BNL-104831-2014-TECH

AGS/AD/Tech Note No. 415;BNL-104831-2014-IR

UPGRADE OF BOOSTER RF POWER AMPLIFIER FOR PROTON CAVITY

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May 1995

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U.S. Department of Energy

USDOE Office of Science (SC)

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Technical Note

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INTRODUCTION

The rf power amplifier for the proton cavity (Band III) was designed to accelerate a beam of 1.5×10^{13} protons per pulse (15 Tp). To provide a 50% factor of safety in the design of the power amplifier the output tube (EIMAC 4CM300,000G) was designed to accommodate a beam of 22.5 Tp. To increase the beam in the AGS to 60 Tp the Booster is required to accelerate a beam in excess of 20 Tp. Thus, the margin of safety is fully used, requiring modification of the operating conditions for the power amplifier. A margin of safety is required to accommodate for an unbalance and for unequal beam loading of the two rf stations.

In addition, the harmonic number (h) of the Booster was changed from h=3 to h=2. At the lower rf frequency, the cavity operates with a 50% increase in flux density. In the original design of the power amplifier only static (fixed-frequency) ferrite losses were available to estimate the cavity losses. At this time dynamic or swept-frequency loss measurements have been obtained for the cavity. The measured losses include components due to frequency sweeping (termed F-dot, $\dot{F}$) and transient domain alignment (termed domain-wall energy loss). These losses have been referred to as "audio" losses by other cavity designers. The measured cavity losses are higher than the original estimates. At 45 Kv the peak cavity loss was measured at the leading edge of the rf burst to be 106 KW.

MODIFICATIONS

The simplest and most practical modification to increase the power capability of the power stage was an increase in the screen voltage from 1100 to 1600 volts and decrease the grid bias from 300 to 380 volts. The increase in negative grid bias maintains the same value for quiescent plate current since the μ of the tube is 6.25. The μ is the ratio of screen grid to control grid voltage to maintain a constant value of plate current. The maximum grid drive is limited by the two ENI-500 watt power amplifiers to 316 volts (nominal 300 volts peak). Grid drive power is 1000 watts. A detailed analysis of the modified amplifier reveals that it operates class AB_1, with 220° of conduction and can accelerate a beam in excess of 30 Tp. The power capability of the stage is presently limited by the grid drive of 300 volts. By increasing the grid drive power to 1500 watts, the grid drive is increased to 380 volts, the limit of class 1 operation. This will further increase the capability of the amplifier to accelerate a beam of 40 Tp.

In addition the plate supply voltage was increased from 13 Kv to 15 Kv. This will certainly decrease the value of screen-grid current. However, it increases the voltage stress of the plate supply conductor threaded through the cavity and should not be increased indiscriminately.

TUBE PERFORMANCE

The load line for a screen voltage of 1500 volts is given in Figure 1. The performance parameters of the output stage have been calculated and are given in Table 1. They are compared to the maximum tube ratings. The calculations have been corrected for a screen supply of 1600 volts by increasing the effective drive by $\frac{100}{6.25}$ or 16 volts; 6.25 is the tube μ relating screen grid to control grid.

TUBE PERFORMANCE		TUBE RATING
E_{BB}	15 KV	20 KV
E_{C2}	1.6 KV	2 KV
E_{C1}	-380 V	
Peak Grid Drive	300 V	
Plate Current		
Quiescent	8 A	
Peak	80 A	
Average	26.6 A	50 A
Fundamental Peak	40 A	
Plate Dissipation		
Peak	171 KW	
Quiescent	120 KW	
Average	145 KW	300 KW
Screen Current		
Peak	2.5 A	
Average	.41 A	
Screen Dissipation	640 Watts	6KW
Grid Current	0	
Average Plate Resistance	594 Ohms	
Class B Operation		

TABLE I

Performance of EIMAC 4CM300,000G

LOAD POWER AND DAMPING

The rf value of peak current, voltage and load power is given in Table II. Allowing 100 KW for the ferrite losses the beam power is also tabulated. The cavity voltage is 45 KV peak and the synchronous angle is calculated as 15.44°. Thus for a beam of 30 Tp the required beam power is 80.6 KW/station.

The Robinson resistance required to damp the beam is 12.5 K ohms. The plate resistance of 600 ohms is stepped up to 9600 ohms at the cavity level. Additional damping is provided by the ferrite dissipation. The ferrite dissipation varies over the cycle with a minimum value of 50 KW. This represents an additional damping of at least 20.25K ohms. Thus the beam damping is 6.5 K ohms.

A second criterion for stability is the relative beam damping Y, $Y = I_B/I_O$. The maximum value of I_B is obtained for short bunches. With a beam of 30 Tp and a rotational frequency of 1.4 Mhz the value of I_B is 13.44 A. The value of I_o is calculated from the resonant cavity resistance (6.5k Ohms) and cavity voltage (45 kV) as 6.92 A. The Y ratio is 1.94. For stability Y must be less than 2. Thus the modified amplifier and cavity can accelerate a beam of 30 Tp. The results of the power calculation and damping are summarized in Table III.

Fundamental Peak Current	40 A
Peak Voltage	11.25 KV
RF Power	225 KW
Cavity Dissipation	100 KW
Beam Power	125 KW

TABLE II

RF POWER

Cavity Voltage	45 KV
Synchronous Phase Angle	15.44°
Maximum Rotational Frequency	1.4 MHz
Beam	30 Tp
Average Beam Current	6.72 A
Beam Power	80.6 KW
Robinsons Resistance	12.5 KΩ
Damping Resistance Tube and Cavity	6.5 KΩ
I_B	13.44 A
I_O	6.92 A
Y	1.94

TABLE III

BEAM POWER AND DAMPING

CAVITY DISSIPATION

The peak cavity dissipation was measured as 106 KW. The volume of ferrite is calculated as 235.8 x 10^3 cm^3. Thus the dissipation density is 450 mw/cc and with a 50% duty cycle the short-time average dissipation is 225 mw/cc. Experience limits water-cooled ferrite to an average dissipation of 200-250 mw/cc. With the low duty cycle of the Booster the increased cavity dissipation does not present a problem.

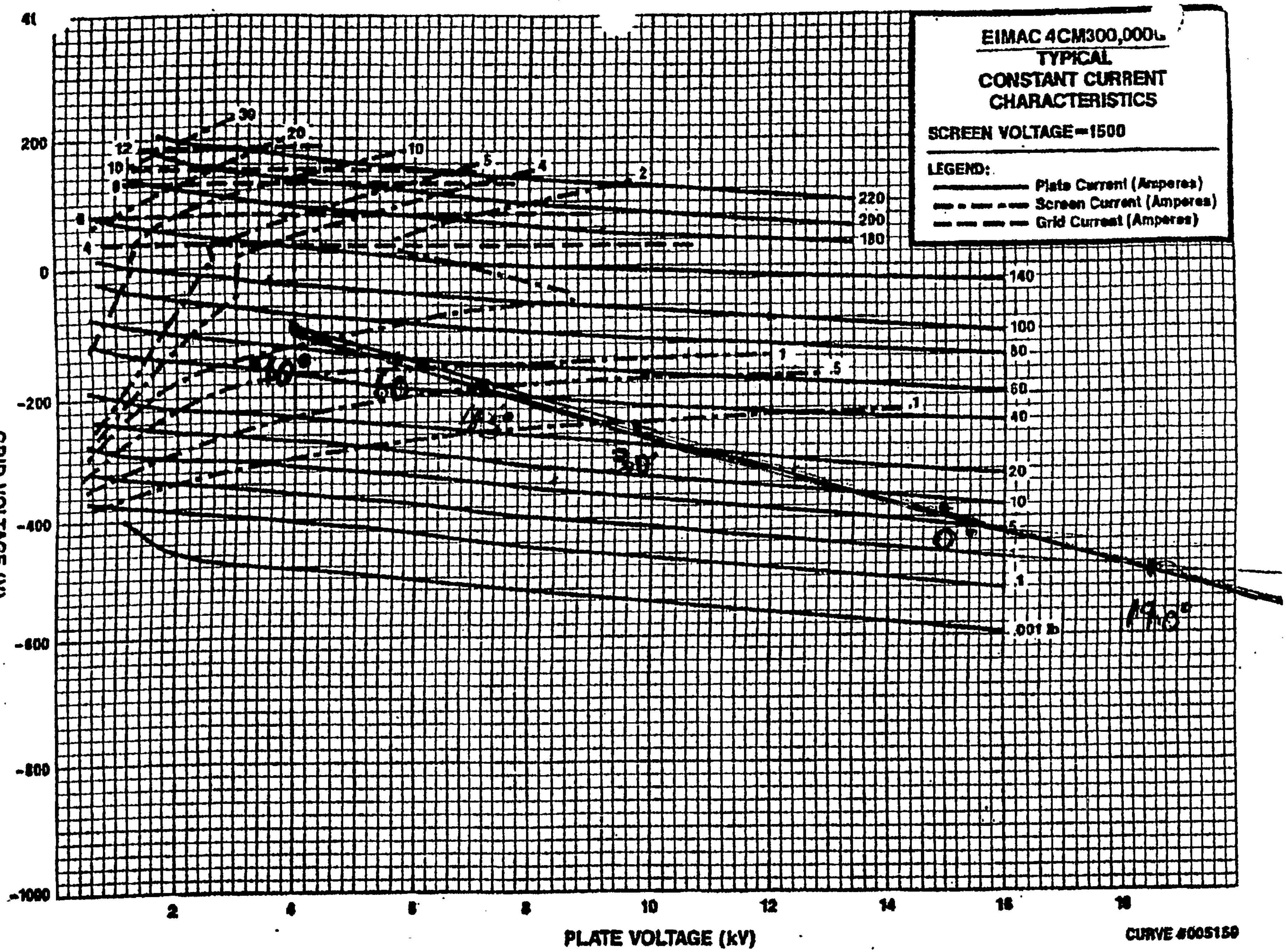

Figure 1

Load Line for Modified Amplifier