NUMERICAL SIMULATION OF THE AIR CONDITIONING SYSTEM DESIGN FOR THE 3 GeV TPS STORAGE RING

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Abstract

The air conditioning (AC) system for the 3.0 GeV Taiwan Photon Source (TPS) is currently under the design phase. This paper presents the latest design of the air conditioning system for the TPS. The capacity of the air handling unit (AHU), the dimension and layout of air exits and air exhausts were specified. Numerical analysis was applied to simulate the air flow and temperature distribution in one of 24 sections storage ring. A 1/12 experimental hall was also simulated.

INTRODUCTION

Taiwan Light Source (TLS), the first third-generation synchrotron radiation facility in Asia, has been operated for more than 16 years since the first beam stored in the storage ring. Although the reliability and stability of the light source have been upgraded for years, TLS has gradually lost its advantage of competition due to its limitation of straight sections and available space for new IDs. In order to meet increasing demand for more state-of-the-art researches, the TPS project was proposed and designed to achieve targets of low emittance, high brightness, stability and reliability. Each subsystem of the TPS will apply the most advanced and reliable techniques to achieve this goal.

Our studies show that thermal effect is one of the most critical mechanical factors on the beam stability. Thus, the design of the AC system of the TPS is crucial to the beam stability. Our operation experiences of the AC system in TLS and AC systems of some foreign advanced accelerators provide valuable references for the design of the TPS AC system. We had constructed a mock-up of 1/24 section of storage ring tunnel to simulate installation and alignment of each subsystem, as shown in Figure 1. The AC system will also be equipped inside to simulate the flow field and temperature distribution. Before the physical experiment, we applied the CFD technique on the design of the TPS AC system, as we had applied on the TLS [1]-[3].

In this study, we performed CFD technique on both TPS storage ring tunnel and the experimental hall.

Simulation Area

Figure 2 shows 3D schematic view of one 1/12 of the TPS storage building. The whole building shown in the figure may be divided into 5 areas, i.e., A. control and instrumentation area, B. utility corridor, C. storage ring tunnel, D. beam-line area, and E. outer area.

Figure 1: Mock-up of 1/24 section of TPS storage ring tunnel.

The ceiling of the storage ring tunnel is omitted in this figure. There are two cases of CFD simulation analysis presented in this paper. One is for the storage ring tunnel (C area) and the other is for the experimental hall. Here we define the experimental hall as the continuous space including area B, overhead of C, area D and ground floor of E.

The AHU for the storage ring tunnel is located near the maze door on B area, as shown in the figure. The AHUs for the experimental hall are distributed in A and E areas, not shown in the figure.

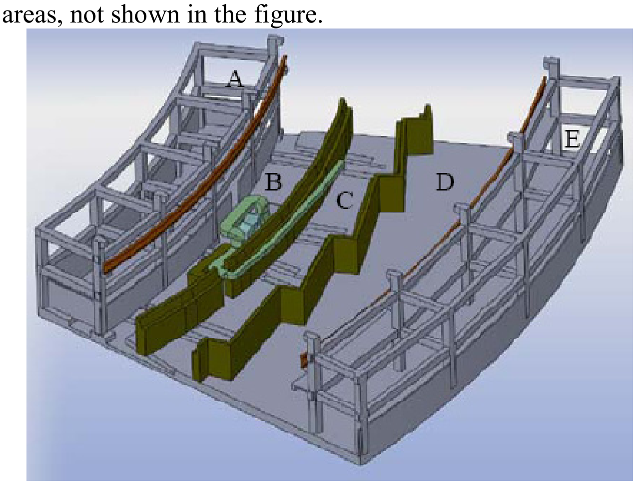

Figure 2: 3D schematic view of one 1/12 of the TPS storage building.

GOVERNING EQUATION

The basic governing equations include the continuity equation, the momentum equation and the energy equation. They can be written in Cartesian-tensor form:

Continuity equation:

$$\rho_{,t} + (\rho U_i)_{,j} = 0 \quad (1)$$

Momentum equation:

$$(\rho U_i)_{,t} + (\rho U_j U_i)_{,j} = -P_{,i} - (\rho \overline{u_i u_j})_{,j} + \rho g_i \quad (2)$$

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Energy equation:

$$T_{,t} + (U_j T)_{,j} = (\alpha T_{,j})_{,j} + \Phi \qquad (3)$$

where

t = time
ρ = density
U_i, U_j = mean velocity in x_i and x_j directions, respectively
P = pressure
$\overline{u_i u_j}$ = Reynolds stress
g_i = gravity acceleration in x_i direction
T = temperature
α = thermal diffusivity
Φ = dissipation function

STORAGE RING TUNNEL

Model Construction and Mesh Generation

Because the whole space of the storage ring tunnel is too large to simulate, we divide the storage ring tunnel into periodically symmetric 24 sections, assume periodic boundary condition for each section and only simulate one section.

Magnets of the storage ring and booster, girders, two front ends, one cable tray, air exits and air exhaust at the maze exit are modeled in the simulation, as shown in Figure 3. The XYZ coordinates is shown and the length unit is mm. The maximum and minimum X and Y coordinates are about (20,594, 3,346) and (82,225, 71,233), respectively. The height of this tunnel is 2.8m. There are total 157,140 tetrahedral meshes generated in the whole space about 274 m^3 in this case.

There are 6 air exits and 6 booster magnets respectively located on upper and lower zones of the inner wall, also left side in the figure. The air exhaust at the maze exit is also located on the inner wall, about at the XY coordinate of (4,000, 73,800).

Boundary Conditions

Boundary conditions are assumed according to designed data of each subsystem. A cross-sectional area was generated through one air exit. The air velocities at each air exit at X,Y and Z directions are -1.5 m/s, 5 m/s and -1.5 m/s, respectively. The air temperature at each air exit is set as 20 ^oC. All magnets of the booster and the storage ring, the cable tray, two front ends are set as heat sources. All girders, walls, the ceiling and the floor are assumed adiabatic.

Simulation Results and Discussion

Figure 3 shows the simulated air vectors in the storage ring tunnel. The length of each vector in the figure is proportional to the magnitude of that vector. The air velocity at air exit is about 5.43 m/s. There is a virtual cross-sectional plane formed through one air exit. Because air exits are distributed upper zone in the tunnel, as the figure shown on the cross-sectional plane, a clockwise circulation around the girders and magnets is formed and air velocities on the upper zone are apparently larger than those on the lower zone.

The air velocities on two sides connecting to adjacent 1/24 sections are also shown. Because the supplied air from air exits flows slightly on the -X direction, -1.5m/s, most air velocities shown on those two sides are also on the negative X direction.

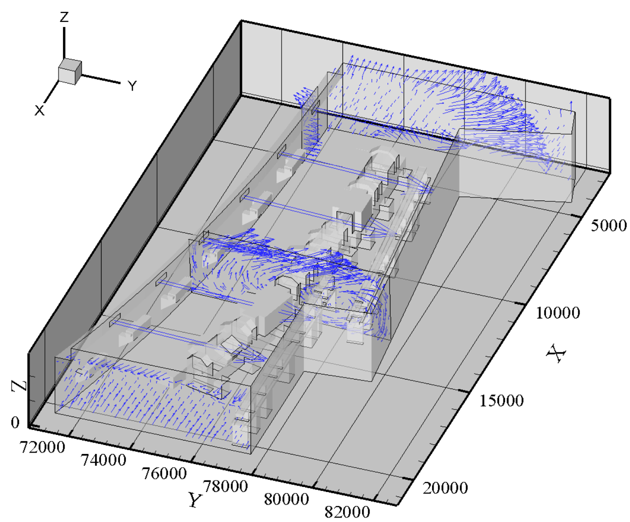

Figure 3: Model of 1/24 storage ring and simulated air velocity vectors.

Figure 4 illustrates the simulated temperature contour in the storage ring tunnel. The temperature ranges from 20 ^oC to 23^oC. It shows that high temperature areas are distributed on the booster magnets and the cable tray. Because the supplied air from air exits flows slightly on the -X direction, -1.5m/s, temperature distribution on the upper area (small X coordinate area) is generally lower than that on the lower area (larger X coordinate area).

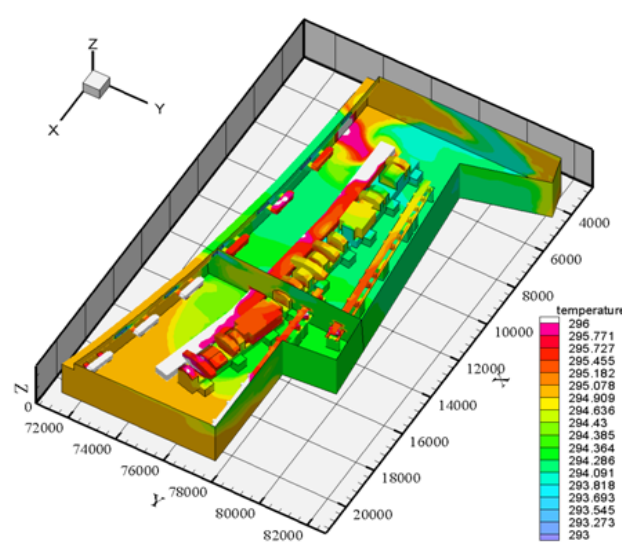

Figure 4: Simulated temperature distribution in the storage ring tunnel.

EXPERIMENTAL HALL

Model Construction and Mesh Generation

Likewise, we divided the experimental hall into periodically symmetric 12 sections and only simulate one of them. Air exits and air exhausts are respectively distributed on the ceiling and the ground floor of outer area (E area in Figure 2).

The storage ring tunnel and an AHU are modeled in the simulation, as shown in Figure 5. The XYZ coordinates is also shown and the length unit is mm. The maximum and minimum X and Y coordinates are about (104,799, 66,943) and (13,113, -39,829), respectively. The height of this tunnel is 10.7m. There are total 2,082,581 mixed meshes generated in the whole space about 12,212 m^3 in this case.

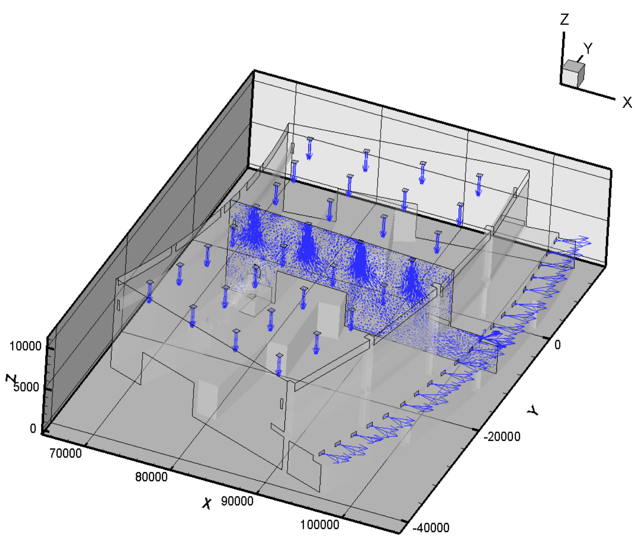

Figure 5: Model of 1/12 experimental hall and simulated air velocity vectors.

Boundary Conditions

Because beam-lines are not modelled, there are few heat sources in this case. There are two window zones respectively designed on tops of inner and outer walls for natural light. We set 40 W/m^2 of heat flux from solar radiation on these two zones. The heat flux from the ceiling is set 20 W/m^2. There is only one apparatus of cooling load, the AHU for the storage ring tunnel, modelled in this case.

The air velocity at air exits is set as 8 m/s normal to the ceiling. The air temperature at air exits is set as 20 ^{o}C. All walls and the floor are assumed adiabatic.

Simulation Results and Discussion

Figure 5 shows the simulated air vectors in the experimental hall. The length of each vector in the figure is also proportional to the magnitude of that vector. There are 32 0.6 m × 0.6 m air exits and 20 0.4 m × 0.8 m air exhausts distributed on boundaries. According to the law of conservation of mass and the assumption of incompressible flow, the air velocity at air exhausts is larger than that at air exits.

There is also a virtual cross-sectional plane formed through four air exits. There is a sudden convergent area on the ground floor of outer area, where air exhausts located. Thus, we can see air with increasing velocity flows into that area on the virtual cross-sectional plane.

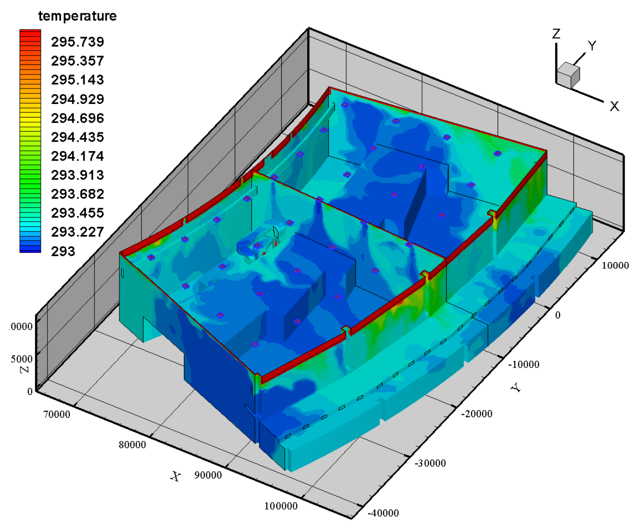

Figure 6: Simulated temperature distribution in the experimental hall.

Figure 6 illustrates the simulated temperature contour in the experimental hall. The temperature ranges from 20 ^{o}C to 25.74 ^{o}C. It shows that high temperature areas appear on inner and outer window zones and zone near the ceiling due to radiation. On the other hand, low temperature area is on the top wall of the storage ring tunnel due to direct cool flow from air exits.

All simulation results are valuable references for further modification.

ACKNOWLEDGEMENT

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