COMPARATIVE STUDY OF BUTTON BPM TRAPPED MODE HEATING*

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Abstract

The combination of short bunches and high currents found in modern light sources and colliders can result in the deposition of tens of watts of power in BPM buttons. The resulting thermal distortion is potentially problematic for maintaining high precision beam position stability, and in the extreme case can result in mechanical damage. We present a simple algorithm that uses the input parameters of beam current, bunch length, button diameter, beampipe aperture, and fill pattern to calculate a relative figure-of-merit for button heating. Data for many of the world's light sources and colliders is compiled in a table. Using the algorithm, the table is sorted in order of the relative magnitude of button heating.

INTRODUCTION

A brief history of the trapped mode button heating problem is presented elsewhere in these proceedings [1]. We present here a simple algorithm that uses the input parameters of bunch charge, bunch length, number of bunches, button diameter, and beampipe aperture to calculate a relative figure-of-merit (FOM) for button heating. These parameters were gathered for many of the world's light sources and colliders, for the purpose of assessing the potential severity of this problem at NSLS-II.

Information regarding detailed button geometry and materials and fill pattern variations was not easily gathered. Consequently, the crucial effects [2-5] of these parameters with regard to button heating and distortion could not be incorporated into the algorithm, which assumes internal details of the buttons are the same in all storage rings considered here. This is obviously not true. Additionally, the bunch fill pattern determines the location of strong revolution harmonics in the frequency domain, and possible resonant excitation of the trapped mode is not considered here. Similarly, possible interactions between the button trapped mode and beampipe modes [6] are ignored. The calculated FOMs are presented with these caveats.

THE ALGORITHM

Ignoring the internal button details makes the algorithm particularly simple. For a given BPM aperture we assume the button geometry is such that buttons in all storage rings present the same trapped mode impedance to the beam. The trapped mode resonance is narrow band. The interaction of the bunch length with the mode impedance can then be relatively characterized by simply taking the power in the Gaussian bunch spectrum at the mode frequency.

The frequency of the button trapped mode resonance is

$$f_{button} = \frac{c}{2\pi r} = 13.65\,\text{GHz} \qquad \text{NSLS-II 7mm dia.}$$

where

c = speed of light
r = effective button radius

The Gaussian bandwidth of a bunch of length σ is

$$f_{beam} = \frac{1}{2\pi\sigma} = 10.6\,\text{GHz} \qquad \text{NSLS-II 15psec}$$

The relative voltage induced in the trapped mode due to the passage of a single bunch is then in the proportion

$$V \propto \frac{Q}{a} e^{-\left(\frac{f_{button}^2}{2f_{beam}^2}\right)} \qquad \text{[eqn. 1]}$$

where

Q = bunch charge
a = BPM half aperture NSLS-II 12.5mm

The corresponding relative power is just the square of the voltage.

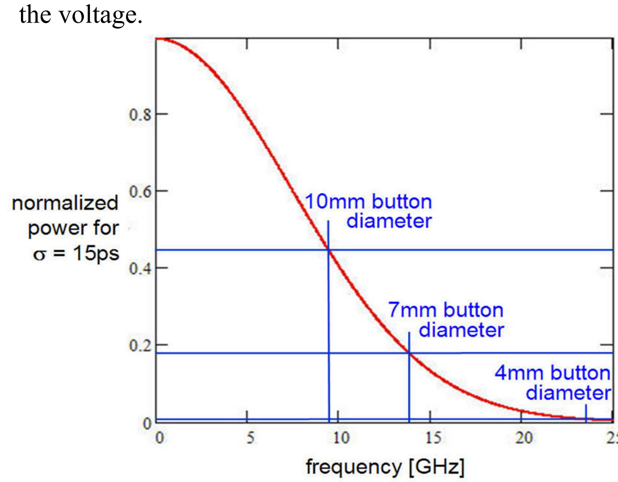

Figure 1: Trapped mode power as a function of button diameter for nominal NSLS-II parameters.

Figure 1 illustrates this for three button diameters considered for NSLS-II. For 15 psec rms bunches, power in the trapped mode resonance is reduced by a factor of

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~2.3 when reducing button diameter from 10mm to 7mm, and by an additional factor of ~30 when reducing diameter from 7mm to 4mm. We note that the half aperture at the 4mm NSLS-II buttons will be ~5mm. With this aperture, for 15psec bunches the 4mm button power will be a factor of ~5 less than for the 7mm button.

Taking into consideration multiple bunches, the algorithm to calculate a relative FOM, proportional to the power delivered to the button by the beam, is

$$\mathrm{FOM} = N f_{rev} \left(\frac{Q}{a} e^{-\left(\frac{f_{button}^2}{2 f_{beam}^2} \right)} \right)^2 \qquad \text{[eqn. 2]}$$

where

N = number of bunches

f_{rev} = revolution frequency

THE COMPARATIVE TABULATION

Table 1 below shows calculated FOMs for possible operating conditions at various storage rings, with considered NSLS-II parameters highlighted in yellow. The machine and beam parameters shown in the table were gathered from web searches and communications with cognizant individuals at the various labs, and do not necessarily represent present operating conditions. The table should be considered only an approximate guide to relative FOMs.

Given the range of beam and pickup conditions, it is not too surprising that the FOM spans over three orders of magnitude in the storage rings considered here. It appears that the most difficult problems with button heating have been at the PEP-II Low Energy Ring. There the stainless steel BPM buttons were press fit onto the molybdenum center conductors, and heating resulted in loss of interference and 'dropped' buttons [7]. While the KEK-B High Energy Ring has a similar FOM, no problems have been reported there. Reasons for this difference might include possible resonant excitation of the button trapped mode by beampipe modes at PEP-II [7,8], and differences in the mechanical construction of the KEK-B buttons. Further optimization of the KEK-B buttons remains under study [9].

The NSLS-II baseline design specifies 500mA beam and 15psec bunch length, with the possibility of bunch currents of 1mA. It was recognized early on [10] that the proposed 10mm buttons were potentially problematic in these conditions, as can be seen in the table. Calculations indicated that signal levels would be adequate to meet resolution requirements with 7mm buttons (although careful attention must be give to optimal analog and digital signal processing), and this design change was made. It should also be noted that the NSLS-II baseline includes a 3rd harmonic cavity, which will likely be operating when beam currents are high, resulting in longer bunches and drastically reduced button heating.

Table 1: Calculated Figures of Merit for Various Light Sources and Colliders

	lab	I [mA]	frev [KHz]	num of bunches	bunch chg [nC]	σ [ps]	σ [mm]	f_{beam} [GHz]	button dia[mm]	f_{button} [GHz]	aperture [mm]	FOM	comments
1	PEP-II LER	2400	136	1440	12.2	35	10.5	4.55	15	6.37	50	6617	Run 5 - dropped buttons
2	KEK-B HER	1400	100	1389	10.1	23	6.9	6.92	12	7.96	50	6021	B factory
3	NSLS-II	500	379	500	2.6	15	4.5	10.62	10	9.55	25	3761	500 bunches, 10mm button
4	PEP-II HER	1800	136	1746	7.6	34	10.2	4.68	15	6.37	50	3428	B factory Run 5
5	KEK-B LER	2000	100	1500	13.3	23	6.9	6.92	12	7.96	94	3219	B factory
6	Soleil France	500	847	416	1.4	14	4.2	11.37	10	9.55	25	2243	design current
7	Elettra Trieste	400	1153	432	0.8	30	9	5.31	16	5.97	14	1849	rotated
8	NSLS-II	500	379	500	2.6	15	4.5	10.62	7	13.65	25	1619	500 bunches, 7mm button
9	Spear 3	500	1281	280	1.4	17	5.1	9.37	12	7.96	34	1171	
10	Diamond Rutherford	300	545	600	0.9	17	5.1	9.37	10.7	8.93	20	1109	>100C at connector
11	TPS Taiwan	400	579	500	1.4	10	3	15.92	6	16	30	904	
12	NSLS-II	500	379	1000	1.3	15	4.5	10.62	7	13.65	25	809	1000 bunches, 7mm button
13	Dafne Frascati	5000	3059	120	13.6	50	15	3.18	15	6.37	88	645	
14	Petra III	100	130	40	19.2	40	12	3.98	11	8.69	11	543	40 bunches
15	Soleil France	300	847	312	1.1	20	6	7.96	10	9.55	25	517	
16	SLS PSI	400	1041	480	0.8	13	3.9	12.25	10.7	8.93	40	471	w/o 3rd harmonic
17	SSRF Shanghai	300	757	440	0.9	14	4.2	11.37	10.7	8.93	38	404	
18	NSLS-II	500	379	500	2.6	15	4.5	10.62	4	23.89	10	335	500 bunches, 4mm button
19	ALBA Spain	400	1114	448	0.8	15	4.5	10.62	7	13.65	28	313	
20	ESRF Grenoble	200	355	992	0.6	13	3.9	12.25	11	8.69	30	305	
21	BEPCII	1000	1260	93	8.5	50	15	3.18	15	6.37	54	215	
22	ALS Berkeley	460	1522	280	1.1	20	6	7.96	10	9.55	50	188	wag on aperture
23	NSLS-II	500	379	1000	1.3	15	4.5	10.62	4	23.89	10	167	1000 bunches, 4mm button
24	Spring-8 Japan	100	209	1610	0.3	12	3.6	13.27	18	5.31	30	113	
25	Australian	200	1394	350	0.4	23	6.9	6.92	12	7.96	32	85	
26	DELTA Dortmund	130	2607	144	0.3	15	4.5	10.62	10	9.55	42	45	
27	APS Argonne	100	272	324	1.1	25	7.5	6.37	10	9.55	38	33	
28	APS Argonne	100	272	24	15.3	40	12	3.98	10	9.55	38	13	present operating condition
29	SLS PSI	400	1041	320	1.2	42	12.6	3.79	10.7	8.93	40	5	with 3rd harmonic

Looking back at equation 2 in more detail, we note that the algorithm has two parts, one related to beam intensity, and the second to beam spectral content at the button resonance frequency. Figure 2 shows data from Table 1, plotted as a function these two parts. The circled numbers correspond to the numbers in the leftmost column of the table. So for instance "1" corresponds to the PEP-II LER data point and "2" to KEK-B HER. The yellow highlighted points correspond to the five NSLS-II data points. On the vertical axis, the data appears to be clustered into two groups. For the points in the lower right portion of the figure, highlighted in aqua in the table, the button diameter is smaller than the bunch length. This effectively reduces heating at high beam intensities.

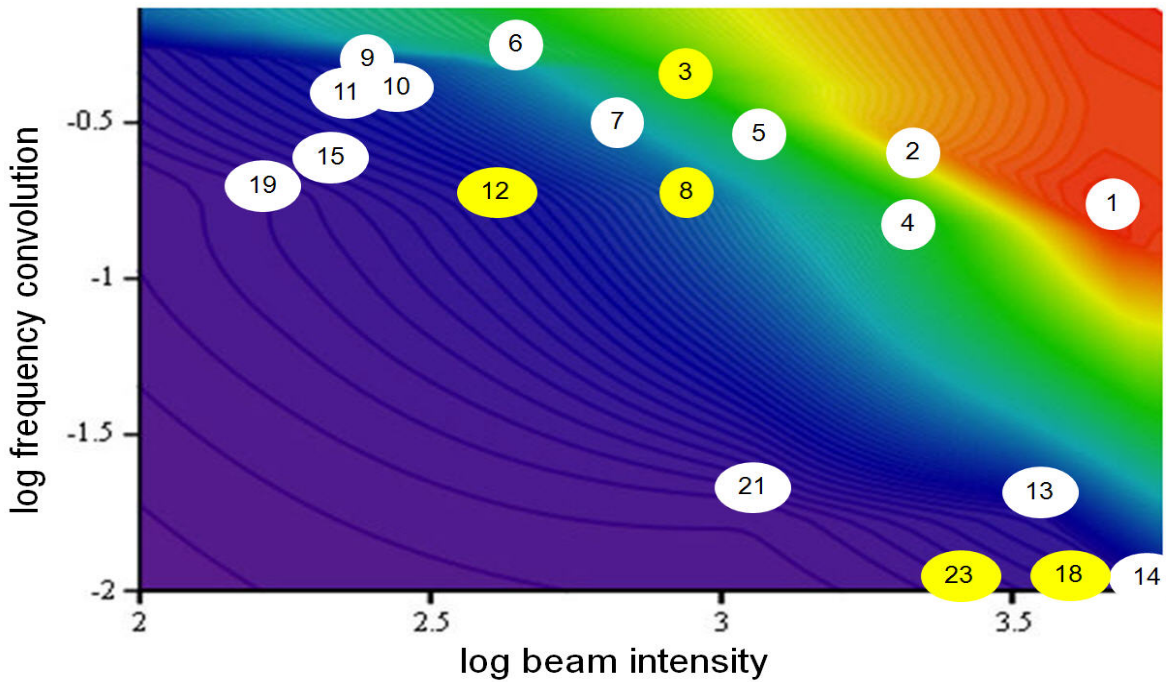

Figure 2: FOM as a function of beam intensity and power in the bunch spectrum at the mode frequency.

CONCLUSION

Considerable effort has been invested world-wide over a good many years in understanding button heating and developing practical and effective solutions. The hope is that NSLS-II will derive full benefit from that effort, and that button performance will go un-noticed as machine brightness increases.

ACKNOWLEDGEMENTS

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