BNL-82323-2009-CP

Evaluation of Heat Dissipation in the BPM Buttons

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Presented at the PAC09 Conference
Vancouver, Canada

May 4 – 8, 2009

National Synchrotron Light Source II Project

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EVALUATION OF HEAT DISSIPATION IN THE BPM BUTTONS*

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Abstract

Growth of circulating current in the storage rings drastically increases heating of the beam position monitor (BPM) buttons due to the induced trapped modes is drastically increasing. Excessive heating can lead to the errors in the measuring of beam position or even catastrophic failures of the pick-up assembly. In this paper we present calculations of heat generated in the button for different geometries and materials. The obtained results are used for the optimizating of the NSLS-II BPM buttons design.

INTRODUCTION

The demand for the high brightness in a light source leads to an increase of circulating current in the storage ring. Combined with short electron bunches high current results in high levels of microwave power inside a vacuum chamber, and can lead to a substantial heating of the BPM buttons, as well as of the other elements [1]. Reduction of the button diameter diminishes power dissipation but also lowers signal level and therefore can only be done to a certain limit. In [1], gold plating the BPM buttons was considered in order to reduce their heating. Later it was suggested to make an entire button from molybdenum [2] which has high electrical and thermal conductivities. In this paper we evaluate the button heating in a such BPM design.

HEATING CONSIDERATIONS

The total energy deposited into the button is defined by its geometry and the bunch length and charge and mostly does not depend on the conductance of materials. The total energy *E* deposited into the button can be found from the formula:

$$E = kq^2 \tag{1}$$

where *k* is the loss factor and *q* is the bunch charge. Total power lost by the circulating beam is $F_{rep}kq^2$, where F_{rep} is repetition frequency (average current is $F_{rep}q$). GdfidL [3] simulations show that with 500 mA circulating current the total power lost by the electron beam is about 1 W for a button with 7 mm diameter (drawn in Fig. 1).

The deposited power is dissipated in four ways:

1. goes into the cable;
2. radiated back into the vacuum pipe;
3. lost to resistive heating of the button;
4. lost to resistive heating of the button housing.

For the worst case scenario we neglected RF power going into the cable and assumed that all losses are due to mechanisms 2-4. This assumption is close to reality for the trapped modes (not coupling into the cable). The distribution of losses between the abovementioned channels can be found from the corresponding quality factors for the particular trapped mode.

For the estimation of the dissipated power we used the approximation that losses *L* are proportional to the real part of the impedance *r* which can be found from the formula:

$$r = \frac{\rho}{Q} \tag{2}$$

where ρ is the characteristic impedance of the resonant circuit and *Q* is the quality factor. The losses for each of three mechanisms are described by resistive impedance r_{rad}, $r_{housing}$ and r_{button}, respectively. The mode quality factor Q is defined by the ratio:

$$Q = \frac{\rho}{r_{rad} + r_{house} + r_{button}} \tag{3}$$

The characteristic impedance is unknown but we are interested only in the ratio of power dissipated in the button to the total power. The ratio was estimated using the formula below

$$\frac{L_{button}}{L_{total}} = \frac{r_{button}}{r_{rad} + r_{housing} + r_{button}} = \frac{1}{\frac{Q_{button}}{Q_{radiation}} + \frac{Q_{button}}{Q_{housing}} + 1} \tag{4}$$

The quality factors *Q* were calculated using GdfidL (in the manner described in [1]) for the H_{11} mode of a 7 mm button and are plotted in Fig. 2 and shown in Table 1. The calculations were performed for the case when button and housing are made from the same material. We assumed that in this case the resistive losses are split evenly between the housing and the button. The quality factor for radiation was estimated by setting the resistance of material to zero.

For the stainless steel button and housing, formula (4) transforms into:

$$\frac{L_{button}}{L_{total}} = \frac{1}{2}\frac{1}{\frac{Q_{SS}}{Q_{rad}} + 1} \tag{5}$$

*Work supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract DE-AC02-98CH10886.
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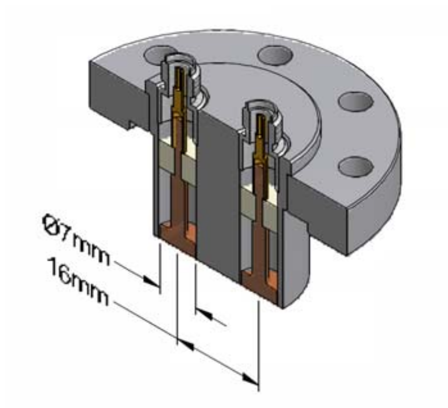

Fig. 1. The 7-mm buttons mounted on a multipole vacuum chamber. Not optimized design is shown.

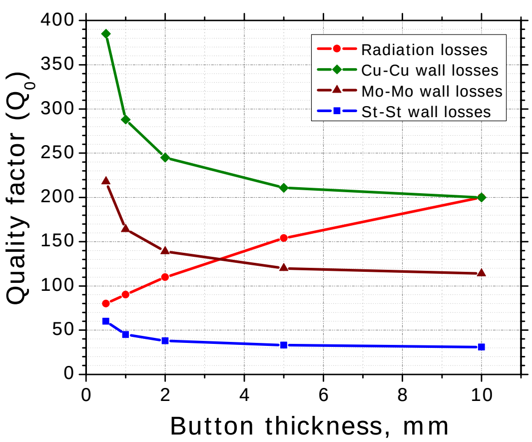

Figure 2: Quality factors for H_{11} mode for different BPM materials and button thicknesses. For radiation losses the superconducting walls were assumed.

Due to proximity of the surfaces the linear current densities induced in the button and the housing are equal to each other and losses are directly proportional to resistivity. The skin depth is inversely proportional to the square root of the specific conductivity. So, if button and housing are built of different materials heat dissipation will be proportional to the square root of the specific resistivity. The conductivities ratio is about 20 for steel and molybdenum. Therefore button made of molybdenum will receive only 20-25% of the power dissipated in the stainless steel button with the same induced current.

For a molybdenum button and the stainless steel housing equation (4) transforms into:

$$\frac{L_{button}}{L_{total}} = \frac{1}{\frac{2Q_{Mo}}{Q_{radiation}} + \frac{Q_{Mo}}{Q_{SS}} + 1} \quad (6)$$

The share of power dissipated in the button for various designs is shown in Table 2. In comparison with conventional full stainless steel construction, using a molybdenum button decreases power dissipation by a factor of three. The optimal value of 5-mm thickness corresponds to the minimum of the heating factor which is defined as a product of the loss factor (power going into the button) and a portion of the power lost in the button. This values are also shown in the Table 2.

Table 1: Values of quality factors for H_{11} mode used for calculations.

Button Thickness, mm	Q_{rad}	Q_{Cu}	Q_{SS}	Q_{Mo}
0.5	80	385	60	218
1	90	288	45	164
2	110	245	38	139
5	154	211	33	120
10	200	200	31	114

Table 2: Ratio of power dissipated in the button to total dissipated power.

Button Thickness, mm	Portion of power dissipated in button		k, [mV/pC]	Heat factor
	SS-SS	SS-Mo		SS-Mo
0.5	0.29	0.10	16	1.6
1	0.33	0.12	13	1.56
2	0.37	0.14	9	1.26
5	0.41	0.16	6.2	0.99
10	0.43	0.17	6.6	1.12

CONCLUSION

We have demonstrated that heating of a BPM button by wakefields induced by circulating beam can be significantly reduced by replacing stainless steel with molybdenum while keeping housing material unchanged. The button geometry was also optimized. The results of the work will be implemented in the design of the buttons [4].

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