FOLDED FERRITE LOADED CAVITIES FOR IMPEDANCE MATCHING IN THE AGS *

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Summary. The AGS conversion requires twice the accelerating volts/turn and driving amplifiers removed from the ring to a central building. The accelerating cavities must be tuned over a frequency range of 2.5 MHz to 4.5 MHz. In addition the number of accelerating positions will be reduced from twelve to eight. These specifications combine to place severe restrictions on the accelerating cavity structure. To minimize power losses in the cavity it is necessary that more ferrite be added. A method of folding the cavities in the radial direction yields a structure which not only raises the cavity impedance, but also enables matching to the input line without using a broad band transformer. A further desirable feature of the structure is the ability to place four gaps, rather than two, in each accelerating straight section thus halving the voltage per gap and halving the voltage on the input lines. A sample computation has been made using currently available ferrite in sizes essentially the same as have been used at the AGS and PPA. The results look favorable and additional ferrites are being investigated to find higher µQf values.

Impedance Matching

The problem of impedance matching to an accelerating cavity can be solved in several ways. Rakowsky's AGSCD Technical Note No. 33 indicates two methods, capacitive networks and tapping down on the ferrite[1]. The required gap voltage of 24 kV presents additional problems in terms of cable voltages, gap clearances, etc. The primary purpose of this impedance matching is to eliminate an additional matching transformer in the ring. With the voltage swings required, commensurate with 24 kV at the gaps, the power amplifiers must be run as anode followers and a step-down transformer is required at the power amplifier to match to the cable.

We have investigated one method of minimizing these problems by the use of folded ferrite loaded cavities[2]. It is possible to get four accelerating gaps per 10-ft straight section with only 12 kV per gap. The cable voltage is now only about 1500 volts at the cavity end and the use of power amplifiers as cathode followers can be investigated. This would eliminate the transformer at the power amplifier end of the cable.

Consider a cavity as shown in Fig. 1. If the condition of resonance is assumed, we can state for a half cavity

$$L_T = L_1 + L_2 \quad \text{and} \quad \omega^2 L_T C = 1 \ .$$

For series resonant condition

$$Q_1 = \frac{\omega L_1}{R_1} \qquad Q_2 = \frac{\omega L_2}{R_2} \ .$$

The simple equivalent circuit shown in Fig. 2 can be used for computations for one-half a cavity.

$$V_{in} = I_1(R_1 + j\omega L_1) + I_2(R_1 + j\omega L_1)$$

$$0 = I_1(R_1 + j\omega L_1) + I_2(R_1 + j\omega L_1 + R_2 + j\omega L_2 + \frac{1}{j\omega C}) .$$

But, if $\omega^2 L_T C = 1$

$$0 = I_1(R_1 + j\omega L_1) + I_2(R_1 + R_2)$$

$$I_2 = \frac{-V_{in}\,(R_1 + j\omega L_1)}{(R_1 + j\omega L_1)(R_2 - j\omega L_1)} = \frac{-V_{in}}{R_2 - j\omega L_1}$$

If $Q_1 >> 1$ and $Q_2 >> 1$ then $\omega L_1 >> R_2$ for practical cases and $I_2 \approx \frac{V_{in}}{j\omega L_1}$

$$\text{Similarly } I_1 = \frac{V_{in}\,(R_1 + R_2)}{(R_1 + j\omega L_1)(R_2 - j\omega L_1)}$$

$$\approx \frac{V_{in}(R_1 + R_2)}{\omega^2 L_1^2} \quad \text{since } \omega L_1 >> R_1$$

$$\omega L_2 >> R_2$$

$$V_{out} = \frac{I_2}{j\omega C} = \frac{V_{in}}{\omega^2 L_1 C} \quad \text{but} \quad \omega^2 (L_1 + L_2)\, C = 1$$

$$V_{in} = \frac{V_{out} L_1}{L_1 + L_2}$$

Case 1

Let us assume a specific case. If we use 75 ohm cables and have four cavities in parallel, then each half cavity must present 300 ohms to the feed cable. To keep the cavity electrically short (≈20°), we may select L_T by scaling the existing AGS cavity to 2.5 MHz, i.e., we now have 15 µH at 1.4 MHz; let $L_T = 15 \times (1.4/2.5)^2 = 4.7$ µH

first assumption: $L_T = L_1 + L_2 = 4.7$ µH

second assumption: we use Ferramic "Q_1" for both L_1 and L_2

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where $\mu_1 = \mu_2 \approx 125$ and assume $\mu Q = 8000$

third assumption: the length of ferrite in a half cavity is 20 cm (total length in a straight section would be 160 cm as compared to 168 cm in existing cavity).

Now $\dfrac{V_{in}}{V_{out}} = \dfrac{L_1}{L_1 + L_2} = \sqrt{\dfrac{Z_{in}}{Z_{out}}}$ since power is conserved

V_{out} for a half cavity is 6 kV peak

$Z_{in} = 300$ ohms, $L_1 + L_2 = L_T = 4.7$ μh

$$\frac{L_1}{4.7} = \sqrt{\frac{300}{Z_{out}}}$$

However, Z_{out} is the total cavity impedance

$Z_{out} = \omega L_1 Q_1 + \omega L_2 Q_2$ at resonance

but $Q_1 = Q_2$

$Z_{out} = \omega Q (L_1 + L_2) = 4720\Omega$

$L_1 = 4.7 \dfrac{300}{4720} = 1.18$ μH

$L_2 = 4.7 - 1.18 = 3.52$ μH

The only parameters in the system we have not yet frozen are the ratios of the ferrite diameters.

$$L_1 = 2\mu t n^2 \ln \frac{r_4}{r_3} \times 10^{-3} \ \mu\text{H}$$

where $\mu = 125$, $t = 20$ cm, $n = 1$

$$\ln \frac{r_4}{r_3} = \frac{1.18 \times 10^3}{250 \times 20} = 0.236, \quad \frac{r_4}{r_3} = 1.266$$

similarly $\ln \dfrac{r_2}{r_1} = 0.714, \quad \dfrac{r_2}{r_1} = 2.04.$

If we let $d_1 = 18$ cm, then $d_2 = 36.5$ cm (in present rings $d_1 = 20$ cm, $d_2 = 35$ cm) let $d_3 = 40$ cm, then $d_4 = 51$ cm.

For a half cavity, $Z_{out} = 4720$ ohms, for full cavity Z = 9440 ohms. For four cavities in parallel

$$Z = \frac{9440}{4} = 2360 \text{ ohms.}$$

$$\text{Power} = \frac{V^2_{out}}{2Z} = \frac{144 \times 10^6}{4720},$$

V_{out} for full cavity = 12 kV.

Power = 30.5 kW

For each side

$$V_{in} = V_{out} \frac{L_1}{L_1 + L_2} = 6000 \times \frac{1.18}{4.7} = 1500 \text{ volts.}$$

To check the flux densities in each ferrite section, we use

$V = n\omega BA \times 10^{-8}$; $n = 1$, B in gauss, A in sq cm. For L_2,

$V_{L_2} = \frac{3}{4} V_{out} = 4500$ volts

For L_1,

$V_{L_1} = 1500$ volts.

$$\text{Peak } B_2 \text{ averaged} = \frac{V \times 10^8}{\omega A}$$

Peak B_1 averaged = 87 gauss.

From the equivalent circuit

$I_1 = 5$ amps, $I_2 = 81$ amps, $C = 860$ μμF.

actual gap capacitance $= \frac{C}{2} = 430$ μμF.

Case 2

If we had assumed a different μQ product, the same computation can be done to see how much change is made in the sizes of the ferrite rings. Again, let the cable impedance be 75 Ω.

Let $\mu Q = 6250$ $\mu = 125$, $Q = 50$

As before

$L_1 + L_2 = 4.7$ μH

$$\frac{L_1}{L_1 + L_2} = \sqrt{\frac{300}{Z}} = \sqrt{\frac{300}{\omega Q (L_1 + L_2)}}$$

$L_1 = 1.35$ μH

$L_2 = 3.35$ μH

$\ln \dfrac{r_4}{r_3} = 0.27$ $\dfrac{r_4}{r_3} = 1.31$, if $d_3 = 40$ cm,

$d_4 = 52.4$ cm

$\ln \dfrac{r_2}{r_1} = 0.67$ $\dfrac{r_2}{r_1} = 1.95$, if $d_1 = 18$ cm,

$d_2 = 35$ cm

For a half cavity $Z_{out} = 3700$ ohms

$$P_{tot} = \frac{144}{3.7} = 39 \text{ kW}$$

$$V_{in} = \frac{L_1}{L_1 + L_2} V_{out} = 1720 \text{ volts.}$$

This yields a cavity very similar in all respects to the first case.

Mismatching

We can now see what would happen if we had built the structure with an assumed Q of 64, but had a Q of only 50.

The mismatch would be:

$$\frac{L_1}{L_1 + L_2} = \sqrt{\frac{Z_{in}}{Z_{out}}} \qquad L_1 = 1.18 \ \mu\text{H}$$

$$L_1 + L_2 = 4.7 \ \mu\text{H}$$

$$Z_{in} = \left(\frac{1.18}{4.7}\right)^2 \text{x } 3700 = 250\,\Omega \qquad Z_{out} = 15.7 \text{ x } 4.7 \text{ x } 50$$

$Z_{out} = 3700\,\Omega$ instead of $4720\ \Omega$

For four in parallel $Z_{in} = 62.5\,\Omega$ instead of $75\,\Omega$.

In this structure, we could adjust the input impedance by having a separate small bias current only around L_1 which would adjust L_1 and therefore, the ratio

$$\frac{L_1}{L_1 + L_2}$$

to yield a good cable match. This would be in addition to the usual main saturating current which would encircle both L_1 and L_2.

There exist many variations of initial assumptions which affect all the parameters. If, for example, we assume a shorter electrical length in the cavity, $L < 4.7\ \mu\text{H}$, all the dimensions change and the ferrite weight decreases substantially and power and flux density increase. It may be desirable to write a computer program to generate a large number of cases and then select the most suitable one.

Available Ferrites

The examples shown above used data for Ferramic Q1. We have subsequently determined that this material has the wrong dc saturation tuning characteristic and is not usable. Ferroxcube 4C4 with similar rf properties, and Tokohu (Japan) ACL1 would be suitable materials for this application. Additional materials should become available before a final choice is made.

References

1. Internal report Accelerator Department, Conversion Division.
2. The LRL 200 BeV proposal (UCRL-16000) uses a similar folded cavity for the ring rf with only enough ferrite to accomodate a 0.55% frequency change.

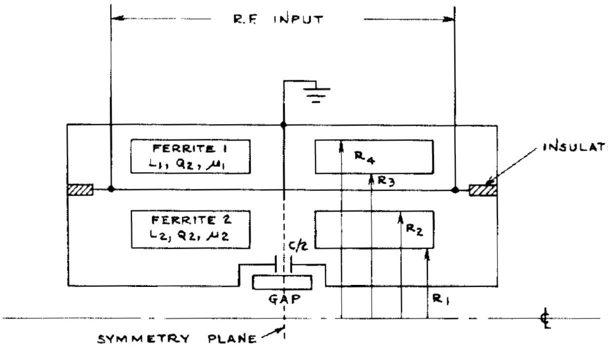

Fig. 1. Schematic Cross Section of Cavity.

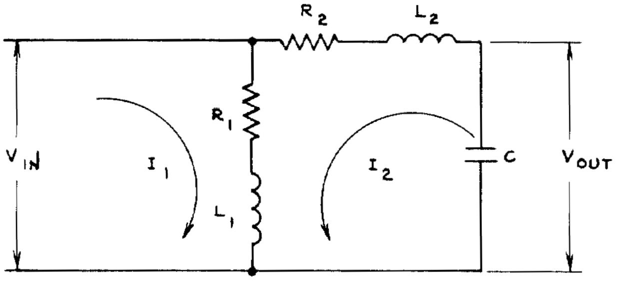

Fig. 2. Equivalent Circuit of Cavity.