TEMPERATURE ISSUES OF THE TPS BPMS

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Abstract

Since the TPS is capable to operate at higher currents, long-term 400mA conditioning runs were conducted. Current-dependent temperature data of BPMs were collected and analysed for both, aluminium and stainless steel BPM chambers. To better understand beam coupling effects in different types of TPS BPMs, electromagnetic and thermal simulation models were established. In this paper, we discuss associated results of such studies.

INTRODUCTION

The temperature rise of stainless steel BPMs located in straight sections of the TPS storage ring have caught some attention during the past years and to better understand this phenomenon, numerical simulations were carried out. The program HFSS is used to find electromagnetic modes inside the BPM structures and GdfidL to evaluate wake field problems [1][2]. The coaxial structure of BPM electrodes can be considered as a transmission line and signals induced on it are transmitted to analog-to-digital converters for further beam positioning determination [3]. In addition to TEM modes, TE and TM modes are also supported by coaxial transmission structures as long as the working frequency exceeds the corresponding cut-off frequency. For short bunches, the frequency spectrum can extend to tens of GHz causing more serious wake field effects compared to longer bunches. Trapped modes around the BPM electrodes have been studied and discussed widely, especially the first higher order mode TE11 (also called H11) in coaxial structures [4]. Starting from the mode TE11, we use HFSS to address BPM button trapped modes and then GdfidL to compute the loss factors for low and high conductivity materials for different bunch lengths. The dissipated power can then be determined with the knowledge of the stored current. Thermal simulations for the BPM bodies are then pursued with Solidworks and finally, simulation results are compared with observations. Studies to completely resolve the issues are still in progress, because of the complicated BPM geometry, taking into account tapered structures and rf fingers. In this paper, we discuss preliminary results in some detail.

BPM BUTTON TRAPPED MODES

The BPM button electrodes are capacitive signal receptors for a transmission line to capture signals from electron bunches which act as an AC current source. Figure 1 shows relevant electrode dimension for the TPS straight section BPM. From theory, we know, that the coaxial cut-off frequency of the TE11 mode is 12.2 GHz (see Fig. 2). The design bunch length is σ_t = 3mm and its Fourier transform , assuming a Gaussian distribution, corresponds to σ_f = 15.9GHz. Therefore, most bunch particles can interact with BPM electrodes via the TE11 mode leading to energy losses to the BPM environment and causing button heating. A larger button size would result in a higher signal although at a lower cut-off frequency for trapped button modes and a compromise has to be made. It is not always necessary to make the TE11 mode cut-off to be higher than one σ_f , while designing BPM electrodes, because it also depends on the vacuum chamber aperture and how much deposited losses on each button are allowable.

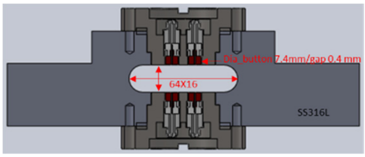
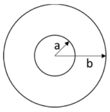


Figure 1: Critical dimensions of the TPS straight section BPM.



$$f_{TE11} = \frac{1}{\pi(a+b)\sqrt{\mu\varepsilon}}$$

Figure 2: Equation for the coaxial TE11 cut-off frequency.

MODELING AND SIMULATION

The code HFSS is a powerful tool to resolve microwave problems. There is no need to simulate the whole structure since it can also deal with sections, where modes easily gather. Since trapped modes are likely captured around the button gap, it is convenient to simulate the feedthrough attached to an electrode alone as shown in Fig. 3. Both end ports are excited independently: the button end is excited by five modes and the SMA end by one. To know more about the interaction, we set the frequency near the frequency of interest and perform a fine scan. After the scans are done, we check the field graphs and regions where they bounce around and get absorbed. An obvious resonance peak at 12.29 GHz of the excitation mode #2 could be observed with the procedure explained above. The *E* and *H* fields of that mode are concentrated around the button electrode identified as the TE11 button trapped mode(Fig. 4). The S11 resonance peak of this mode slightly deviates from 12.2 GHz and is believed to be slightly affected by other parts of the feedthrough. GdfidL is then used to quantify the loss parameter and to save simulation time, only one quarter volume must be analysed due to symmetry. Bunch length and material conductivity are part of the input parameters and the results are compiled in Table1. Although the mesh size can influence the numerical results, we actually ignore those effects because we are only interested in the comparison of the relative magnitude. A finer mesh is recommended for reduced computing errors. For a 3mm bunch length, the loss factor

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL059

of the TPS straight section BPM is about 0.024 V/pC and is reduced to 0.007 V/pC for a bunch length of 5mm. The difference is mainly due to higher order modes in the 20-30 GHz range. It's hard to determine each of them, but it can be inferred that the next higher order modes would reside near 25GHz and compared to the TE11 mode, HOMs are spread over longer distances as shown in Fig. 5. If the pipe material is modified to be almost perfectly conducting, i.e. Aluminium, the loss factor for a 3mm bunch length reduces only to 0.019 V/pC, indicating that conductivity has a minor effect on this issue. It could be confirmed that, the loss factor for the same cross section, same pipe length, same material but smooth beam pipe is about 0.005 V/pC. Figure 6 displays the real part of the impedance for different conditions. Like σ_t and σ_f, the impedance (frequency domain) is the Fourier transform of the wake field (time domain). Changing the bunch length, one could get information within the corresponding frequency bandwidth and by changing the button size, the resonance frequency shift due to the geometry change could be resolved. Resistive wall effects in a small aperture beam pipe, made of finite conductivity material, are evident and it is suggested to take material effects into consideration when it comes to short bunches and small beam pipe apertures. The *H* fields of the TE11 and TE21 modes are along the axis of the feedthrough and integration of these fields across the cylindric side surfaces of the button allows to determine the conductor losses as seen in Eq. 1. With loss factors from GdfidL, the computation represents all losses and the worst case is to assume that all losses are deposited on the four buttons only. One could go through a detailed analysis from the impedance spectrum but since the working frequencies are very high, modes are bundled together and instead of a sharp resonance peak, broad band peaks usually appear, as shown in low and high frequency regions of Fig. 6. Three thermal simulations are made, one is the worst case, where all losses are deposited on buttons, in the second the losses are all on BPM flange surfaces and the third is thought to be close to reality, where the losses are shared between buttons and flanges. For a 500mA stored current, a total average power loss of 12W can be inferred from a loss factor of 0.024 V/pC. The top graph of Fig. 7 represents the case where all power is deposited on four buttons and the middle graph assumes all losses are on inside surfaces and the bottom graph assumes that 7W is deposited on the flat beam pipe and the remaining 5W on the four buttons, a case, we think to be close to reality. We evaluated the magnitude of the losses from the impedance spectrum for different bunch lengths and materials. Both cases indicate that the temperature on the air-side of flanges is almost the same, but the button heating for these three cases differ from each other. It might be the reason for different temperature behaviours in BPMs within the same group. Further wake field studies of the nearby detailed geometrical environment is required.

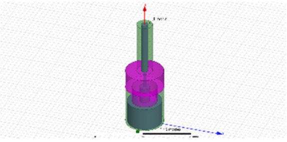


Figure 3: HFSS model for trapped mode simulation.

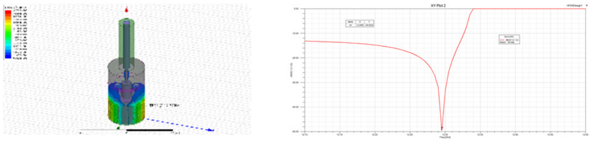


Figure 4: TE11 mode pattern and return loss graph.

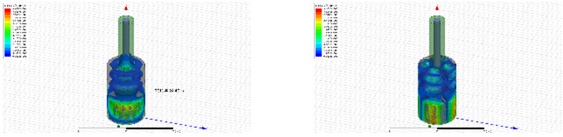


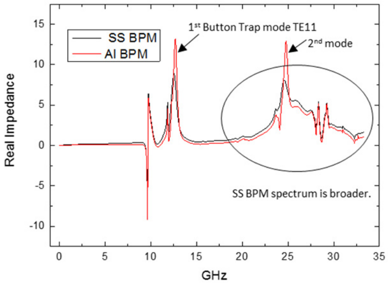
Figure 5: HOMs penetrate the structure more than the fundamental mode.

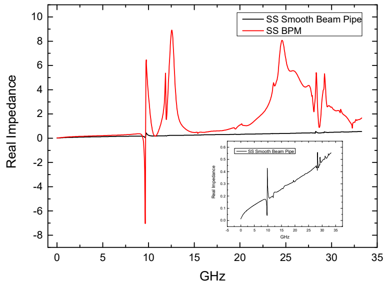
$$P_{conductorloss} = \frac{R_S}{2}\int_S \left|\overline{J}_S\right|^2 ds = \frac{R_S}{2}\int_S \left|\overline{H}_t\right|^2 ds$$

$$R_S = \frac{1}{\sigma\delta}, \delta = \sqrt{\frac{2}{\omega\mu\sigma}} \qquad (1)$$

Table1: Loss factor k in V/pC for Different Cases

bunch length	3mm	4mm	5mm
SS_BPM_64x16	0.02447	0.01298	0.00765
Al_BPM_64x16	0.01947	N	N
SS_Pipe_64x16	0.00496	N	N
Button_6.4	0.02063	N	N





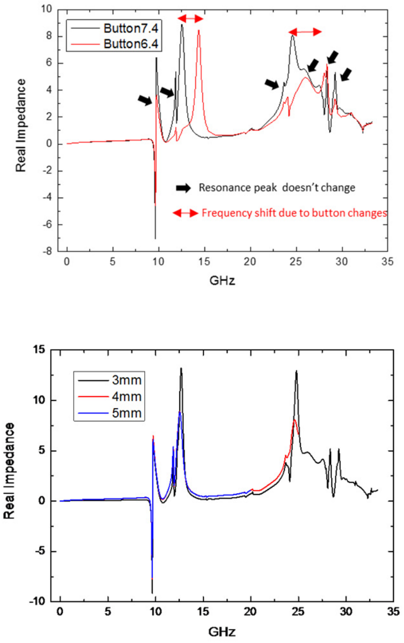


Figure 6: Real part impedance derived from GdfidL wake field computations for different materials, different button sizes and different bunch lengths.

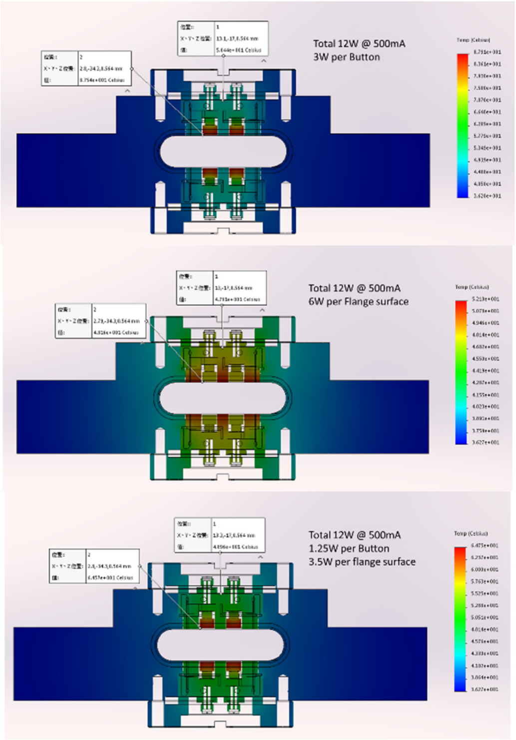


Figure 7: Temperature distribution for three different cases.

DISCUSSIONS AND SUMMARY

During the past two years and at beam currents of 300mA, the temperature of most BPMs was 37-43^{O}C without specific cooling, only natural cooling. Although we don't have natural cooling data for 500mA, an increment of about 10-15 ^{O}C can be reasonably expected. Not only the BPM flanges, but also two SS flanges are found at elevated temperatures and, existing data show that, for a 400 mA beam current, flanges are heated to 39-41 ^{O}C (Fig. 8). SS BPM flanges mounted on an Al chamber in the middle section of the SR05, SR13, SR14, and SR21 chambers seldom experience heating except for SR14 where a nearby bellow is also found to be warmer. The loss factor for a 5mm bunch is 0.07V/pC and that might be the major contribution to the TE11 button trapped mode and the resistive wall effect because electromagnetic fields above 20GHz are barely induced from 5mm long bunches. Considering a finite conductivity, the impedance spectrum is broader in the stainless case than in Aluminium and as for a smooth beam pipe, the resistive wall is characterized as a broadband impedance. Therefore, more attention should be directed to the resistive wall effect when considering very short bunches. It seems that not all the losses are deposited on buttons based on the impedance spectrum analysis. Some sections display serious temperature rises which are attributed to discontinuities in geometry near BPMs and therefore the environment including tapers and rf fingers and their wake effects must be taken into consideration to give a relatively correct picture. In fact, the TPS is operated with 4.5mm bunches and it seems inconsistent that the real BPM temperature data are much worse than numerical computation for the worst case [5]. Normally, 4.5mm Gaussian bunches do not include frequencies above 20GHz and there shouldn't be any TE21 trapped modes around the button. It is, therefore, believed that part of the BPM flange temperature rise comes from somewhere else not all from the buttons. Results of thermal simulation hint that it is the total loss distribution that determines the final temperature on BPM flanges. The percentage of total energy loss on buttons seriously affects button temperature but hardly changes the temperature of air-side flanges as long as the total losses are kept at the same level. Although a resistive smooth beam pipe contributes little to the wake fields, unavoidable discontinuities can create a broadband resistive wall impedance and can interact especially at high frequencies, thus causing more losses being deposited to discontinuities and imperfections. Material selection is critical for devices with high risk to wake fields. Wave guide modes of the beam pipe are not discussed here, but small aperture beam pipes have the advantage of a higher cut-off frequency which could reduce low frequency wake fields. This study is not yet complete and must be expanded to include waveguide modes of the beam pipe and structures near a BPM. So far, we know from wake fields and the impedance spectrum that the 1st and 2nd button trapped modes reside at 12-13GHz and 24-25GHz and they contribute wake losses of about 0.01V/pC. For bunch lengths longer than 4.5mm, the 2nd trapped modes are weaker. A desired design would be to push the fundamental mode frequency as high as possible, but this is not always realistic.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL059

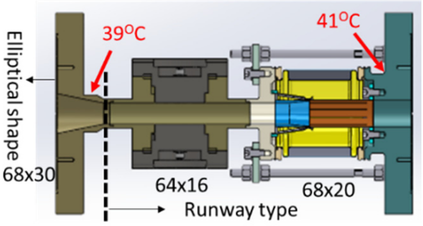


Figure 8: Temperature data in the upstream BPM of SR02.

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