

# THERMAL TESTS ON TPS BEAM POSITION MONITORS

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## Abstract

Beam position monitors mounted in straight sections exhibit an unusual temperature rise which is attributed to poor thermal and electrical conductivity of the stainless steel BPM chamber, to the vicinity to RF-bellows, and the large button electrode size to get superior signal levels. Thermocouples tied to BPM flanges and RF bellows show that the temperature could reach 50 °C when storing a beam current of 400 mA and BPMs located between two RF-bellows in RF cavity sections responds by even 5-10 °C higher values than average. To resolve this issue, off site experiments and simulations were conducted to further understand the heat flow in the whole structure. In this paper we discuss more details of these studies.

## INTRODUCTION

By the end of 2015, unusual BPM heating was observed while trying to store a current of about 200 mA. At that time, thermocouples (PT100) were placed on the side of an RF bellows to detect the occurrence of such an event. Then we increased the number of thermal detectors and mounted them on suspicious hot spots of BPMs and RF bellows. In addition, irreversible thermal labels were applied to mitigate for any deficiency due to a shortage of archive channels (see Fig. 1). More and more fan coolers were set-up in warming areas. In the middle of 2016, all straight sections were equipped with fans and in some very serious sections water cooling was used to enforce heat dissipation so as to allow running a current in excess of 300 mA without beam trip which is mostly caused by temperatures exceeding 50 °C and triggering an alarm system (Table. 1). So far, a beam current of 520 mA could be successfully stored in the TPS for about 5 min while a stored current of 400 mA would last for at least one day and standard operation is presently set to 300 mA. We compared heat dissipation capabilities by convection, fan and water cooling, and marked potential hazard sections to respond directly to the stored current. Moreover, the temperature distribution up- and down-stream of straight sections is observed and most of them show the same tendency: The highest temperature is likely to be found at RF bellows, which may be attributed to the RF fingers in the bellows. Off-site tests and simulations are proceeding to understand the impedance effects of BPMs, bellows and tapered structures. This paper will discuss and summarize related studies.



Figure 1: Monitoring location for the PT100 and thermal labels (left). Fan cooling system (right).

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Table 1: RF cavity sections (**bold**); IU and EPU sections (*italic*); sections with water cooling (regular letters). (Note: additional water cooling on R08 and removal of R19 are based on experimental considerations.)

R01	R02	<b>R03</b>	R04	<b>R05</b>	R06
R07	<b>R08</b>	R09	R10	<b>R11</b>	<b>R12</b>
<b>R13</b>	R14	R15	<b>R16</b>	R17	<b>R18</b>
<b>R19</b>	R20	<b>R21</b>	R22	<b>R23</b>	R24

## THE TPS SR BPM CONFIGURATION

The TPS storage ring is composed of 24 DBA cells [1] where each cell includes seven BPMs, five of them being distributed along the bending section and two are located up- and down-stream of straight sections (S1 and S2) (Fig. 2). FOFB correctors are mounted directly to RF bellows which are close to BPMs at S1 and S2. Considering electric conductivity and robust mechanical properties, use of stainless steel is superior to aluminium when it comes to dissipating eddy currents; therefore, the BPM chambers in straight sections are made of stainless steel which is also the material for adjacent RF bellows. Moreover, the shape and cross section of the straight section vacuum pipes is different from those in bending sections, the former being of racetrack shape (68\*20 mm) while the latter is elliptic (64\*16 mm). The aperture of the BPMs is a 64\*16 mm racetrack designed to be compatible with RF bellows. Generally, there is just one bellows next to each BPM up- (S1) and down-stream (S2) of the straight sections, but in some long straight and RF sections, BPMs are surrounded by two RF bellows (see Fig. 3). The loss factors for BPMs and bellows located in straight sections are 0.0639 V/pC and 0.0612 V/pC, respectively [2] and the average power is about 10W for a stored beam current of 300 mA which is higher than for the BPMs in bending sections with a loss factor of 0.0335 V/pC for the elliptical aperture.



Figure 2: Layout of one TPS SR cell.

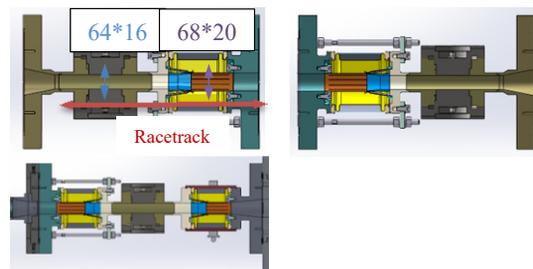


Figure 3: BPMs in the upstream (top left) and downstream (top right) end of straight sections. Bottom: BPM in IU, EPU, and RF sections.

### TEMPERATURE DISTRIBUTION

Over the past two years, efforts were made to mitigate the heating problems arising from BPMs and RF bellows located in straight sections. On average, the temperature rises 5-8 °C per 100 mA in straight sections and considerably more in RF cavity sections where it could be as high as 10-11 °C per 100 mA, Figure 4 and 5 show temperature readings for 300 mA at RF bellows being about 5 °C higher than those on BPMs. However, the BPM temperatures are 2 °C higher than at RF bellows while both of them are fan cooled to 10-20 °C (see Fig. 5). A water cooling system is installed on sections where the temperature raise is much higher than elsewhere: These are the IU, EPU and RF straight sections and most of them are connected to two up- and down-stream RF bellows. Systematic data records show that water cooling is efficient to reducing RF bellows heating but not BPM heating, as shown in Fig. 6. This is explained by the fact that the BPM electrodes are the main components to be heated while they have poor conductance to cooling; furthermore, they are very small limiting heat conductance and therefore water cooling works only locally. With fan cooling the temperature dependence on beam current can be reduced to under 4 °C per 100 mA which is superior to natural convection (see Fig. 7). Thermal labels show that the most serious regions are concentrated around up- and down-stream RF bellows with similar tendencies (see Fig. 8). It is interesting to note that without fan or water cooling, the highest temperature was observed at bellows while active cooling shifts the high temperature points to nearby collars. This phenomenon might come from the conductivity properties of stainless steel being the origin of resistive wall impedance. Similar BPM structures with racetrack apertures (68\*20 mm / 68\*8 mm) made of aluminium stay under 40 °C for 400 mA even though they are only cooled by natural convection (see Fig. 9). The different temperature versus current dependence for the two BPM chambers (SS316 and Al) is quite obvious.

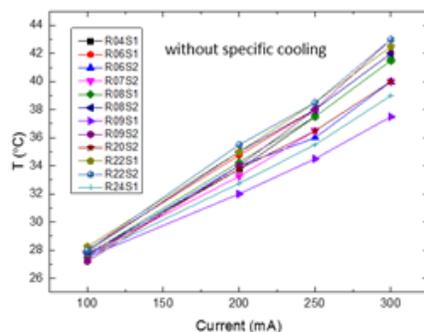


Figure 4: Dependence of the BPM flange temperature on stored beam current.

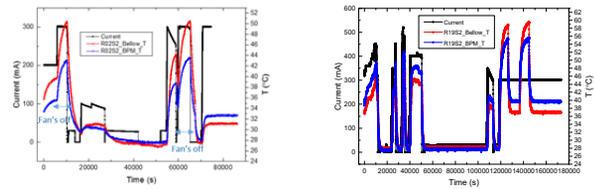


Figure 5: Fan tests in standard(left) and RF(right) sections.

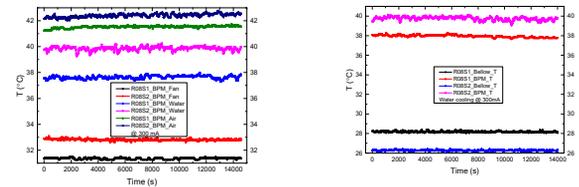


Figure 6: Various cooling methods(left) and water cooling.

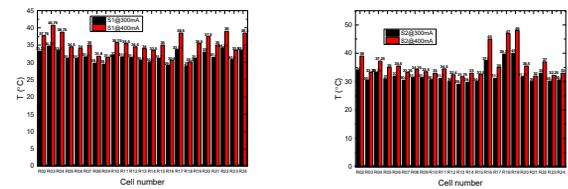


Figure 7: Fan cooling can suppress a rapid temperature rise under high current conditions.

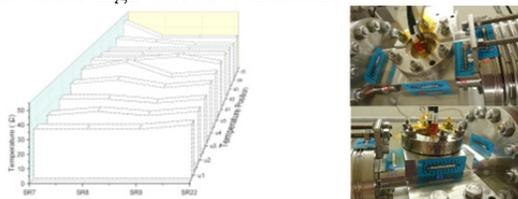


Figure 8: Thermal labels show that most of the heating occurs in RF bellows (u5 & d1) and connected collars (u4 & d2). Test spots are shown on the right.

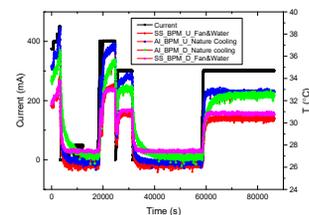


Figure 9: A BPM in an Al chamber is less sensitive to current heating compared to a SS chamber which needs extra cooling.

### EXPERIMENTAL OBSERVATIONS AND DISCUSSIONS

An offsite test was done to simulate the thermal distribution along a vacuum pipe; four electrodes are heated by 2.8 W from four independent electric heaters and two dual-channel power supplies. This setup is

supposed to imitate the heat generated around the BPM electrodes and other places if desired; another test focuses on the heat transport from bellows to BPM. Since a RF bellows is too costly to be used for thermal testing, we try to use a heater on one collar of the BPM chamber providing 8 W to determine the temperature distribution as shown in Fig. 10. As one can see, the BPM flange temperature changes little if heat is conducted from one port to the other in a BPM chamber. That means, the temperature rise of the BPM flange originates mainly in the electrodes and little comes from the bellows. That's consistent with the effect of water cooling on the whole structure; although it greatly reduces the temperature in bellows, it barely changes the BPM flange temperature. The 11 W applied to four electrodes should result in a temperature rise of the BPM chamber of about 20 °C and both chamber collars should get warmer by the same amount. That is different from observations, where we measured a temperature difference between both collars of the BPM chamber in the TPS storage ring. Therefore, we conclude that part of the power on the collar comes from RF fingers of the bellows, stainless steel chambers and taper transitions. It requires about 2 hours for thermal equilibrium which agrees with recorded temperature data from the SR. Simplified thermal simulations are tested by applying 2.8 W to each electrode with the condition that air convection cooling is held to 12 W / m<sup>2</sup> · K at 22 °C. The simulation matches experimental data regarding temperature of the BPM flange and is also at the same level as temperature readings of the BPM flange in the SR during 300 mA commissioning (see Fig. 11 and 12). The temperature rise in the BPM flange is dominated by BPM electrodes except for cases in the RF cavity sections for which the mechanism hasn't been understood yet. More knowledge of impedance effects on the vacuum beam pipe and its consequences are desired.

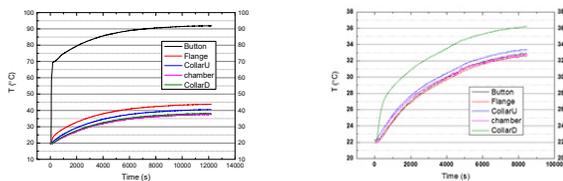


Figure 10: Temperature distribution along the BPM chamber while applying 11 W to BPM buttons (left) and 8 W to the downstream collar of the BPM chamber (right).

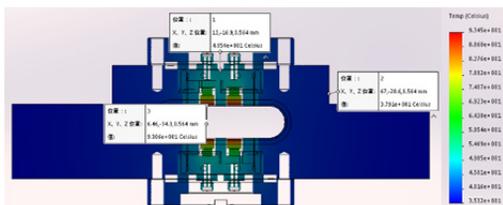


Figure 11: Thermal simulation setup for a BPM (2.8 W/button).

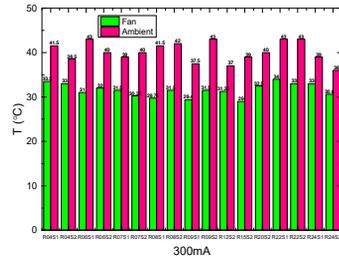


Figure 12: Temperature distribution on BPM flanges along the SR TPS at 300 mA.

### SUMMARY

In summary, the temperature of insertion and RF sections with two RF bellows are more sensitive to stored current compared to other sections; only downstream of the R16, R18 and R19 cavity sections are the three more sensitive ones among 24 cells. Therefore they will be cooled by both fan and/or water cooling. Stainless steel chambers are more sensitive to beam current than Al chambers because of its poor electric and thermal conductivity leading to more severe heating problems. This could be verified by comparing the temperature variation of these two BPM chamber types with the same electrode dimensions and almost the same cross section (SS: 64\*16 and Al: 68\*20). Fan cooling is practical for many cases while water cooling is limited. Therefore all BPM regions in straight sections are equipped with fans to enforce heat dissipation. Generally, the temperature of the BPM flanges increase by 7 °C per 100 mA without effective cooling while nearby bellows warm up by more than 8-10 °C per 100 mA. Owing to poor thermal conductivity of stainless steel chambers, two chief heating sources might be considered, the electrodes of BPMs and the RF fingers of bellows, which warm up the BPM flange and bellows, but hardly influence each other. Few sections are found to have serious heating on reducer flanges (u1 and d5 described in Fig. 8) instead of bellows. It is hypothetically thought that there exist small displacements that enhance the impedance effect of the taper of the reducer flange. To further understand what's going on inside the BPM beam pipe, it's necessary to study each of the impedance effects on the beam pipe. Presently, it could be verified that application of 10 W inside the BPM housing would result in a temperature rise of about 20 °C on the outside surfaces (see left of Fig. 10) allowing to speculate an approximate power for the BPM chamber heating.

### REFERENCES

- [1] C. C. Kuo, *et al.*, "Progress Report of TPS Lattice Design", in *proc. PAC'09*.
- [2] A. Rusanov, "Impedance Study For The TPS Storage Ring", in *proc. IPAC'10*.