UPGRADE OF AGS RF CAVITIES FOR INCREASED BEAM LOADING

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INTRODUCTION

The AGS RF System must be upgraded to accommodate an increase in beam loading. The system has two major facets. One is the power amplifier; the second is the cavity. This note addresses the problems associated with the cavity.

Increased beam loading due to the injection of a bunched beam from the booster into the AGS has two aspects. During the accelerating phase, steady state beam loading imposes a limit on the drive (or output) resistance of the amplifier, the Robinson resistance. The injection of a bunched beam induces a transient response in the cavities. This transient response manifests itself as a phase delay and amplitude modulation of the gap voltage, and is dependent on the product of the gap capacitance and gap voltage.

TRANSIENT RESPONSE

The transient response has been analyzed^{1,2}. Each injected bunch induces a phase delay in the RF gap voltage. The delay is given by

$$\sin^{-1} N \frac{\Delta Q}{CV} \quad (1)$$

where ΔQ = charge/bunch
C = cavity (station) capacitance
V = cavity peak voltage
N = numerical, depending on charge distribution of the bunch

For an impulse $N = 1/2$, for a half-wave sinusoid $N = \pi/8$, for a rectangular distribution $N = 1/\pi$. Limiting the induced phase shift to 30° requires that

$$CV > \Delta Q.$$

Design parameters of the AGS cavity are:

ΔQ : based on 6×10^{13} protons per pulse, with a 50% safety factor $\Delta Q = 1.2 \times 10^{-6}$ coul/bunch.

C : the equivalent capacitance of 4 gaps in series. Initially we believed that the gap capacitance was in the range of 300 - 330 $\mu\mu\text{F}$. Subsequent measure-

ments indicate that the capacitance is 400 - 410 $\mu\mu\text{F}/\text{gap}$ or 100 $\mu\mu\text{F}/\text{cavity}$.

V : the peak accelerating voltage. With injection at full voltage $V = 40\text{KV}/\text{cavity}$.

Thus the CV product is 4 μ coul.

Injection consists of the sequential injection of 3 bunches from the booster, for an injection of 3.6 μ coul/Booster pulse. The duration of the transient produced by each pulse depends on the cavity quality factor Q_0 . For the transient to decay in one RF cycle Q_0 must be less than 2. The cavity, loaded by the amplifier output resistance has a Q_0 greater than 15. Thus the sequential injection of the three Booster pulses is equivalent to a transient disturbance produced by a ΔQ of 3.6 μ coul. The CV product of 4 μ coul is marginal and should be increased to approximately 8 μ coul.

UPGRADE

The increase of cavity capacitance and voltage are not independent of each other and is limited by the Q-loss phenomenon, and ferrite dissipation. Q-loss^{3,4} is a time-dependent magnetic phenomena. For a constant input power the output voltage is characterized by a period of constant output followed by a decrease of output voltage. The output voltage can be held constant by increasing the drive following the on set of Q-loss. A properly functioning AGC loop can hold the output voltage constant over its linear range. During the high loss period the output voltage appears noisy. Oscillograms depicting Q-loss are included and described within the Appendix. In the references cited and in the older literature this phenomena is called high-loss effect.

The minimum voltage at which Q-loss develops was measured as a function of gap capacitance and is given in Table 1. Measurements leading to Table 1 were made with the AGC loop open.

Table 1. On Set of Q-Loss
F = 4.5 MHz

Gap Capacitance $\mu\mu(\text{F})$	On Set of Q-Loss (Kv)
400	14
500	12
700	11
800	7
1,000	6.5

As the value of gap capacitance is increased, the stored energy and associated ferrite dissipation also increase.

In addition, the upgrade must provide for cavity operation over a frequency range from 1.7 MHz to 4.5 MHz. The lower limit is based on a RHIC operational requirement. Based on the existing gap capacitance of $400\ \mu\mu\text{F}$, the capacitance must increase to at least $610\ \mu\mu\text{F}$.

Choosing $700\ \mu\mu\text{F}$ as the gap capacitance and 10 Kv as the gap voltage yields a CV product of $7\ \mu\text{F}$. The ferrite bias is limited to 1100A.

The ferrite tuning current was measured and is given in Figure 1. The CW dissipation for a gap voltage of 10 KV was measured as a function of frequency and is given in Figure 2.

Additional measurements were obtained for the AGS test cavity and are included in the Appendix.

PERFORMANCE

With an added capacitance of $300\ \mu\mu\text{F}/\text{gap}$ (including a 100 to $150\ \mu\mu\text{F}$ contribution from the power amplifier) and a gap voltage of 10 KV the following additional parameters are projected for the test cavity.

$$\begin{aligned}V &= 40\ \text{KV} \\C &= 175\ \mu\mu\text{F} \\CV\ \text{Product} &= 7\ \mu\text{F} \\\Delta Q &= 3.6\ \mu\text{F} \\\text{Ferrite CW Dissipation} &= 65\ \text{KW, or } 251\ \text{mw/cc} \\\text{Ferrite Shunt Resistance} &= 12.3\ \text{K}\Omega \\\text{Amplifier Output Resistance} &= 6.4\ \text{K}\Omega\end{aligned}$$

Based on class AB operation of the EIMAC 4CM300,000 and an external 1:1 transformer:

$$\begin{aligned}\text{Output Resistance} &= 4.2\ \text{K}\Omega \\\text{Robinson Resistance} &= 6.35\ \text{K}\Omega \\\text{Peak Beam Power} &= 125\ \text{KW} \\Q_o\ \text{of Cavity} &= 19\end{aligned}$$

Figure 1. Cavity Tuning

Figure 2. Cavity Dissipation

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APPENDIX

The tuning curves for additional gap capacitance of 620 $\mu\mu\text{F}$, 720 $\mu\mu\text{F}$ and 925 are included and given in Figure A-1.

Oscillograms depicting Q-loss are given in Figure A-2. Measurements were made with 300 $\mu\mu\text{F}$ of capacitance added to each gap ($C = 700 \mu\mu\text{F}/\text{gap}$) and driven from a 4.5 MHz power source. A 1000:1 voltage probe was employed, such that the vertical sensitivity is 5 KV/cm. In Figure A-2 (A), the cavity drive is adjusted for an output of 10 KV-peak, the AGC loop is open and the response is free of Q-loss. In Figure A-2 (B), the drive is adjusted for an output of 12 KV, the AGC loop is open and Q-loss is present. Note the noise during the high-loss phase. In Figure A-2 (C), the AGC loop is closed and adjusted for an output of 12 KV. Note the constant output voltage level but the manifestation of noise during the high-loss phase.

Figure A-1. Tuning Curves
Additional Gap Capacitance of 620, 720 and 925 μF

Fig. A-1(A)
AGC Loop Open
 $V = 10 \text{ KV}$

Fig. A-2(B)
AGC Loop Open
 $V = 12 \text{ KV}$

Fig. A-2(C)
AGC Loop Closed
 $V = 12 \text{ KV}$

Fig. A-2 Oscillograms Depicting the Q-Loss Phenomena
 $F = 4.5 \text{ MHz}$
 $C = 700 \mu\mu\text{F}/\text{Gap}$
Probe = 1000:1