

BPM BUTTON OPTIMIZATION TO MINIMIZE DISTORTION DUE TO TRAPPED MODE HEATING*

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Abstract

The outer circumference of a BPM button and the inner circumference of the button housing comprise a transmission line. This transmission line typically presents an impedance of a few tens of ohms to the beam, and couples very weakly to the 50 ohm coaxial transmission line that comprises the signal path out of the button. The modes which are consequently excited and trapped often have quality factors of several hundred, permitting resonant excitation by the beam. The thermal distortion resulting from trapped mode heating is potentially problematic for achieving the high precision beam position measurements needed to provide the sub-micron beam position stability required by light source users. We present a button design that has been optimized via material selection and component geometry to minimize both the trapped mode heating and the resulting thermal distortion.

INTRODUCTION

Awareness [1] and measurement [2] of BPM button circumferential resonances preceded the design of synchrotrons in which button heating would first become an issue. The problem was studied in some detail in the design of BPM systems for the B-factories at SLAC [3,4] and KEK [5]. With the continuing push for greater brightness, button heating and the resulting thermal distortion has emerged as an issue for the stability of position measurement in light sources, and the problem has been studied in greater detail [6-10]. An informal mini-workshop to discuss this problem and possible solutions was organized concurrent with the recent EPAC conference in Genoa.

As shown in figure 1, the outer circumference of a BPM button and the inner circumference of the button housing comprise a transmission line. This transmission line typically presents an impedance of a few tens of ohms to the beam, and couples very weakly to the 50 ohm coaxial transmission line signal path out of the button. The resonant mode which is consequently excited and trapped can deposit tens of watts of power in the button. The resulting thermal distortion is potentially problematic for maintaining high precision beam position stability, and in the extreme case can result in mechanical damage.

DESIGN RULES

A collection of simple design rules has emerged from the various publications, workshops, and discussions. These rules fall into one of two categories:

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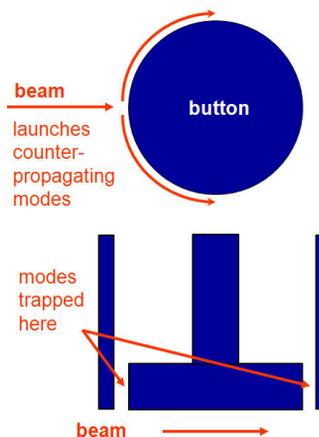


Figure 1: Illustration of the trapped modes.

1. Geometric design rules
 - a. Make the buttons as small as possible consistent with signal power and position measurement resolution requirements – the frequency of the trapped mode is high relative to the position signal frequency, and power at the mode frequency drops off very quickly as it moves into the tail of the coherent beam spectrum.
 - b. Minimize the trapped mode impedance and the resulting power deposited in this mode by the beam – the transmission line impedance is minimized by minimizing its inductance and maximizing its capacitance, resulting in a button which is thick and has a small gap to the outer housing.
 - c. Maximize the power re-radiated back into the beampipe – this is accomplished by making the button thin with a large gap to the outer housing, requirements that are in conflict with minimizing the mode impedance.
 - d. Adjust the button diameter to keep the trapped mode resonance away from strong lines in the beam spectrum to avoid resonant excitation – the strongest lines are at multiples of the bunching frequency, which in the case of bunching at the RF frequency are separated by 500MHz, permitting them to be avoided.
 - e. Minimize the distance from the button to the thermal and mechanical anchors – while previous rules seek to minimize power deposited in the button, this rule seeks to minimize temperature rise and resulting deformation.
2. Materials design rules
 - a. Electrical conductivity – maximize conductivity of the outer circumference of the button and minimize conductivity of the inner

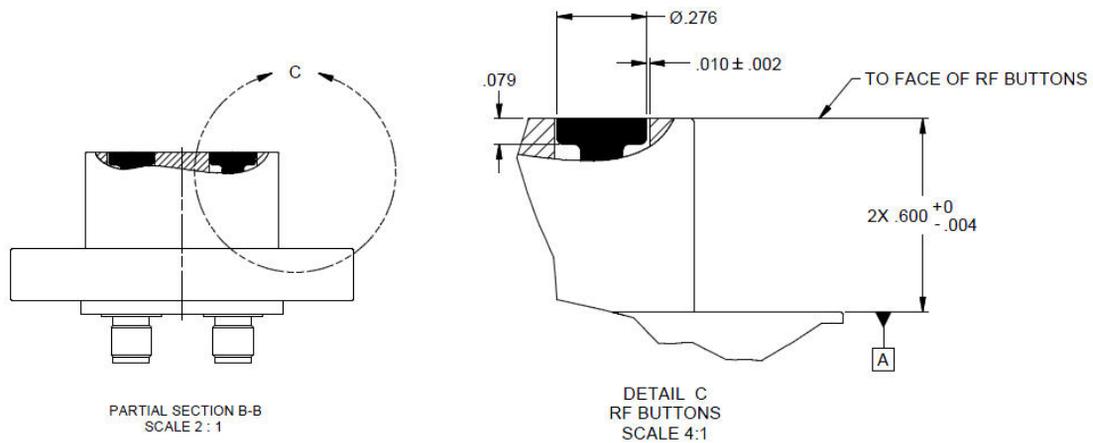


Figure 2: Two-in-one button assembly showing button details (dimensions in inches).

circumference of the shell in the vicinity of the button [6], the difference in resistances resulting in the majority of the trapped mode power being dumped into the well thermally anchored shell, rather than the comparatively isolated button.

- b. Thermal conductivity – maximize thermal conductivity of all materials between the button surface and the thermal anchor.
- c. Thermal expansion – minimize the coefficient of expansion of all materials between the button surface and the thermal anchor.

Prior to optimization of specific internal geometric and materials details of the pickup, attention was given to the tradeoff between horizontal and vertical sensitivities and to button dimensions, as indicated by items 1a thru 1d of the design rules. The result of those preliminary studies is shown in figure 2.

The initial studies [11] made it clear that reducing button diameter from 10mm to 7mm would provide substantial relief from the trapped mode heating problem, without unduly compromising the available power at the 500MHz signal frequency, satisfying design rule 1a. With the 7mm button diameter, a horizontal button separation of 16mm was needed to achieve the desired vertical sensitivity in the 25mm aperture. The mechanical constraints of this comparatively close horizontal spacing resulted in the two-in-one design shown in the figure.

With the overall geometry defined, button dimensions were then optimized [10] via GdfidL simulations to satisfy rules 1b thru 1d. This resulted in a button diameter of 7mm, thickness of 2mm, and spacing to the outer housing of 0.25mm, as shown in figure 2.

FINAL DESIGN DETAILS

With the overall feedthu and button geometry defined, a design competition was initiated. Qualified vendors were provided with an outline drawing and specifications, and invited to submit designs for details of the internal construction. Given that the vendors are the experts in the art of this detailed design, and that such information is proprietary and closely guarded, this was seen to be the best approach to arriving at an optimized design. The

proposals were evaluated, and the best design was selected to provide five first article assemblies, which are presently in production. Details of the winning proposal are proprietary, however it can be said that they conform well to the design rules.

GdfidL simulation indicated that, with 10psec bunch length and 500mA beam current uniformly distributed in the 1320 NSLS-II 500MHz buckets, the resulting trapped mode power in the button would be about 4 watts. This power was applied to the design in an Ansys simulation, and the resulting temperature distribution and thermal deformation is shown in figures 3 and 4.

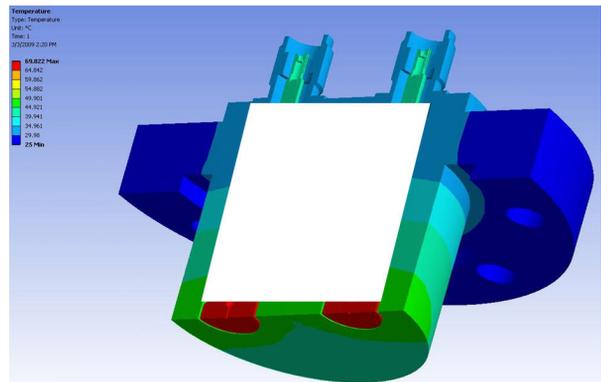


Figure 3: The temperature distribution.

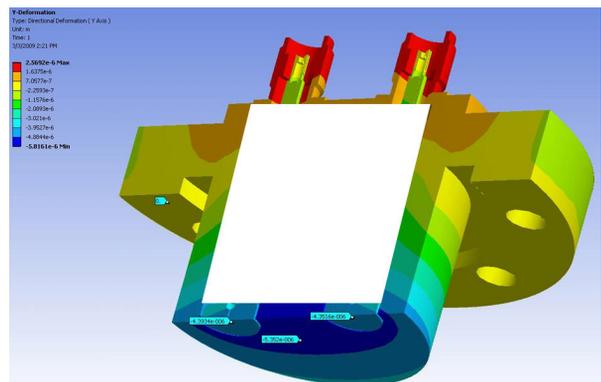


Figure 4: The thermal deformation.

Button temperature with this beam condition was calculated to be $\sim 70^{\circ}\text{C}$, and the resulting thermal displacement of the button relative to the reference mounting surface is ~ 4.4 microns.

The item of interest is not the beam current dependent displacement of the individual buttons, but rather the current dependent error in the position measurement that results from these displacements. If the beam is centered in the pickup there will be no differential displacement, and no error in the position measurement. Knowing the position dependence of the power deposited in the individual buttons, the measurement error as a function of position offset and beam current can be calculated. This is plotted in figure 5.

The vertical axis in the figure is the beam offset in the pickup. The horizontal axis is the average trapped mode power in the buttons with no beam offset, with 4W corresponding to previously mentioned 10psec bunch length and 500mA beam current uniformly distributed in the 1320 NSLS-II 500MHz buckets. The z-axis displacements are in microns.

CONCLUSION

A reasonable expectation is that beam will be vertically centered in the pickups within a few hundred microns. The red line in figure 4 is drawn at 200 microns beam offset. The resulting current dependent measurement error in the extreme circumstance of going from no beam to the full design current is about 260nm, as indicated by the red dot. The design manual requirement is that vertical thermal stability shall be less than 200nm rms on the time scale from minutes to 8 hours. The button design clearly meets this requirement for any reasonable operations scenario.

ACKNOWLEDGEMENTS

The authors thank Julien Bergoz, Fritz Caspers, Jean-Claude Denard, Robert Hettel, Eric Plouviez, Guenther Rehm, Kai Wittenberg, and the participants in the EPAC08 mini-workshop on button heating for many helpful comments and discussions.

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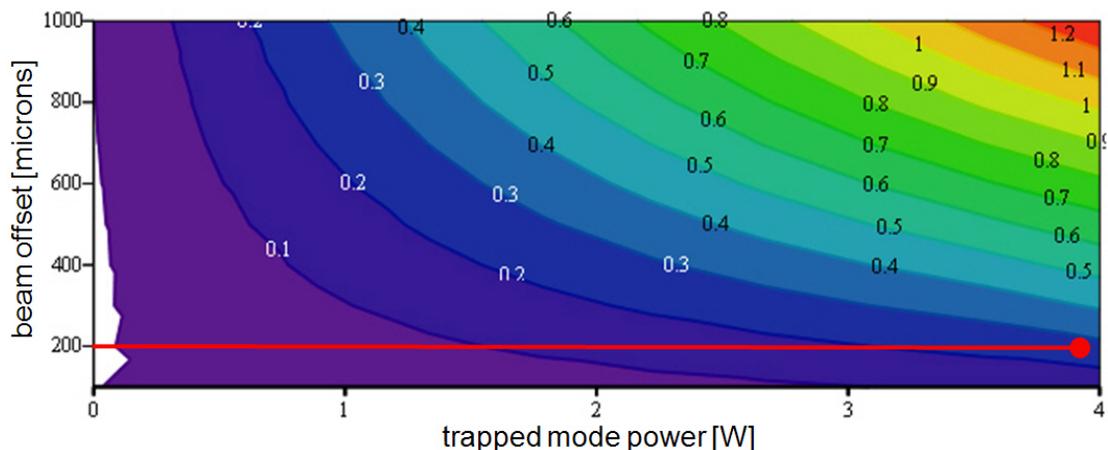


Figure 5: Position measurement error as a function of beam offset and trapped mode power.