

BNL-105124-2014-TECH

Booster Technical Note No. 77;BNL-105124-2014-IR

## General design feasibility curves for Booster ferrite cavities

M. Plotkin

April 1987

Collider Accelerator Department Brookhaven National Laboratory

## **U.S. Department of Energy**

USDOE Office of Science (SC)

Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No.DE-AC02-76CH00016 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

# GENERAL DESIGN FEASIBILITY CURVES FOR BOOSTER FERRITE CAVITIES

AD Booster Technical Note No.77

> MARTIN PLOTKIN APRIL 22, 1987

ACCELERATOR DEVELOPMENT DEPARTMENT Brookhaven National Laboratory Upton, N.Y. 11973

#### GENERAL DESIGN FEASIBILITY CURVES FOR BOOSTER FERRITE CAVITIES

Martin Plotkin

#### INTRODUCTION

.

For any particular ferrite, the method of establishing the feasibility of constructing a ferrite cavity is very straightforward. The curves presented in this note are intended to facilitate the selection, or rejection, of a ferrite material based upon an initial sample measurement. It is still essential to measure (small and large samples) ferrite thoroughly, and do more detailed computations, for any potentially acceptable ferrite.

The curves are in two groups for two different approaches. The first is very specific for Booster cavities I and II at 17 Kv. The second is more general for Booster cavities I, II, III for varying gap voltages. GENERAL DESIGN FEASIBILITY CURVES FOR BOOSTER FERRITE CAVITIES

Martin Plotkin

Design Criteria:

- 1. 17000 volts/cavity
- 2. Frequency Range
  - a. Cavity I 178.5 675 KHz
  - b. Cavity II 675 2500 KHz
- 3. Total axial length available/cavity 250cm.
- These designs predicated on small samples of TDK Ferrite SY-7 (Mike Goldman data - Fig. I)

 $V=\omega BA \times 10^8$  (B-gauss A-cm<sup>2</sup>, V-volts A=N (r<sub>2</sub>-r<sub>1</sub>) x 2.5, N=number of 2.5cm thick rings).

Using the data in appendix I, Fig, II represents a set of design curves for SY7 and V=17KV. For any  $r_2-r_1$ , (10cm, 12.5cm and 15cm) as shown and a power loss level selected, the number of rings is determined. The power loss level is a function of the method of cooling, the duty factor and the requirement for temperature control of the ferrite. For example, with water cooling and a 250 mw/cc power loss and a 50% duty factor, we look at the 500 mw/cc line and see that we can use 48 rings at  $r_2-r_1=15$ cm or 56 rings at  $r_2-r_1=12.5$ cm.

Available length of ferrite for a double cavity/station:

gaps (2) + clearance: 2 x 15cm	30cm
center plates:	бст
end plates: 20 1.5cm	3cm
end spaces: 40 2.5cm	10cm
	49cm

For 250cm total - 200cm available for ferrite and cooling plates (or cooling spaces for air cooling). Cooling plates may range from 0.3cm (for edge cooling) to 0.6cm for overall cooling plates. Air cooling requires about 0.6cm between ferrite rings.

Maximum number of rings of 2.5cm thickness for various cooling  $N = \frac{200}{2.5+c}$  c = cooling thickness requirement.

		N ma	lХ
edge cooling	(.3cm)	71.4	(72)
overall cooling	(.6cm)	64.5	(64)
air cooling	(.6cm)	64.5	(64)

All the previous numbers are for the starting frequency. As the ferrites are dc biased to tune to the top frequency of 675 KHz the losses (at the same voltage level) may increase or decrease. This must be measured specifically for each ferrite. In general, when a ferrite is used within its normal frequency range, the impedance over the tuning range remains fairly uniform.

Since  $P = V_{pk}^2/2Z$  the power loss does not vary too much. The top frequency for cavity I is well within the operating frequency range of TDK SY-7.

It is fortuitous that as the frequency rises by a factor of, let us say 3, the inductance decreases by a factor of 9 and the Q increases by about a factor of 3. Thus  $Z = \omega LQ$  remains relatively constant.

Similarly for the heavy ion cavity II, the data in appendix II provides the curves in Figure III.

In Fig. III, for the same number of rings as in Cavity I, the power losses are considerably smaller. However, the top frequency of 2.5 MHz is above the normal, unbiased, operating frequency of SY7. With bias the ferrite behavior above its normal operating frequency is significantly improved. There may be larger losses at 2.5 MHz than at 675 KHz. for this reason, and also for the simplicity of making Cavity I and Cavity II identical, as many rings should be used in Cavity II as in Cavity I.

The sequence of steps in the cavity design necessitate a selection of the cooling method, which limits the maximum number of rings allowed. The diameter of the rings, commensurate with the manufacturer's capability of fabrication, should be kept as small as possible. The important criterion for the ferrite is the cross section area of the ferrite, not the ferrite volume. A ring 40cm OD - 20cm ID will perform exactly the same as one 50cm OD - 30cm ID. The smaller ring has 25% less weight and, for the same mw/cc, 25% less total power loss. Since the cost is influenced by total weight the smaller rings may be cheaper. Also cavity structures will be smaller and the rings will be easier to handle.

Having selected the cooling method, which dictates the maximum number of rings, the ferrite ring size and the duty factor, the number of rings required can be read off the curves.

40cm x 20cm rings are closer to the size rings used in the old AGS cavities. these rings were 35cm x 20cm and ran successfully with edge cooled copper plates. The voltage on the old AGS cavity was 8 KV/gap compared to the 8.5 KV/gap in the Booster cavities. If they can be manufactured, and if the duty cycle allows, 40cm x 20cm rings seem to be a viable solution. The ferrite rings experience a thermal shock if the temperature rise during the pulse, irrespective of the duty factor, is excessive. For the case of 1w/cc the temperature rise is

 $\Delta T = \frac{w/cc \ x \ duty \ factor}{4.186 \ x \ sp.gr. \ x \ sp.heat} \qquad \begin{array}{l} \mbox{ferrite specific grav} \approx 5 \\ \mbox{ferrite specific heat} \approx .17 \end{array}$ 

 $\Delta T = \frac{\text{W/cc x duty factor}}{3.56}$ If duty factor = 50% at 1 W/cc  $\Delta T$  = .14°C/pulse = 25% at 1 W/cc  $\Delta T$  = .07°C/pulse

These values are not large but a mechanical analysis should be made.

If we consider using the old AGS cavities and rebuilding them for the vacuum requirements we can estimate the cavity behavior. The cavity will require a high vacuum flange in the center and an additional section can be added allowing for about 10% more ferrite (Peter Cameron information). We can use rings which are 42 cm OD and 20 cm ID and use the 1/8" copper, edge cooled, cooling plates.

If N is the number of rings in each of 4 stacks in the double cavity, and the thickness of the ferrites is 2.5 cm, then 4N(2.5) + (4N+4)(0.3) = L, the available length for the stacks. (0.3 cm  $\approx 1/8$ " the cooling plate thickness.) Cameron indicates enough space for 88 rings at 2.1 cm which yields an available length of 214 cm. Solving for N for 2.5 cm rings we get N = 18, or 72 rings in four stacks.

$\mathbf{V} \times 10^8$	<sup>8</sup> V =				17000 volts						-
$D_{gauss} = \frac{\omega A}{\omega A}$	ω	=	2π	х	.1785	х	10 <sup>6</sup>	=	1.122	2 x	106
B = 765 gauss	A	=	72	(-	2.20	)	2.5	=	1980	$cm^2$	

For SY7, at 0.1785 MHz, P = 390 mw/cc.

With a 50% duty cycle the average power loss is 195 mw/cc. This is an acceptable value for water cooling with edge cooled plates.

Another approach to generate a more useful set of curves is to have plots of flux density vs number of rings at a given frequency (the starting frequency) with peak voltage as a parameter. Three curves are presented for each starting frequency for the difference in inner and outer radii of 10 cm, 12.5 cm and 15 cm, for 178.5 KHz and also for 675 Hz. The curves are used by selecting a power level which considers the cooling system and the duty cycle. The flux density for this condition is found from measured data and, for the voltage desired, the number of rings are determined. Similar curves can be readily made for any set of conditions.

Figure IV A,B,C is for a starting frequency of 0.1785 MHz. Figure V A,B,C is for a starting frequency of 0.675 MHz. Figure VI A,B,C is for a starting frequency of 2.5 MHz.

The data are presented in appendix III.



B-gauss























### APPENDIX I

Cavity I:  $\omega = 2\pi f = 1.1 \times 10^6$  (Data was taken at 175 KHz but 178.5 KHz was used in the evaluations.)

$$BA = \frac{1.7 \times 10^4 \times 10^8}{1.1 \times 10^6} = 1.515 \times 10^6$$

<u>r<sub>2</sub> 1</u>	<u>^1 N</u>	A	В	mw/cc
<u>50</u>	<u>30</u> 44	1100	1409	excessive
r2-r1=	=10 48	1200	1292	excessive
	52	1300	1192	970
	56	1400	1107	840
	60	1500	1033	720
	64	1600	969	625
	68	1700	911	550
	72	1800	861	500
	76	1900	816	435
	80	2000	775	390
<u>50</u> 2	25 44	1375	1127	870
	48	1500	1033	720
r2-r1=	=12.5			
	52	1625	953	610
	56	1750	886	520
	60	1875	826	440
	64	2000	775	390
	68	2125	729	345
	72	2250	689	310
	76	2375	652	270
<u>50 2</u>	<u>20</u> 44	1650	939	590
	48	1800	861	500
r2-r1=	15 52	1950	795	415
	56	2100	738	365
	60	2250	689	310
	64	2400	646	275
	68	2550	608	235
	72	2700	574	205
	76	2850	544	185

### APPENDIX II

Cavity II:  $\omega = 4.24 \times 10^6$ , BA = 4.01 x 10<sup>5</sup>

$r_2 - r_1$	N	А	В	mw/cc
10	44	1100	364	890
	48	1200	334	750
	52	1300	308	630
	56	1400	286	550
	60	1500	267	470
	64	1600	251	425
	68	1700	236	375
	72	1800	223	325
	76	1900	211	295
	80	2000	200	255
12.5	44	1375	292	570
	48	1500	267	470
	52	1625	247	410
	56	1750	220	350
	60	1815	214	305
	64	2000	200	255
	68	2125	189	235
	72	2250	178	208
. –	76	2375	169	190
15	44	1650	243	400
	48	1800	223	335
	52	1950	206	285
	56	2100	191	245
	60	2250	178	208
	64	2400	167	180
	68	2550	157	160
	72	2700	148	143
	76	2850	141	130

$V = \omega BA$	x 10 <sup>-8</sup>			N == Nu	mber of 2.5	cm rings
B = <u>V</u>	$\frac{x \ 10^8}{\omega A} = \frac{10^8}{2\pi}$	$\frac{V \times 10^8}{fN \times 2.5}$ (r	2 <sup>-r</sup> 1)			
	B = ·	6366 V <sub>kv</sub> f <sub>MHz</sub> (r <sub>2</sub> -r <sub>1</sub> )	<u>1</u> N			
r <sub>2</sub> -r <sub>1</sub> =	10 f =	.1785				
	B = -	3566 V <sub>KV</sub> N				
<u>N</u>	B(9KV)	<u>B(11KV)</u>	<u>B(13KV)</u>	<u>B(15KV)</u>	B(17KV)	<u>B(19KV)</u>
44 48 52 56 60 64 68 72	729 669 617 573 535 502 472 446	892 817 754 701 654 613 577 545	1054 966 892 828 773 724 682 644	1114 1029 955 892 836 787 743	1082 1020 947 892 842	1129 1059 996 941
	1	$r_2 - r_1 = 1$	2.5 f =	.1785 B =	= <u>2853 V<sub>KV</sub></u> N	
<u>N</u>	<u>B(9KV)</u>	<u>B(11KV)</u>	<u>B(13KV)</u>	<u>B(15KV)</u>	<u>B(17KV)</u>	<u>B(19KV)</u>
44 48 52 56 60 64 68	584 535 494 459 428 401 378	713 654 604 560 523 490 462	843 773 713 662 618 580 545	972 892 823 764 713 669 629	1102 1010 933 866 808 758 713	1232 1129 1042 968 903 847 797
72	357	436	515	594	674	753

		$r_2 - r_1 = 1$	5.0 f =	.1785 B	<u>= 2378 V<sub>KV</sub> N</u>	
<u>N</u>	<u>B(9KV)</u>	<u>B(11KV)</u>	<u>B(13KV)</u>	<u>B(15KV)</u>	<u>B(17KV)</u>	<u>B(19KV)</u>
44 52 56 60 64 68 72	486 446 382 357 334 315 297	595 545 503 467 436 409 385 363	705 646 596 554 517 484 456 431	811 743 686 637 595 557 525 495	919 842 777 722 674 632 595 561	1027 941 869 807 753 706 664 628
		$r_2 - r_1 = 1$	0 f =	.675 B	= <u>943 V<sub>KV</sub></u> N	
<u>N</u>	<u>B(9KV)</u>	B(11KV)	<u>B(13KV)</u>	<u>B(15KV)</u>	B(17KV)	<u>B(19KV)</u>
44 48 52 56 60 64 68 72	193 177 163 152 141 133 125 118	236 216 199 185 173 162 153 144	279 255 236 219 204 192 180 170	321 295 272 253 236 221 208 196	364 334 308 286 267 250 236 223	407 373 345 320 299 280 263 249
		r <sub>2</sub> - r <sub>1</sub> = 12	.5 cm f =	675 KHz B =	$= \frac{754.4 \text{ V}_{\text{KV}}}{\text{N}}$	
<u>N</u>	<u>B(9KV)</u>	B(11KV)	<u>B(13KV)</u>	<u>B(15KV)</u>	<u>B(17KV)</u>	<u>B(19KV)</u>
44 48 52 56 60 64 68 72	154 141 131 121 113 106 100 94	189 173 160 148 138 130 122 115	223 204 189 175 163 153 144 136	257 236 218 202 189 177 166 157	291 267 247 229 214 200 189 178	326 299 276 256 239 224 211 199

	r	$r_2 - r_1 = 15$	cm f =	675 KHz	$B = \frac{628.7 V_{KV}}{N}$	<u>_</u>
<u>N</u>	B(9KV)	<u>B(11KV)</u>	<u>B(13KV)</u>	<u>B(15KV)</u>	<u>B(17KV)</u>	<u>B(19KV)</u>
44	129	157	186	214	243	271
48	118	144	170	196	223	249
52	109	133	157	181	206	230
56	101	123	146	168	191	213
60	94	115	136	157	178	199
64	88	108	128	147	167	187
68	83	102	120	139	157	176
72	79	96	114	131	148	166

f = 2.5 MHz:

 $r_2 - r_1 = 10$   $B = \frac{254.6}{N}$  Vkv f = 2.5 MHz

N	B(22.5V)	<u>B(30 KV)</u>	<u>B(45 KV)</u>
1. 1.			
44	130.2	173.6	260.4
48	119.3	159.1	238.7
52	110.2	146.9	220.3
56	102.3	136.4	204.6
60	95.5	127.3	191.0
64	89.5	119.3	179.0
68	84.2	112.3	168.5
72	79.6	106.1	159.1
76	75.4	100.5	150.8

r <sub>2</sub>	- r1	-	12.5	f	=	2.5	MHz	В	Ŧ	203.7V N
	<u>N</u>		B(22.	<u>5V)</u>		I	3(30	KV)		<u>B(45 KV)</u>
	44 48 52 56 60 64 68 72 76		104 95 88 81 76 71 67 63 60	2 5 1 8 4 6 4 7			138. 127. 117. 109. 101. 95. 89. 84. 80.	.9 .35 .1 .9 .9 .9 .9		208.3 191.0 176.3 163.7 152.8 143.2 134.8 127.3 120.6
r <sub>2</sub>	- r <sub>1</sub>	=	15	B =	1	69.7 N	<u>7 V</u>	f	н	2.5 MHz
	<u>N_</u>		B(22.	<u>5V)</u>		Ē	3(30	KV)		B(45 KV)
	44 52 56 60 64 68 72 76		86.8 79.5 73.7 68.2 63.6 59.7 56.2 53.0 50.2	3 5 7 2 2 2 2 2			115. 106. 97. 90. 84. 79. 74. 70. 67.	7 1 9 9 9 5 9 7 0		173.6 159.1 146.9 136.4 127.3 119.3 112.3 106.1 100.5