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VIBRATION MEASUREMENTS IN THE TPS VACUUM SYSTEM

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Abstract

The Taiwan Photon Source (TPS) is currently operated in top-up mode for users. In order to improve the stability of the synchrotron light source, vibrations related to the vacuum system have been investigated and improved by turning off pumping systems and reducing the flow rate in chamber cooling water circuits. In this paper, vibrations in different vacuum chambers with normal cooling water condition were investigated, their sources were recorded and clarified and properties of different materials for water tubes were also compared.

INTRODUCTION

Stability is always of great importance in synchrotron radiation facilities, especially in low-emittance light sources, such as the TPS. It was suggested, that the electron beam stability should be less than 10% of the electron beam size. Among all vibration sources, those induced by the water cooling system were obvious because intense water cooling is necessary, especially in the vacuum and magnet systems. Vibrations of vacuum chambers caused by the cooling water create eddy currents in quadrupole magnets, which in turn produce bending fields then deflecting the electron beam.

Two vibration sources related to the vacuum system have been studied and improved. Specifically, a 29 Hz signal originating from mechanical vacuum pumps was identified and disappeared when the pumps were turned off [1]. Another vibration improvement was achieved by decreasing the cooling water flow. The power spectral density (PSD) of horizontal orbit oscillations is reduced by a factor 2-3 at frequencies under 100Hz when the water flow is reduced from 10 to 6 LPM, while the vertical orbit oscillations were almost completely eliminated in the range of 40-120Hz.

In this paper, design criteria for vacuum water cooling systems are discussed and chamber vibrations were observed. Some solutions, like reducing the water pressure or using plastic pipes, were also studied to understand vacuum system vibrations better.

SYSTEM DESIGN

Aluminium is the chosen material for the TPS vacuum system. There are three types of vacuum chambers, elliptical and race track square beam ducts are used for straight sections and large triangle shaped chambers, fabricated from two 4m long half plates, for the bending sections. In bending chambers, a photon absorber is installed in the downstream end thus intercepting more than 70% synchrotron light from the bending magnets. Each of the 24 vacuum section chambers comprising the whole ring consist of one straight section and one cell section. 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 by two SGVs. In addition to the necessary fixed supports for beam position monitors (BPM), another 7 fixed support points are used in each regular cell. A 3D drawing of the vacuum chambers, supports and cooling water system in the cell section is shown in Fig. 1.

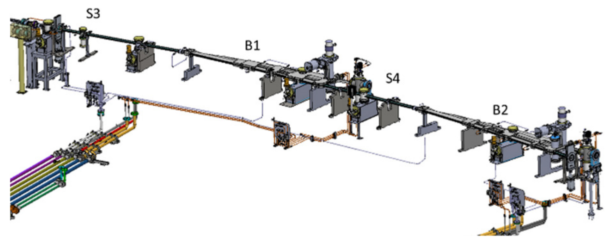

Figure 1: 3D drawing of one vacuum cell.

In order to take absorb the synchrotron radiation heat load and reduce the thermal desorption in vacuum chambers, two water cooling systems are used. The first one is used for the aluminium chambers (Al system) and the other is for crotch absorbers and stoppers made of copper material (Cu system). In the Al system, there are two extruded cooling water channels on both sides of the straight beam ducts and across the two half plates of the bending chambers. In contrast, two cooling water circuits, one in the top and the other in the bottom of the absorber Cu. Metal water pipes were chosen for the vacuum system because metallic material has a better radiation resistance.

In the TPS, all main cooling water equipment, including towers, chillers and pumps, are located in a remote utility building to eliminate or at least reduce vibrations from heavy-duty machines. The cooling water pipes to the storage ring building are distributed into 48 manifolds for 24 sections before entering the storage ring tunnel. Each manifold consists of filters, flow-balance valves, temperature sensor, pressure and flow rate meters providing optimal flow balance and real-time status [2]. Rubber hoses were used between water manifolds and accelerator to reduce vibration propagation from cooling-water facilities [3].

In the storage ring tunnel, sub-manifolds exist for the vacuum cooling water system. There are seven branch circuits used in each vacuum section, including three circuits for the Al system and four circuits for the Cu system. In each sub-manifold branch, needle valves, located at the inlet and outlet piping, allow to adjust the water flow rate. Temperature sensors (PT100) are mounted in the outlet piping to monitor the water temperature and 230μm filters are installed in the inlet piping to avoid

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clogging. The sub-manifold layout is also included in Fig. 1 [4].

To deal with the distribution of the synchrotron radiation power, the flow rate in each Al branch circuit was set to 6 litre per minute (LPM) and to 10 LPM in each Cu branch circuit. In Table 1, the specifications of the Al and Cu systems are compiled. We noticed that the Reynold's number (*Re*) far exceeded the turbulent flow threshold, *Re* ~2000, in both water circuits. In turbulent flow, water interacts with the channel walls while flowing through for effective heat transfer, but the disadvantage is that vibrations occur simultaneously. In addition, vibrations by turbulent flow along with a rigid channel wall transmit also vibrations from other cooling system components, like fittings, filters and valves, which do not fit well or demand a higher pressure. Those elements were relocated into sub-manifolds, well removed from vacuum chambers. To shorten the length of cooling tubes and isolate vibrating elements, is a good policy to reduce vibrations induced into the cooling water system.

Table 1: Specification for the Al and Cu Water Cooling Systems

	Cu system	Al system
Branches	4	3
Flow rate /L min^{-1}	10	6
Diameter /mm	7.5	12.58 (9.4)
Flow speed /m s^{-1}	4.53	0.8 (1.44)
Reynold's number	36335	10644(13427)

VIBRATION MEASUREMENT

In general, vibrations are a compound phenomenon, being caused by mechanical sources, induced by turbulent cooling water flow or being excited by other elements. Vibrations in the vacuum system were observed, clarified and classified.

A seismic accelerometer WR731-207, optimized for ultra-low frequencies, together with a NI cDAQ controller and a NI 9234 module, were used for the measurements. All three-axes were aligned such that the *x*-axis was parallel to the electron beam, the *y*-axis pointing in the horizontal and the *z*-axis in vertical transverse direction to measure vibrations in all three directions separately. The set-up for the experiments is shown in Fig. 2 for the straight section on the left side and on the right side for the bending chamber.

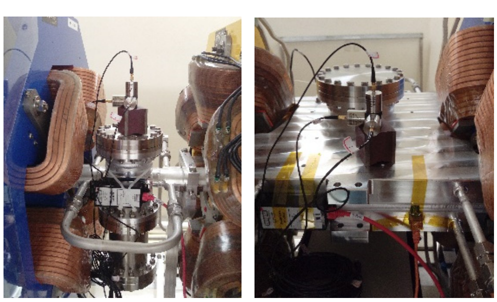

Figure 2: Experiment set-up in vacuum chambers.

The conditions without cooling water flow was measured first. Table 2 lists the vibration results during machine maintenance. Three vacuum sections, R02, R14 and R11, were chosen and four locations distributed along each vacuum section, from upstream to downstream, were monitored. The lowest power spectrum density (PSD, g^2/Hz unit) signal was detected to be of the order of 1E-14 and was treated as the background level. At S3, S4 and B2 measurement points of section R02, the amplitude of the PSD was three orders of magnitude higher than the background level, with a major vibration peak located near 60 Hz and its harmonics for all three axes. The cause was not clear, but we suspected vibrations induced by electrical devices since the 60 Hz frequency is used in Taiwan for electrical power.

Table 2: Vibration Results without Cooling Water Flow

		straight section (S3)		bending section (B1)		straight section (S4)		bending section (B2)	
		major peak	amplitude	major peak	amplitude	major peak	amplitude	major peak	amplitude
R02	X	60.2	1.3E-11	119.7	9.9E-14	59.7	2.3E-11	60.2	2.6E-11
	Y	59.8	1.6E-11	119.9	1.4E-13	179.9	2.2E-11	180.1	2.2E-11
	Z	60.4	2.1E-11	120.0	1.9E-13	59.9	3.4E-11	60.2	2.2E-11
R14	X	119.6	4.8E-13	18.3	2.6E-14	180.2	4.6E-14		
	Y	120.2	7.5E-13	141.4	2.3E-14	141.9	3.6E-14		
	Z	119.9	8.0E-13	60.0	6.5E-14	61.2	5.1E-14		
R11	X							179.6	8.2E-14
	Y							70.4	4.7E-14
	Z							179.8	8.2E-14

Next, the vibrations for normal flow conditions, 6 LPM in the vacuum chambers and 10 LPM in absorbers, were measured as illustrated in Fig. 3. Compared to the background data listed in Table 2, eight to nine orders of magnitude higher signals were observed. The major peak is still located near 60 Hz and it's harmonics and is found also in parts of the SR02 section but the amplitude is five orders of magnitude lower than under normal flow conditions. Vibrations from mechanical water pumps propagating along water pipes were suspected. Comparing two types of vacuum chambers, the elliptical beam duct (S3, S4) and the square chambers (B1, B2), we found no significant difference.

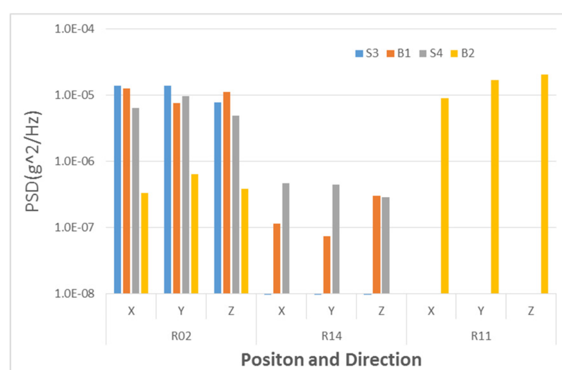

Figure 3: Vibration results under normal cooling water flow condition.

Another issue was to distinguish between vibrations from Al or Cu cooling circuits, where the water flow in the Cu system is higher than in the Al system. But the Cu cooling circuits are only used for Cu absorbers located at the bending chambers in contrast to the Al circuits which are in all chambers including beam ducts and bending chambers. From measured results, as listed in Table 3,

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there is no significant difference between those two water flow conditions.

Table 3: Comparison of Vibrations for Two Different Water Flow Conditions

		Al flowed + Cu flowed				only Al flowed			
		straight section (S3)		bending section (B1)		straight section (S3)		bending section (B1)	
		major peak	amplitude	major peak	amplitude	major peak	amplitude	major peak	amplitude
R14	X	120.1	2.0E-07	179.7	1.2E-07	180.0	8.1E-08	119.9	1.2E-07
	Y	60.1	1.4E-07	180.2	9.7E-08	119.9	9.1E-08	120.4	8.0E-08
	Z	119.5	8.9E-08	120.0	1.2E-07	120.0	1.4E-07	120.1	1.4E-07

Vibrations induced by the cooling water pressure was also studied, where the sub-manifolds were considered as vibration sources because of high pressure conditions like filters, control valves, etc. Accelerometers were mounted near the outlet tube of sub-manifolds in the Al cooling system of section R02. Cooling water pressure specifications by the utility group call for 7.5 Kg/cm^2 but are currently set at 3.7 Kg/cm^2. Three different water pressures of 3.7 Kg/cm^2, 2.5 Kg/cm^2 and 1.7 Kg/cm^2 were used while the water flow was kept the same at 6 LPM, by adjusting the needle valves in the inlet and outlet tubes. The measured results are shown in Fig. 4. For three different operating water pressures, all major vibration peaks were located near 60Hz. The PSD spectra were of the order of 10E-5, which is of the same level as observed in sections R02 and R11.

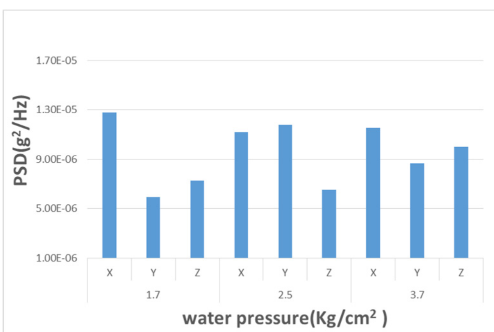

Figure 4: Vibration measurements for different water pressures.

Although no significant vibration difference was observed between sub-manifold and vacuum chambers, a possible damping effect of plastic material tube was investigated. Replacing all metal cooling tubes of a vacuum chamber with plastic was a big risk because of radiation damage, and replacement was not easy in a short time because some cooling circuit connectors were located in the small gap between vacuum chambers and magnets. During the last machine shut down, 10cm long plastic tubes were installed near the floor to keep them away from high radiation and additional supports were connected to the floor behind the plastic tubes. The dimensions of the plastic tubes are the same as the metal version and their installation is shown in Fig. 5.

The PSD data in vacuum chambers was compared between all-metal tubes used in section R14 and partial plastic tubes in section R20. A little improvement of the PSD spectrum was observed as shown in Fig. 6, especially in the straight section.

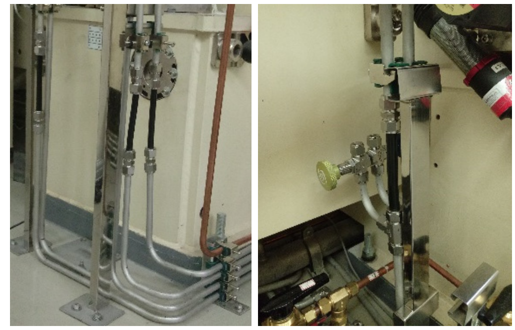

Figure 5: Plastic tubes as installed in section SR20.

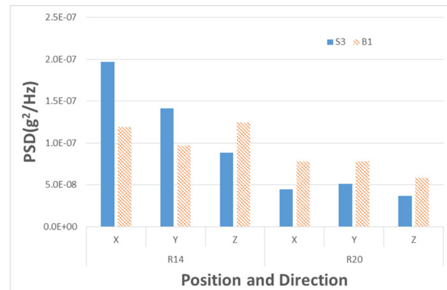

Figure 6: Comparison of vibration measurements between two different materials for the water tubes.

CONCLUSIONS

Vibrations in vacuum chambers were observed and analysed. Main vibration source in the vacuum system was induced by the Al water cooling flow through all aluminium chambers, even though the water flow in absorbers located in the same bending chambers was higher. There was no significant difference of vibration detected between beam ducts and plate shaped chambers. Using plastic water tubes was helpful to improve the vibration propagating from manifolds. Related vibration issues, such as coupling between magnets and girders, induced by electric devices and optimization of cooling circuits, will be studied in the future.

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