CHARACTERIZATION OF HIGH POWER CW KLYSTRONS AND ITS APPLICATION TO LOW LEVEL RF CONTROL*

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Abstract

The power gain, phase delay, and line harmonic spectrum of a 1.3 MW, 350 MHz, CW klystron amplifier have been measured as a function of input power. These measurements of the klystron were taken at several constant perveance and constant impedance operating points. The results are used to enhance the performance of the low level RF control system.

1 INTRODUCTION

Accelerator control systems attempt to maintain a constant cavity field by monitoring the field and modulating the driving RF amplifiers to cancel out any perturbations. The extent to which this can be done depends on the characteristics of the cavity, the strength of the amplifiers, and the quality of the control system. An accurate characterization of the cavity and the amplifiers can be used to improve the performance of the control system. The purpose of this paper is to show results from measurements made on a 350 MHz 1.2 MW klystron amplifier. The measurement technique, while not unique, is relatively simple and can be used on a variety of CW amplifiers.

The 350 MHz klystron tested will be used to drive the RFQ on the Low Energy Demonstration Accelerator (LEDA) for the APT project. The RF architecture of LEDA places several constraints on the low level control system which were quantified by these tests. The LEDA RFQ will be driven by three klystrons operating at 2/3 power or, if one fails, two klystrons operating at full power. In either case the DC bias parameters of the klystrons will be set to allow for an amplitude control margin of about 10%. One control system will be used to drive these klystrons so having the proper phase relationship between the klystrons is critical. Since the klystrons will be operating near saturation it was necessary to get accurate gain curves for a variety of DC bias conditions. Also line harmonic frequencies on the output RF were measured since regulating these could decrease the control margin. Finally, the phase length of the klystron was measured as a function of the DC bias and the input power.

*Work supported by Department of Energy.

2 EXPERIMENTAL SETUP

Figure 1 Shows a block diagram of the experimental setup.

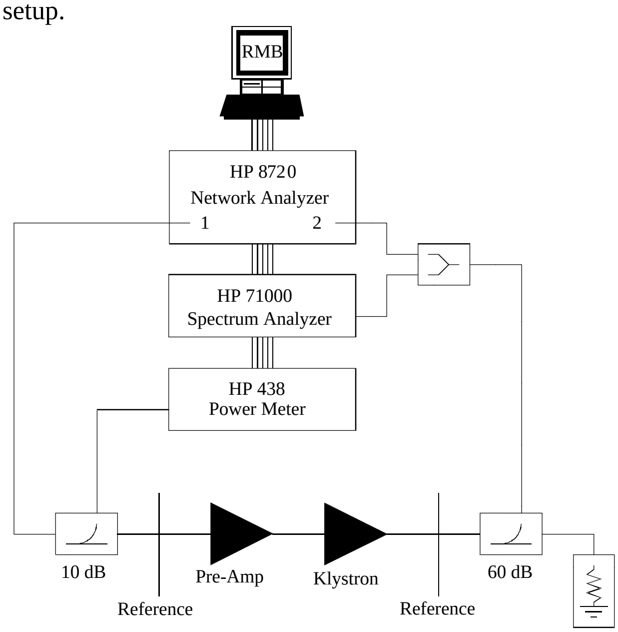

Figure1. Experimental Setup

A HP 8720 network analyzer operating in CW mode at 350 MHz was used to drive the klystron and measure its output power and phase length. A HP 71000 series spectrum analyzer was used to measure line harmonic sidebands (N*60 Hz) on the output RF. Lastly, a HP 438 power meter was used to measure and adjust the RF output power of the network analyzer. The three instruments were controlled, and data was collected, via HPIB by a PC running Rocky Mountain Basic. All measurements were made as a function of input power once the DC bias of the klystron had been established. The line losses from port 1 of the network analyzer to Reference Plane 1 as well as from Reference Plane 2 to port 2 were carefully measured and recorded. The measurements proceeded as follows. First the computer instructed the network analyzer to go to a prescribed output power. The power meter measured the true output power using a well defined 10 dB directional coupler. The true power was relayed back to the computer which used a converging algorithm to adjust the output of the network analyzer until the prescribed RF power was present at Reference Plane 1. The network analyzer then measured the magnitude and angle of S_{21} after which, at the operators request, the input power was incremented and another test point was taken.

From the magnitude of S_{21} the gain between Reference Plane 1 and 2 could be calculated since the line losses were known. Also, since the input power at Plane 1 was known, the output power at Plane 2 could be derived. The angle of S_{21} was the phase length between Planes 1 and 2 plus a fixed angle due to the lines. At several points along a curve the spectrum analyzer was poled to get the output RF spectrum. The spectrum analyzer would measure the main klystron peak as well as any other peaks within 750 Hz of the center. The sidebands occurred exclusively at line harmonic frequencies, and their power relative to the main peak was recorded.

Once the DC bias for the klystron was fixed the input power was initially set at a low level generating less than 50 kW output from the klystrons. The input power was then raised in 1 dB increments, 0.2 dB increments, and finally 0.1 dB increments as the klystron neared saturation. Table 1 shows the different DC bias conditions for which the klystron was tested. The beam current was set to maintain a constant tube perveance in points 1-4 and a constant tube impedance in points 4-7.

Test Point	Beam Current (A)	Cathode Voltage (kV)	Saturated Pout (kW)	Number of Data Points
1	9.85	60.0	279	51
2	15.3	80.0	725	40
3	17.6	88.0	963	42
4	19.4	93.9	1161	50
5	18.3	88.4	1008	30
6	16.4	80.4	806	42
7	12.4	60.2	365	46

Table 1.

3 RESULTS

The test results are summarized in Figures 2, 3, and 4 which respectively show the power, efficiency, and phase characteristics for the klystron.

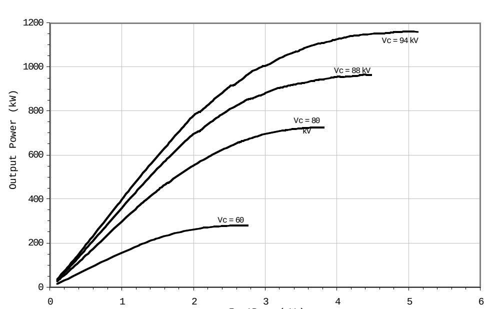

Figure 2. Output power characteristics.

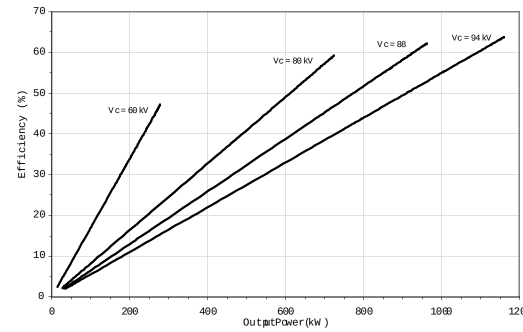

Figure 3. Power efficiency characteristics.

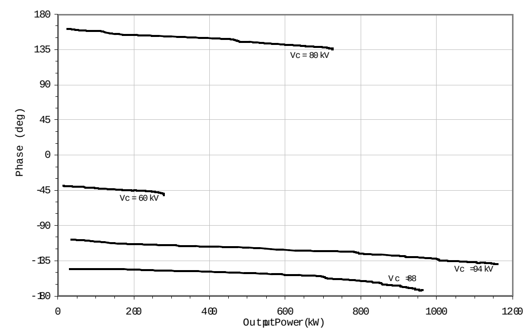

Figure 4. Output phase characteristics.

The figures show the results for bias points 1 through 4. The efficiency is calculated as the ratio of the output RF power to the input DC power. Table 2 show the line harmonic data at several output power levels for bias point 4. There was no appreciable power in the line harmonics above 120 Hz, and only at 1000 kW output was there power in the 60 Hz harmonic.

Pout (kW)	60 Hz Power (dBc)	120 Hz Power (dBc)
117	< -70	-52.8
504	< -70	-53.2
1000	-55.7	-46.9
1159	< -70	-48.3

Table 2. Line harmonic data.

4 CONCLUSION

Several observations about the architecture and performance requirements of the control system can be made from the above data. Measurements of the line harmonic power show that it will introduce about 0.5% error in the cavity voltage and will not seriously reduce the control margin of the system. With respect to the klystron phase data, it is obvious that some sort of individual phase control is necessary for each klystron.

The phase length of the klystron can change by many tens of degrees with cathode voltage and by ten degrees or more for a set DC bias condition. For LEDA three klystrons will drive a single cavity and be controlled by a single system. The cavity phase is the superposition of the three klystron phases and will be maintained at a constant value by the control system. However, without individual control of each klystrons phase, large inefficiencies in transmitted power can occur which will degrade the control margin of the system.