# DESIGN OF FERRITE LOADED HIGH VOLTAGE BARRIER CAVITY[1]

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*Abstract*

An efficient ferrite loaded high voltage barrier cavity has been designed for the AGS synchrotron. The requirements for designing the cavity are to maximize the induct-ance and minimize the capacitance of the cavity. The freq-uency response of complex permeability for several prospective ferrite materials have been measured. And, a new circuit has been tested out for driving a control-grid of a high power tetrode. Using this technique and a prototype of a barrier cavity, we have succeeded in generating a sinusoidal barrier voltage (of 10kV) on the gap.

## 1 INTRODUCTION

Space charge induced tune shifts limits the intensity in a proton synchrotron. In order to reduce related beam losses, it is desirable to make beam distributions uniform. In a longitudinal phase plane, higher harmonic rf-systems are practically applicable, and the longitudinal barrier rf-system[1] is the ultimate technique to maximize longitudinal bunching factor in a bucket-to-bucket beam transfer.

In the AGS main ring, the longitudinal barrier experiment was carried out to demonstrate the efficacy of this technique for the intensity upgrade[2]. As of this success-full experiment, the conceptual design of a dedicated barrier rf-system have been initiated.

## 2 AGS BARRIER SYSTEM

To accumulate $10^{14}$ of proton beam in the AGS, the longitudinal barrier potential of 80 kV with the gap inter-val of 250ns are required. The system consists of two bar-rier cavities, each of which is able to supply 80kV. One of cavities creates a stationary longitudinal barrier every revolution period of 2.8*μsec*, and another forms an iso-lated bucket adjacent to the stationary barrier for coming bunches from the AGS Booster. The isolated bucket is shaped just on a beam injection and turned off adiabatical-ly so that the longitudinal emittance will not blow-up.

The multi-gap cavity system has been considered in order to achieve a high barrier voltage of 80kV. And, the sizes of cavity has been designed 103”(=2,616mm) of length in order to fit in the AGS ring. Thomson TH558 tetrode single-ended amplifier is designed to be availed of driving the cavity.

## 3 BARRIER CAVITY

Designing the efficient ferrite loaded high voltage barrier cavity, total rf current must be optimized. According to the current capability of tetrode, we have set the value less than 400A at the operating frequency (4 Mhz).

In order to produce an isolated sinusoidal barrier waveform, the required rf current when the cavity is on resonance is given by,

$$I(t) = \begin{cases} \omega C V \left( 1 + \sin(\omega t) / Q \right) & 0 \le \omega t \le 2\pi \\ 0 & others \end{cases} \quad (1).$$

where $\omega$ is a resonant frequency, $C$ total capacitance, $V$ a gap voltage and $Q$ a loaded-$Q$ factor. Considering the resonant condition of the equivalent circuit for the multi-gap cavity system, total capacitance ($C$) is represented by Eq.(2).

$$C = C_o + N_{gap} \cdot C_{gap} \quad (2)$$

Then, the peak current ($I_p$) is given from Eq.(1) when $sin(\omega t) = 1$.

The capacitance ($Co$) denotes that an output capacitance of tetrode including a stray capacitance surrounding the rf feeders and other trim capacitance in parallel, and its value is around 150pF.

On the other hand, the inductance per unit cell (per gap); ($L$), is given by,

$$L = \frac{N_{gap}}{\omega^2 C} = \frac{1}{\omega^2 (C_o / N_{gap} + C_{gap})} \quad (3).$$

And, the contribution of $Co$ in L is one $Ngap$-th. For the sake of minimizing a drive current, therefore, it becomes a key to maximize the inductance ($L$) /or to minimize the gap capacitance ($Cgap$)[3].

### 3.1 Ferrite Material

Assuming a uniform $\mu$ distribution in large ferrite cores, the cavity inductance is proportional to a permeability ($\mu'$) and geometrical factors; ln($b/a$) and length ($l_f$), where $a$ and $b$ are an inner and outer diameters of

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core, respectively. Since the diameter ($b$) is restricted by a manufacturing limit and also the cavity has length limitation, relative permeability ($\mu'$) of ferrite material, in order to achieve the designed gap inductance, must be > 500, and also the quality factor ($Q$) has to be • 5 for reducing the peak rf-current[2]. Finally, the material of which $\mu'Q$-product is > 2500 at 4MHz is specified.

The frequency responses of complex permeability ($\mu'$, $\mu''$) for several small samples have been investigated. Among the commercially available products, a few samples could achieve the specifications, see Table 1.

Table 1: Summary of Complex Permeability ($\mu'$, $\mu''$) at 4MHz

| *Name of Core* | *μ'* | *Q = μ''/μ'* | *μ'Q-product* |
|---|---|---|---|
| *4A11* | *490* | *1.2* | *590* |
| *4B3 (org)* | *370* | *5.7* | *2100* |
| *4B3* (mod)* | *490* | *4.9* | *2400* |
| *4L2* | *240* | *30* | *7200* |
| *L6H* | *650* | *1.3* | *850* |
| *CMD10* | *780* | *1.4* | *1100* |

** the modified 4B3* is superior to the original 4B3.*

Considering required specifications and concerning dis-sipative power inside ferrite, the 4B3 series and 4L2 ferrite materials are possible choices for the barrier cavity and the 4B3* is the most promising material among them so far.

## 4 POWER SOURCE

### *4.1 Final Tube*

A single-ended amplifier with Thomson TH558 tetrode is designed. TH558 tetrode (600kW output power) is able to be mounted on the AGS 300kW amplifier, because TH558 has the same rf connectors. In a barrier operation mode, the duty factor is as much as 8.9%. The AGS rf amplifier including the power supplies can also be adapted to driving the new rf amplifier for the barrier system.

### *4.2 Grid Circuit*

The control grid voltage waveform should be approxi-mated to the current waveform given in Eq.(1). In order to get such high voltage rectangle waveform, the grid circuit shown in Fig.1 has been designed. The grid voltage is generated by combining the rectangle pulse and single sinusoidal waveforms. For the high voltage pulse, two of fast FET switches (*BEHLKE HTS-switch*) are operated in push-pull, and a wideband amplifier takes the part of generating a sinusoidal voltage waveform. The wideband amplifier is coupled through a step-down transformer, because of a large input capacitance of the TH558 tetrode.

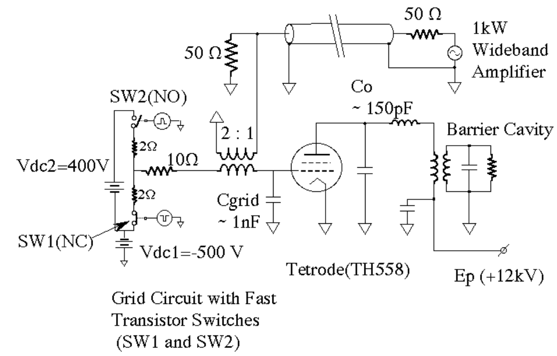


Figure 1 Schematic Drive Circuit

The control grid is biased -500V in quiescent state and biased up to -100V by SW1 and SW2. The FET switches are controlled by external TTL triggers. The rise time of this circuit has been achieved as fast as 25nsec.

## 5 DESIGN OF CAVITY

According to μ-characteristics of the samples, multi-gap cavity with 8-cells and 6 cores per cell has been designed. A preliminary sketch has been done and shown in Fig.2.

The designed gap potential is to be 10 kV amplitude at 4MHz and six pieces of ferrite cores are loaded per unit cell. The sizes of ferrite rings are the manufacturing limits of $\phi500^{mm}$ x $\phi200^{mm}$ and $t28.1^{mm}$ and total number is 48.

In the case of 4B3* ferrite, estimated shunt impedance is 2 k• per cell, and the peak power dissipation becomes 200kW. The dissipation density inside the ferrite

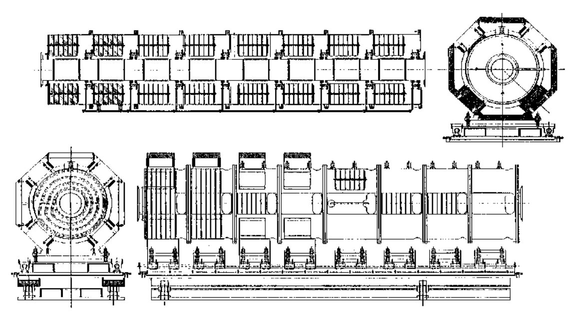

Figure 2 The New AGS Barrier Cavity : External quad-rupole biasing system[4] is equipped for trimming a resonant frequency.

materials is 2.6 W/cc max., not considered 8.9% of the duty factor, and peak magnetic field becomes 26mT corresponding to 1.7kV of average rf voltage per core. Those estimated values are relatively higher than in the accelerating cavity. It is tolerable, however, in a low duty and intermittent barrier operation. Estimations of design parameters for the 4B3* barrier cavity are summarized in Table-2. The 4L2 has a much higher $\mu'Q$-product. In comparison with the same structural 4B3* cavity, total rf current becomes much higher and exceeds a current capability of the TH558 tetrode, because of its lower $\mu'$ value.

Table 2: Estimations of Design Cavity Parameters at 4MHz

| *Items* | *Value* |
|---|---|
| *Barrier Potential* | *Total 80kV* |
| *Number of Gaps/or Cells* | *8* |
| *Number of Cores* | *Total 48* |
| *Core (μ',μ")* | *4B3* (490,4.9)* |
| *Sizes of Core* | $\phi 500^{mm} \times \phi\ 200^{mm} \times 28.1^{mm}$ |
| *Rsh* | *Total  245 •* |
| *Peak Power* | *200kW* |
| *Operation Duty* | *8.9%* |
| *Inductance per cell* | *16μH* |
| *Peak RF Current* | *240A* |
| *Peak Power Density** | *2.6 W/cc* |
| *Bmax at r=a* | *26mT* |

* *Peak power density is defined as a local power density at r=a , and the value is not considered 8.9% duty.*

## 6 SINGLE-CELL TEST CAVITY

A single-cell test cavity has been designed. The cavity is capable to have maximum 6 pieces of full-sized ferrite cores. And, high power rf tests have been accomplished in order to investigate a newly designed grid circuit and also to approve the design value of 10kV gap voltage per unit cell with full-sized ferrite cores. Figure 3 shows (a) the gap voltage achieved 10kV designed value, (b) the control grid waveform shown a very fast rise time of 25nsec and (c) the rf current through the cavity.

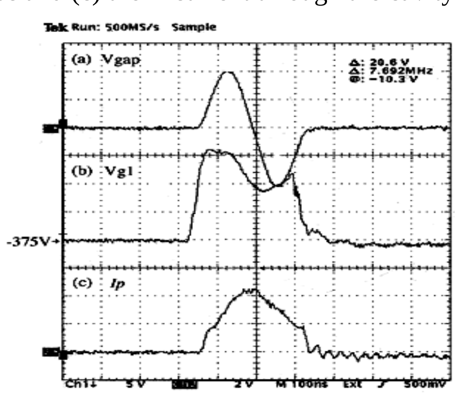


Figure 3 Barrier Waveforms (3.7MHz): The cavity has 6 of 4L2 cores; (a) Vgap; 5kV/div, (b) Vg1; 100V/div and (c) Ip; 40A/div

Another interesting result is that these ferrite materials exhibit very linear behavior against the high rf power input (see Fig.4). Measurements have been done by ener-gizing the single-cell cavity with single ferrite core. The rf voltage per unit core could be achieved more than 2kV without any non-linear phenomena observed. This is not in agreement with a behavior in a CW operation.

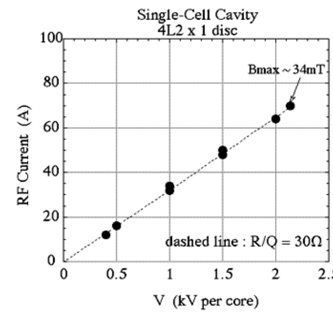


Figure 4 Barrier Voltage vs. RF Current; single-cell cavity has single 4L2 core

## 7 SUMMARY

The efficient ferrite loaded high voltage barrier cavity has been designed for a new AGS barrier system. The fun-damental design issues have been cleared. The ferrite mate-rials for this purpose are well selected from among the commercially available products. The possible choices are the 4B3 series and 4L2 materials. The sample evaluations have been carried out for small size of materials at begin-ning, and later, with respect to those promising full-sized ferrite materials, the rf power tests has been planned and studied by using the single-cell test cavity. With this test cavity, we have succeeded to demonstrate a designed value of 10kV per gap with 6 pieces of ferrite cores. And, we have found that, as far as the 4B3 and 4L2, non-linear effects of $\mu'$ and $Q$ related to high rf $B$-field had not been observed in periodic power input like a barrier operation mode.

## 8 ACKNOWLEDGMENTS


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