DESIGN OF THE WATER-COOLING SYSTEM FOR THE VACUUM SYSTEM OF THE TPS STORAGE RING

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Abstract

Taiwan Photon Source (TPS) has been under construction since 2009. Its vacuum system was designed to operate at a level 10^{-10} torr; the heat load from the bending magnet was almost confined to the bending chambers. The system to cool water was designed to protect vacuum equipment, including the vacuum chambers and absorbers, to avoid melting by synchrotron light and decreasing thermal desorption. Three cooling loops serve the aluminium chambers, with four for the copper absorbers in one unit cell. One prototypical unit cell, including an arrangement of the control terminal, piping and monitors of flow rates and temperatures, will be tested.

INTRODUCTION

TPS is a synchrotron storage ring of energy 3 GeV and circumference 518.4 m divided into 24 periods of unit cells (bending sections) and long (ID) straight sections, of which six have length 12 m and 18 have length 7 m. An aluminium alloy (A6061T6) was chosen for the material of the vacuum chamber because of its large thermal conductivity, absence of magnetism, ease of fabrication and other benefits. Bending chambers designed with a large triangularly shaped chamber and a crotch photon absorber located downstream that intercept most synchrotron radiation from the bending magnet confine and evacuate the load of gas induced by synchrotron light in the chamber. The pumps near the crotch absorber in the antechamber increase effectively the pumping speed and decrease the number of pumping ports on axis so as to produce a smooth vacuum surface with small impedance. There are 48 bending chambers in the TPS storage ring; each dipole magnet generates power ~9 kW at beam energy 3 GeV, beam current 500 mA and bending radius. 8.4 m. The power density of the bending magnet results in area power density 261 W/mrad^2, linear angular power density 68 W/mrad and beam size 0.34 mrad.

To remove the heat load from the synchrotron light and to decrease the thermal desorption of the vacuum chambers, a water-cooling system is designed that provides deionized water (DIW) at 25 ^{o}C for the vacuum chambers (Al system) and absorbers (Cu system) at pressure 7.5 kg/cm^2. In the storage ring, the DIW system is divided into 48 manifolds for 24 sections of the accelerator machine, as shown in Figure 1. Each manifold consists of filters, valves to balance the flow, and sensors of temperature, pressure and flow rate, which provide an optimally balanced flow and real-time status. One flexible pipe was designed to be placed between the DIW tubes and the accelerator machine to prevent the transfer of vibration [1].

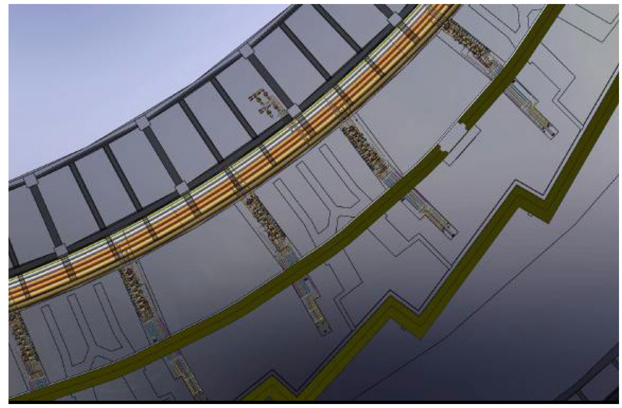

Figure 1: Manifolds of the accelerator machine.

LAYOUT OF THE VACUUM SYSTEM

Figure 2 illustrates the layout of 1/24 section of the TPS vacuum system, which has two sector gate valves with RF shielding (SGV), two pumping gate valves (PGV), two front-end valves (FEV), six metal angle valves (MGV), six ionization gauges (IG), ten non-evaporable getter (NEG) pumps, six sputtering ion pumps (IP), and eight turbo-molecular pumps (TMP). The vacuum chambers inside the cell contain two straight ducts S3, S4, and two bending chambers B1, B2; the S1 and S2 ducts are located at both ends of the cell isolated with the two SGV [2].

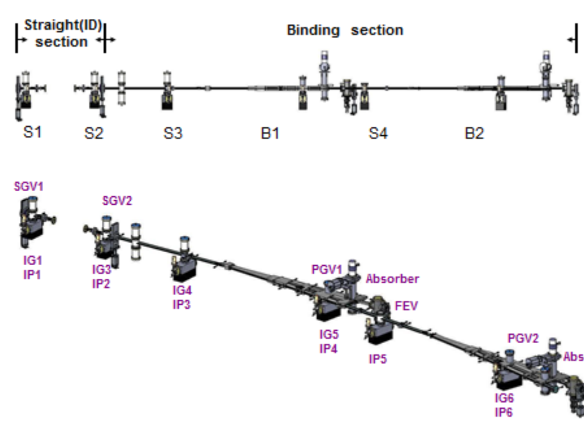

Figure 2: Layout of a typical vacuum system for one unit cell.

In a straight section, aluminium tubes of elliptic shape (68×30 mm^2) are chosen as straight beam ducts; the channels for cooling water are extruded on both sides of the beam ducts. To protect the vacuum parts with no cooling-water channels, for example bellows, beam-position monitor (BPM) blocks and valves avoiding illumination by synchrotron light, photon absorbers made of aluminium are arranged before that equipment. The length is calculated from the formula shown in figure 3; an additional length 2 mm is reserved for the case of beam mis-steering [3]. A 3D schematic drawing of a photon absorber before a BPM block is shown in Figure 4.

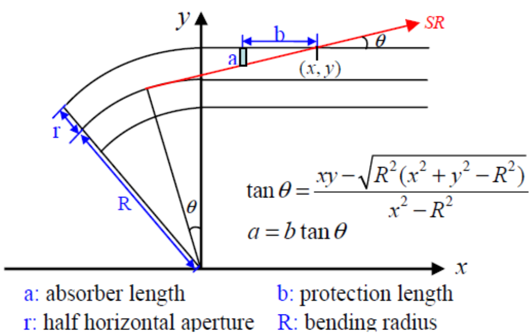

Figure 3: Sketch of synchrotron light incident on a straight section.

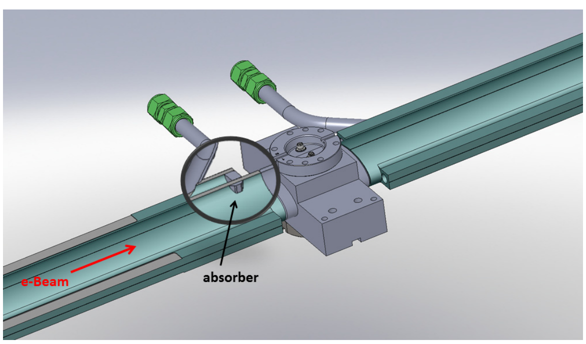

Figure 4: 3D schematic drawing of absorber in front of BPM block.

In a bending chamber, a crotch absorber made of oxygen-free highly conductive (OFHC) copper installed downstream of the bending chamber intercepts more than 70 % of the power load of a bending magnet as shown in Figures 5 and 6. Bending chambers number three types: B1 for an insertion device (ID), B2 for a bending magnet (BM) and B3 for IR. Each crotch absorber has a similar design except a varied length and aperture. Two loops of cooling water, one in the top block and the other in the bottom, are built into the absorber [4]. Besides a crotch absorber, each bending chamber has designed eight cooling channels crossing two half plates of the chamber to cool the chamber so as to decrease thermal desorption, especially during machine study.

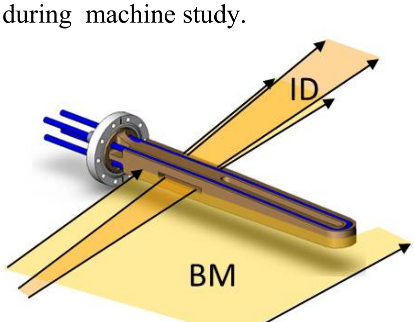

Figure 5: 3D schematic drawing of a crotch absorber.

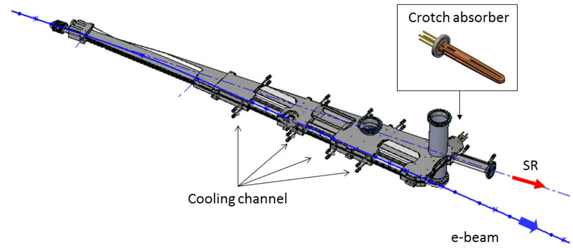

Figure 6: Layout of a B1 bending chamber.

DESIGN OF THE COOLING SYSTEM

According to the plan of the utility group, two manifolds are used for a 1/24 section of straight (ID) and bending sections of the vacuum system. The capacity of each manifold is 8 gal min^{-1} DIW for the Al system and 12 gal min^{-1} for the Cu system located under the girder, as shown in Figure 7. Table 1 presents the specifications of the Al and Cu systems. The Al system includes S1, ID, S2, S3, B1, S4 and B2 (or B3) chambers. Because more than 70 % of the heat power from a bending magnet is intercepted by a crotch absorber, the remaining power that illuminates a straight chamber is roughly 31 W in S1, 3.9 W in S2, 11.7 W in S3 and 91.65 W in S4. Based on a horizontal deflection of an ID, the S2 and S3 chambers behind an ID section must use cooling channels at both sides to protect the vacuum chamber, whereas S1 and S4 use only one illuminated side. Two manifolds for the Al system are divided into four branches: the first for S1, ID and S2, the second for S3 and B1, the third for S4 and B2, and the fourth is spare. Each branch is set at flow rate 6 L/min with needle valves located in the inlet and outlet piping; temperature sensors (PT100) mounted in a cooling tube near the vacuum chamber monitor the temperature of the cooling water. A cooling tube (diameter 16 mm) of a S-chamber has a flow of speed ~0.8 m/s, but 1.44 m/s for the tube (12.6 mm) of the B-chamber. To maintain a flow speed < 2 m/s is important to decrease corrosion that occurs in welded joints of aluminium cooling pipes and the chamber.

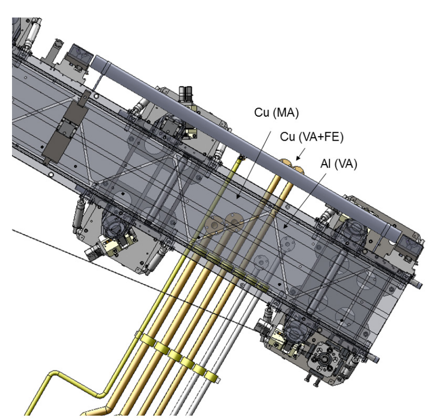

Figure 7: Manifolds under a girder.

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Table 1: Specification of Al and Cu Systems

	Cu system	Al system
capacity / gal min^{-1}	12	8
pressure / kg cm^{-2}	7.5	7.5
branches	4	3
flow rate /L min^{-1}	12	6
diameter /mm	7.5	12.58 (9.4)
flow speed /m s^{-1}	4.53	0.8 (1.44)

The Cu cooling system for an absorber has a similar design in which one manifold is divided into two branches, one for the top and the other for the bottom of each crotch absorber. The thermal analysis displays that the maximum temperature ~136 ^{o}C occurred in a 60^{o} V-shaped groove; the cooling tube is about 83 ^{o}C, as shown in Figure 8 [4].

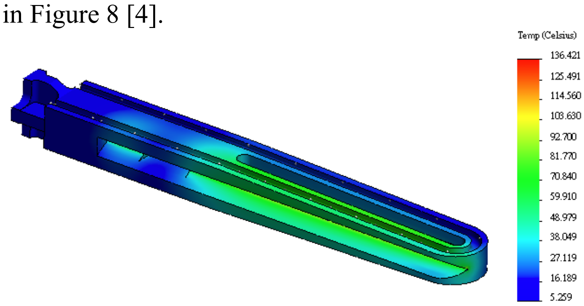

Figure 8: Thermal analysis of a crotch absorber

One 3D drawing shown in Figure 9 has been finished for a simulation and the interface was checked with other groups. Four control terminals, two for the Al system and two for the Cu system, located before the girders provide the information about the cooling system. In the control terminal, the flow rate 6 L/min is set on adjusting needle valves in both inlet and outlet piping, with 3 L/min of the flow sensor to trigger an output.

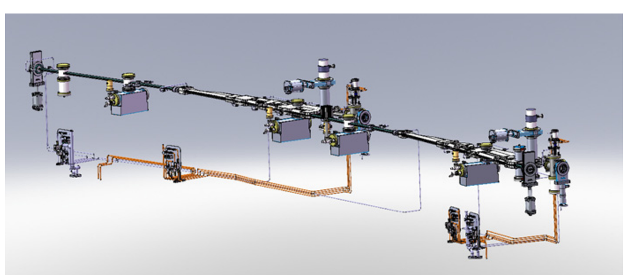

Figure 9: 3D drawing of a cooling system in one bending cell.

MONITOR AND INTERLOCK

To monitor the status of cooling system is necessary. More than 30 PT-100 temperature sensors in a 1/24 section are installed in the cooling loops and the vacuum equipment to ensure that each works well. The readings of the rate of flow of cooling water are monitored and recorded. Figure 10 shows a logic flow chart of the temperature-monitoring system in Taiwan Light Source (TLS) [5]. The temperature readings and trigger outputs of a flow meter are taken as interlock conditions of the temperature-monitoring system. The temperature-monitoring system of TPS is under construction, but the concept of its design will be similar to that of TLS.

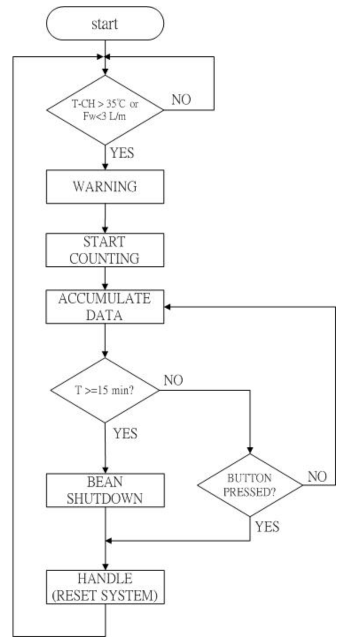

Figure 10: Logic flow chart of the temperature-monitoring system in Taiwan Light Source (TLS).

CONCLUSIONS

In the cooling system for the TPS vacuum system as designed, three Al cooling loops and four Cu cooling loops effectively protect the vacuum equipment and decrease thermal desorption. One 3D drawing of the vacuum cooling system has been completed for optimization and interface checks with other groups. One prototype, including the arrangement of control terminals and piping will be tested in a SR04 cell and an inspection of the vibration will be tested.

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