted on various aspects of a single pinhole design such as the spiral wire pitch height, the flow rate, the direction of the flow and the end wall geometry. This work is of interest since few information is available for design, only the empirical correlations from [2] provide the wall heat transfer coefficients for a couple of pitch heights in a similar pinhole design but with different dimensions. Based on the previous results, several pinholes connected in series have also been simulated.

The current design of ALBA crotch absorbers is shown in Fig. 1. A detail of the spiral wire at the end wall and the two possible flow directions, forward and reverse, are indicated in Fig. 2.

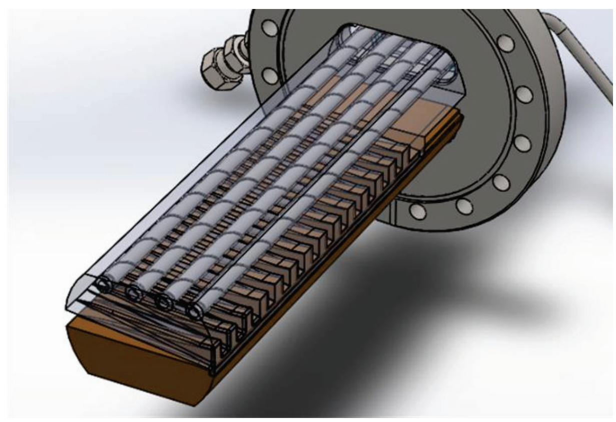

Figure 1: Transparent view of a crotch absorber to visualize the internal cooling pinholes with the spiral wire.

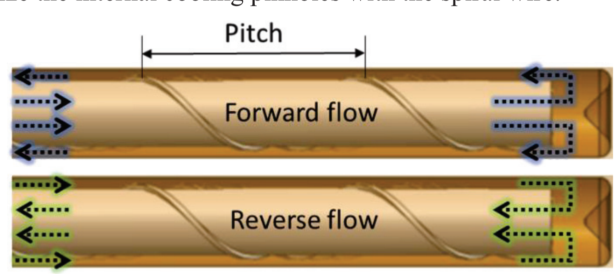

Figure 2: Pitch height of the spiral wire. Forward and reverse flow rate directions inside the pinholes.

CFD MODEL

A mesh sensitivity analysis has been carried out to identify the optimal mesh for the model. As a result, a final mesh of about 1.5 M elements with good quality has been used for a single pinhole. The total thermal load has been uniformly distributed along the contact wall surface with the fluid. At the inlet, the mass flow rate has been imposed ranging from 0.03 to 0.09 kg/s. At the outlet, the boundary condition has been set constant to a relative

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pressure of 0 Pa. The Shear Stress Transport (SST) turbulence model has been used.

SINGLE PINHOLE

Effect of Pitch and Flow Direction

For a fixed mass flow rate of 0.06 kg/s, the effect of increasing the pitch height from 0.005 to 0.05 m on the pressures loss and the average wall heat transfer coefficient is shown in Fig. 3 and Fig. 4, respectively. Both parameters tend to decrease as the pitch is increased. The maximum heat transfer coefficient and pressure loss are found for the minimum pitch height. For pitch heights above 0.03 m, the effects are insignificant.

In relation to the flow direction, a slightly higher heat transfer coefficient is achieved in the whole range of flow rates with the reverse sense. Moreover, the pressure losses are significantly reduced. Therefore, the global performance of the reverse flow is clearly superior to the forward flow.

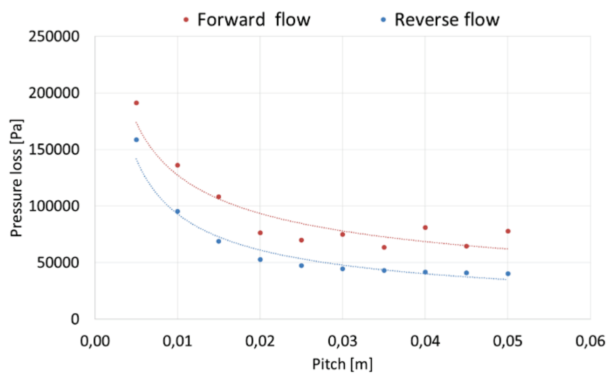

Figure 3: Pressure loss as a function of pitch height for forward and reverse flow.

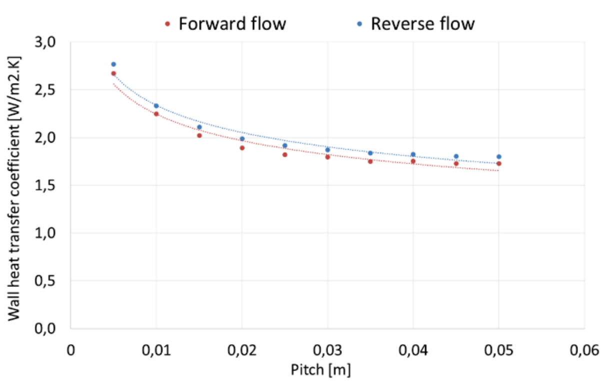

Figure 4: Wall heat transfer coefficient as a function of pitch height for forward and reverse flow.

The flow streamlines inside the pinhole for a reverse flow rate of 0.06 kg/s and a pitch height of 0.03 m are plotted in Fig. 5. The guiding effect of the spiral wire on the flow orientation is clearly observed within the annular section.

Effect of Pitch and Mass Flow Rate

The effect of increasing the forward flow rate is observed in Fig. 6 and Fig. 7 for the pressure loss and the average wall heat transfer coefficient, respectively. For the reverse flow, analogous results are obtained.

The pressure losses increase following a power law as the flow rate increases. Meanwhile, the heat transfer coefficients appear to increase linearly with the flow rate. The results obviously indicate that the maximum heat transfer coefficient is found for the highest flow rate and the minimum pitch height. For this condition, the maximum pressure loss is also found.

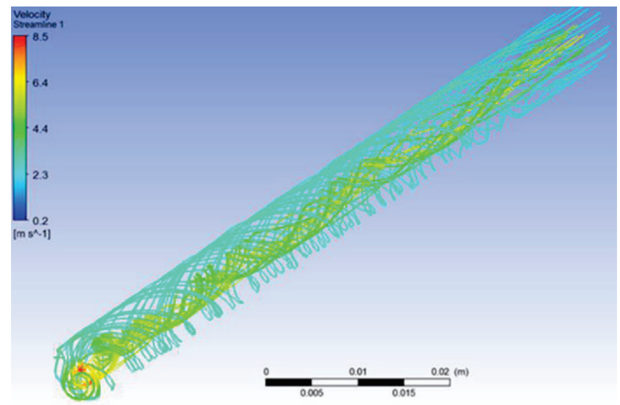

Figure 5: Flow streamlines indicating velocity magnitude.

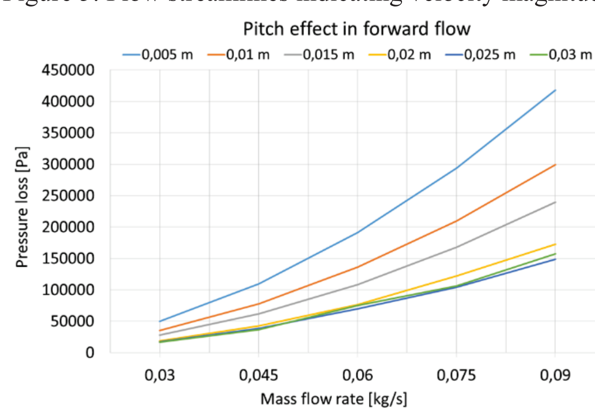

Figure 6: Pressure loss as a function of forward mass flow rate for different pitch heights.

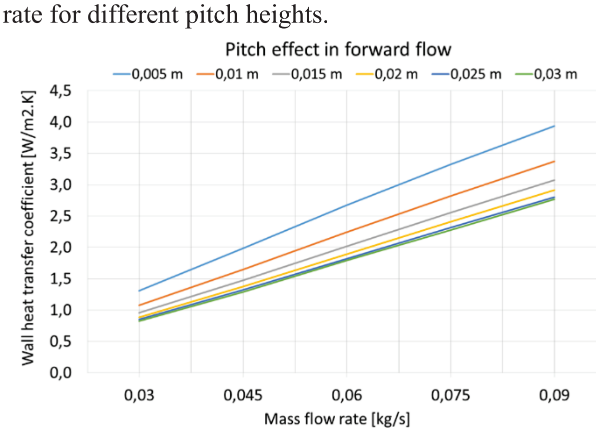

Figure 7: Wall heat transfer coefficient as a function of forward mass flow rate for different pitch heights.

Effect of end Wall Geometry and Mass Flow Rate

As it can be seen in Fig. 5, the strongest flow perturbations and maximum velocities are found at the end of the pinhole. In this location also the maximum temperatures are found as shown in Fig. 11. Consequently, a verification of the already predicted influence of the end wall geometry [1] has been carried out. The current flat wall and two cone-type configurations (inward and outward) have been simulated to determine the optimal one.

The pressure losses and the average wall heat transfer coefficients have been compared in Fig. 8 and Fig. 9, respectively, for the three geometries in the case of reverse flow and a pitch height of 0.015 m. It can be observed that the geometry change has an insignificant effect on the average heat transfer but a significant effect on the total pressure loss. The inward cone presents the minimum pressure losses for all the mass flow rates. Therefore, this wall geometry optimizes the flow 180° turnaround at the end of the pinhole.

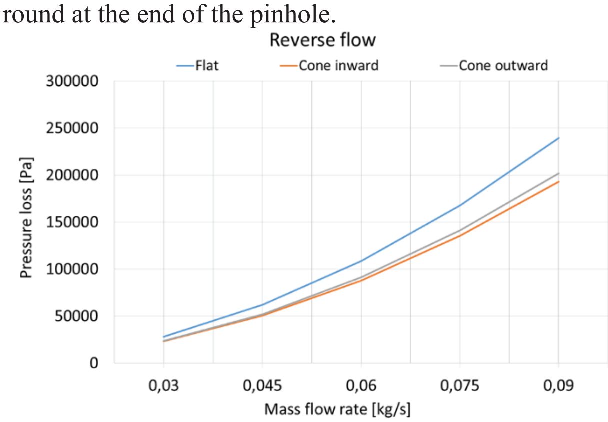

Figure 8: Pressures loss as a function of reverse mass flow rate for different end wall geometries.

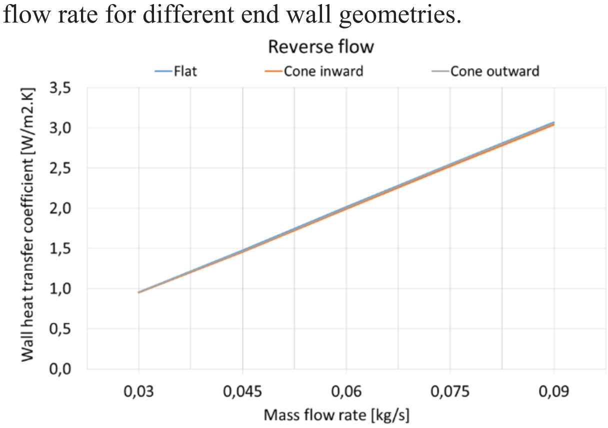

Figure 9: Wall heat transfer coefficient as a function of reverse mass flow rate for different end wall geometries.

MULTIPLE PINHOLES

To finish, the complete cooling system of a type 3 crotch absorber composed of two independent circuits with 4 pinholes each has been simulated. Given the symmetrical design of the piece, only the performance of one circuit has been considered and the results of pressure loss have been presented in Fig. 10.

The current cooling system of the Storage Ring can provide a maximum pressure level at the entrance of the crotch absorbers of about $6{\cdot}10^5$ Pa (6 bar). As a result, the unfeasible combinations of flow rate and pitch height have been shaded in Fig. 10 with red colour. Thus, only the remaining values are the possible ones to design an adequate system from the hydraulic point of view.

In Fig. 11, the wall temperature distribution indicates that maximum levels are found at the end walls of two pinholes located on the left.

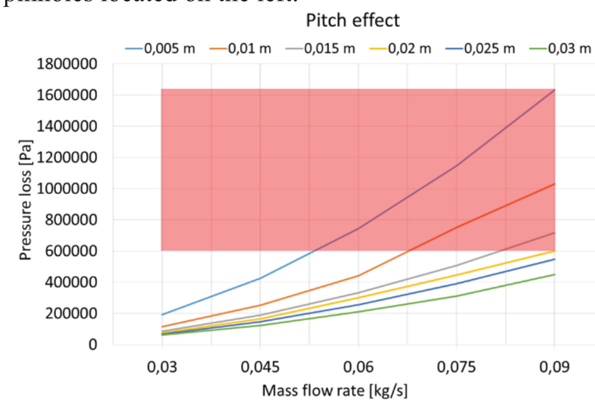

Figure 10: Pressure loss as a function of mass flow rate for different pitch heights in crotch absorber type 3. Red area conditions are not possible due to insufficient driving pressure.

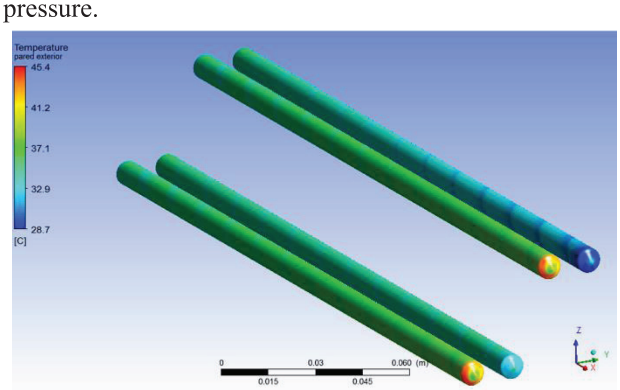

Figure 11: Wall temperature distribution on a set of 4 connected pinholes of the crotch absorber type 3.

CONCLUSION

The CFD simulation of the thermo-hydraulic behaviour of the crotch absorber's cooling pinholes has leaded to the following conclusions:

- Minimum pitch height and maximum flow rate maximizes the convective heat transfer but also requires the highest driving pressure.
- Reverse flow performance is better than forward one.
- Optimal end wall geometry is outward cone type.
- SR available driving pressure limits the choice of design parameters.

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[2] G. Heidenreich and L. Schulz (PSI), private communication.