BNL-105117-2014-TECH

Booster Technical Note No. 70;BNL-105117-2014-IR

Proton cavity for the AGS Booster

M. Plotkin

December 1986

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

PROTON CAVITY FOR THE AGS BOOSTER

AD

Booster Technical Note

No. 70

M. PLOTKIN

December 18, 1986

ACCELERATOR DEVELOPMENT DEPARTMENT

Brookhaven National Laboratory

Upton, N.Y. 11973

PROTON CAVITY FOR THE AGS BOOSTER

The requirements for the Booster proton cavity have been described in the Puglisi/Massarotti Booster Tech. Note 64. There are two cavities each with 45 KV peak voltage, a single gap with a tapped input feed, and a discrete bias winding.

Although these requirements are not necessarily the final design a review of the cavity and possible alternatives and directions is given. The ferrite selected for Tech. Note 64 design is a Mn-Zn ferrite made by Ceramic Magnetics and designated MN8CX. Mn-Zn ferrites of this type have an unbiased useful frequency range to perhaps 1 MH_Z. Above 1 MH_Z the losses become excessive. Under heavy DC bias, however, they may be used to about 2-3 MH_Z with the losses starting to rise very rapidly with frequency. The datum point used in TN 64 is from data taken by M. Goldman and the loss numbers, 0.35 watt/cc at 355 gauss, are used in TN 64. This ferrite could not be used at frequencies above 2.5 MH_Z.

The old AGS cavity ferrite is a nickel-zinc ferrite which was measured under many conditions. A rebuilt old cavity with this ferrite is in operation for heavy ions in the AGS and supplies useful data on bias requirements for large frequency swings.

Some initial calculations indicate that 4H is very marginal for use in the two cavities at 45 KV each planned for the Booster, from the standpoint of power loss and DC bias requirements.

Old AGS Ferrite 4H cavity

Ferrite size 35 cm OD, 20 cm ID, 2.1 cm thick

Total rings/cav - 40

Peak volts/cav - 8000

$V = \omega BA \times 10^{-8}$, B - gauss, A - sq cm

$$A = 2.1 \times 40 \times \frac{35 - 20}{2} = 630 \text{ cm}^2$$

$$B = \frac{V \times 10^8}{\omega A}$$, at starting frequency, no DC bias, 1.4 MH_z

$$B = \frac{8 \times 10^{11}}{2\pi \times 1.4 \times 10^6 \times 630} = 144 \text{ gauss}$$

Measured power loss under these conditions was approximately 0.2 watt/cc

Measured slope: Power $\alpha\ B^{2.5}$

Power = $0.2 \left(\frac{B}{144} \right)^{2.5}$ at 1.4 MH_z, no DC bias.

As measured, with DC bias tuning, the power loss was relatively constant from 1.4 MH_z to 4.5 MH_z.

The initial μ of this ferrite is 400 as measured at the starting frequency (pre-start before injection) of 1.36 MH_z.

$$\mu \text{ at } 2.5\ MH_z = 400 \times \left(\frac{1.36}{2.5} \right)^2 = 118$$

This is close enough to the Puglisi number in Tech. Note 64 to do a rough design using 4H ferrite.

To use this ferrite at 2.5 MH_z, for 144 gauss at 1.4 MH_z, then $B = 144\ \frac{1.4}{2.5} = 80.6$ (for equivalent 200 $^{mw}/_{cc}$ power loss).

For the Booster cavity we have a total available cavity length of 2.5 meters and a duty factor of 0.5.

Using the figures for the required non-ferrite lengths in the cavity from the Puglisi Tech. Note 64, we have:

gap	- 9 cm
gap flanges	- 6 cm
ends	- 20 cm
clearance for tap 2x5=10cm (Tech.Note shows 4x5)	
clearance around tap	- 10 cm
TOTAL	= 55 cm

Therefore, 195 cm is available for ferrites and cooling plates. Puglisi uses 0.3 cm/cooling plate. Assume 2.5 cm thick ferrite

let N = number of ferrite rings

length available = [(N + 4) 0.3 + (N x 2.5)] = 195 cm.

N = 69 (say 68 for an even number)

<u>CASE 1</u> Ferrite OD = 50 cm, ID = 30 cm (Tech Note 64)

$f = 2.5\ MH_z$

$$B = \frac{V \times 10^8}{\omega\ A} \qquad A = 68 \times 2.5 \times 10 = 1700\ cm^2$$

$$B = \frac{45 \times 10^{11}}{2\pi \times 2.5 \times 10^6 \times 1700} = 168 \text{ gauss}$$

$$\text{Expected power loss} = \left(\frac{168}{80.6}\right)^{2.5} \times .2 = 1.25 \text{ watts/cc}$$

This is much too high for available, and acceptable, cooling methods.

<u>CASE 2</u> Decrease inside ferrite radius to 25 cm.

The area goes to 68 x 2.5 x 12.15 = 2125 cm^2

$$\text{and } B = 168 \times \frac{1700}{2125} = 134 \text{ gauss}$$

$$P = \left(\frac{134}{80.6}\right)^{2.5} \times 0.2 = 718 \text{ mw/cc still too high for proper cooling.}$$

If we wish to include the duty factor of 0.5, the loss is now 359 mw/cc which is close to the capability of cooling.

The next step must be an investigation of Ni-Zn ferrites in the frequency range of 2.5 MH_Z to 4.5 MH_Z. 4H was developed in the late 1950's and the ferrite tuning range in permeability is small, $\left(\frac{4.5}{2.5}\right)$= 3.24. The Puglisi design, as well as the above cases for Ferroxcube 4H, require the ferrite to be DC biased for a reduction in permeability at the start of the cycle. In the Puglisi design the μ of MN8CX is about 2500 so there is an initial reduction of a factor of 25 in μ to reach μ = 100. In the 4H case there is a reduction of a factor of 4 to reach the starting μ of 100. On top of each of these there is the operating reduction by a factor of 3.24 to a total factor of 81 for MN8CX and 13 for 4H.

If we wish to use the same tuning capacitance as in the Puglisi report, 376 pf, L = 10.8 μh.

L for case 2 at 2.5 MH_Z

$$L = 2\mu t \quad \frac{r_2}{r_1} \times 10^{-3} \ \mu h$$

$$\mu = \frac{L x 10^3}{2t \quad \frac{r2}{r1}} \qquad t = \text{ferrite length} = 68 \times 2.5$$

$$\mu = \frac{10.8 \times 10^3}{2 \times .693 \times 170} = 45.8$$

The initial reduction in μ is from 400 to 45.8, a factor of 8.73, and then an operating reduction of 3.24 making a total reduction of 28.3.

A reduction of this amount will take a very large bias current! New investigations must look at low loss Ni-Zn ferrites with an initial permeability of 100 or less.

It is possible to make a rough estimate on the bias current for 4H. In the heavy ion AGS cavity now installed there is a reduction in μ of a factor of 25. The average path length in the 35 x 20 cm rings is about 25π. The new cavity rings have an average path length (case 2) of about 33π. For the same H_{dc} (bias) the current will be $\frac{33}{25}$ times higher than in the AGS cavity which is running at about 3000 amperes. Thus, for a 25 factor, about 4000 amperes is required. The extra requirement from 25 to 28.3 may add 50% more current to reach 6000 amperes because, at high H_{dc}, the slope of the μ vs H curve becomes extremely small. This is the primary reason for looking for a lower μ ferrite. The total required capacitance as selected by Puglisi is about as low as should be used because there is a non-trivial amount of capacitance in the cavity and amplifier and too low a total capacitance selection would not leave enough capacitance right at the gap for beam loading considerations.

An additional investigation should take place on TDK ferrite SY6. It is a nickel-zinc-copper ferrite and is used in a cavity at the "TARN II" heavy ion synchrotron at The University of Tokyo Institute of Nuclear Study. In this machine the SY6 is tuned over a range of 0.61 MH_z to 8 MH_z. The accelerating voltage is, however, only 6 KV. The exact amount of ferrite is not specified but the scaling on B to the booster cavity is $\frac{45}{6}$ or a reduction of a factor 7.5. The loss in ferrites generally goes as the 2.7 power of B so the reduction in loss is $(7.5)^{2.7} = 230$ compared to the BNL Booster requirement. It is not likely that this SY6 is a usable material but samples are on hand and it should be measured.

Another Ni-Zn ferrite for which some data is available is Ferroxcube 4L2. 4L2 is used in the existing AGS cavities.At zero bias and 2.5 MH_z the loss is 160 mw/cc at 130 gauss. For case two rings the flux density is 134 gauss. Mike Goldman has measured 4L2 at this flux density region and has found a non-linearity in the loss vs. flux density plot. Using the loss value of 160 mw/cc at 130 gauss, he has measured 180 mw/cc at 134 gauss (Case 2) and 360 mw/cc at 168 gauss (Case 1).

Case 1: Vol = π ($v2^2$ - $v1^2$) x 68 x 2.5 = π (25^2 - 15^2) x 170 = 214000cc

Case 2: Vol = π (25^2 - 12.5^2) x 170 = 250000cc

Case 1: Power = 214000 x .36 = 77 KW

Case 2: Power = 250000 x .18 = 45 KW

Either of these cases is a viable solution

The Q of the system for case 2 is:

$$Z = \omega LQ, \quad Q = \frac{Z}{\omega L} = \omega CZ \text{ at resonance}$$

$$P = \frac{E^2}{2Z} \qquad Z = \frac{E^2}{2P}$$

$Q = \frac{\omega CE^2}{2P}$; for 376 pf (Puglisi Report), 2.5 MH_z, 45 KV, 40 KW

$Q = 150$

SUMMARY:

1. Mn-Zn ferrites, such as MN8CX, cannot be used.
2. Ferroxcube 4H, a Ni-Zn ferrite is very marginal for a two cavity system.
3. Ferroxcube 4L2 is a potentially acceptable material and should be measured thoroughly.
4. Other Ni-Zn ferrites from different manufacturers should be studied. Also Ni-Cu-Zn Ferrites, such as SY6 and SY7 must be investigated.