Acceptance Test Performance of the Rocketdyne Radio Frequency Power System

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Abstract

We present initial results of performance testing of the RF power system built for the Rocketdyne Free Electron Laser program. The RF power system consists of a SLAC 5045 klystron powered by a modulator unit built by the Beta Division of the Titan Corporation. The system is capable of providing 65 MW, 3.5 μsec macropulses at 180 pps and employs innovative feedback and feed-forward control techniques in order to achieve amplitude flatness and phase stability. Preliminary rf amplitude, pulse flatness and phase stability measurements indicate phase stability better than ±1° and pulse flatness better than ±0.25% are achievable at the 65 MW operating point.

I. INTRODUCTION

The Rocketdyne Free Electron Laser group is currently under contract to demonstrate a high-current, high-brightness electron beam injector based on a photocathode-driven, rf microwave gun with magnetic compression. The rf power system supplies the electron-beam injector [1] with highly regulated rf power at the 5-10 MW level. The remaining 55 MW of available rf power will feed four linac sections allowing electron beam energy to be increased from 5 MeV to 80 MeV. The high-brightness, 80 MeV electron beam will enable FEL operation in the visible portion of the spectrum using previously fabricated undulators [2].

II. SYSTEM DESIGN

A. 5045 Klystron Tube

The klystron unit was purchased by Rocketdyne and supplied to Titan-Beta Corporation for integration into the rf power system. The klystron unit consisted of the klystron tube, solenoid focusing magnet, 15:1 oil-immersed transformer and high-voltage cable. The SLAC 5045 klystron is characterized by typical operating parameters as listed in table 1.

Table 1.
Nominal operating parameters of a 5045 klystron

PARAMETER	UNITS	VALUE
operating frequency	MHz	2856
beam voltage	kV	350
beam current	amps.	420
pulse repetition frequency	pps	180
peak rf output power	MW	65
average rf output power	kW	45

Operating experience accumulated at SLAC with the 5045 klystron suggests an average tube life of 40,000 hours.

B. Modulator

The modulator was designed to power the 5045 klystron over a large operating range by providing variable PFN charging and variable pulse repetition frequency. The required PFN voltage needed to achieve a 350 kV pulse at the klystron is give by:

$$V_{PFN} = \frac{2V_{beam}}{15} = \frac{700[kV]}{15} \approx 47[kV] \qquad (1)$$

The design goals for the rf power system were to design and fabricate a robust, highly regulated system capable of operating at variable peak power levels between 20 MW and 65 MW and variable pulse repetition frequencies between 1 pps and 180 pps. The most challenging specifications were placed on rf pulse flatness and phase stability.

Table 2.

RF pulse specifications for the RF power system

RF PARAMETER	UNITS	VALUE
pulse width	μsec	3.7
peak power	MW	20 - 65
pulse repetition frequency	pps	1 - 180
phase stability	degrees	±1°
pulse flatness	%	±0.25
pulse jitter	nsec	±10
long term ampl. stability	%/hr	±0.5
short term ampl. stability	%/5 min.	±0.2

C. Control System

An innovative control system was designed to achieve the desired performance goals which would incorporate differing levels of feedback and feed-forward control on both phase and amplitude parameters associated with the rf drive and high voltage pulse supplied to the klystron. It was felt that controlling the flatness of the high voltage pulse to the klystron at the ±0.1% level would insure rf pulse flatness at the ±0.25% level. If this approach was not sufficient to meet rf pulse specifications then modulation of the rf drive amplitude and phase would be added to obtain the required rf specifications. The rf power system design incorporated a number of feedback and feed-forward control loops, as depicted in figure 1., to achieve the desired regulation and stability.

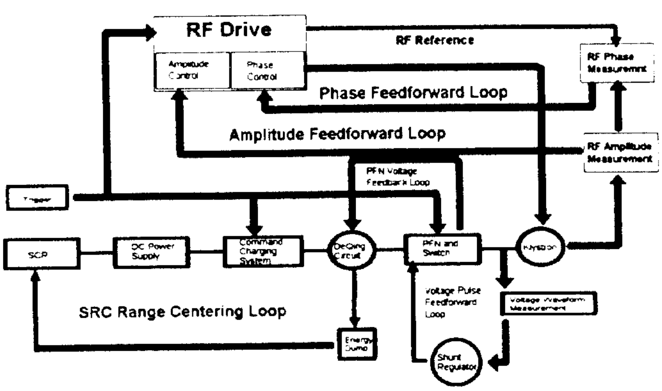

Figure 1. Block diagram illustrating the feedback and feed-forward control loops built into the control system.

The need for control of the rf power system from a remote area was required and accomplished by incorporating an IEEE 488 bus which linked the rf power system interface module with a Macintosh II computer running LABVIEW software. The rf power system could run in either local mode or remote mode set by a switch on the control panel. The software was written to provide a relatively simple user interface for control of the rf power system.

D. Interlock System

Another important feature of the rf power system was the interlock-chain design built to prevent component damage due to unsafe operating conditions. The interlock system was built with first-fault detection capability to assist operators in rapidly debugging system problems.

III. EXPERIMENTAL TEST SETUP

The rf pulse characteristics were measured by outcoupling a small fraction of forward-going rf power from a test port located just downstream of the klystron. The rf power was attenuated to levels compatible with a HP detector which was used to measure rf amplitude and pulse flatness. A portion of the forward-going power was diverted to the phase measuring system where it was mixed with the rf reference to provide a phase error profile across the pulse. A Tektronix 540 oscilloscope was used to display and analyze the captured data as illustrated in figure 2. The measurement of small error signals in the presence of large current loops associated with the rf power system required judicious placement of highly shielded cables in order to keep the signal to noise within acceptable levels.

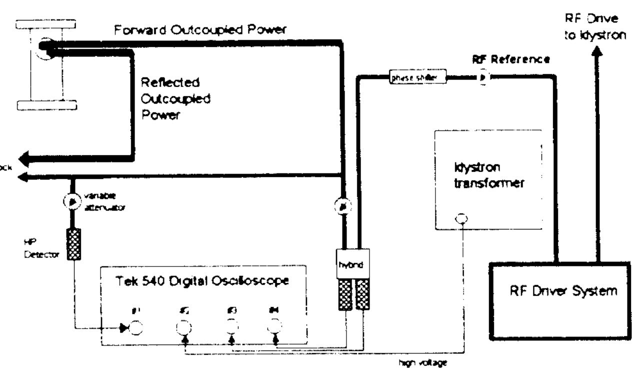

Figure 2. Block diagram of the test setup used to measure rf pulse parameters.

A. Measurement System Calibration

Calibration of the detectors, attenuators, outcouplers and phase measurement system were crucial in verifying compliance with contractual specifications. Calibration of the total rf output power using a power-balance technique was attempted but did not provide adequate calibration accuracy at low average power operation necessitated by the damaged klystron window. A peak power meter was used to measure the magnitude of outcoupled rf power and calibrated against the supplied rf output power curves as a function of beam voltage and current. The phase measurement system was calibrated against controlled variation of the phase shifter. Manufacturer specifications were used for detector, attenuator and cable characterization.

IV. PERFORMANCE DATA

The acceptance test matrix originally included measurements of rf output parameters, as listed in table 2., at three peak power levels (20,45,65) MW and two pulse repetition frequencies (10,180) pps. In addition, a 6 hour "heat-run" at the system's maximum average power level was required to measure system robustness. Unfortunately, a vacuum mishap resulted in a klystron window failure which would not permit high-average power rf operation. The rf amplitude flatness was measured at the 65 MW and 10 pps operating point. The rf pulse flatness at 65 MW peak output power was achieved by employing two arbitrary waveform generators used to control both phase and amplitude modulation of the rf drive signal. Achieving the required flatness and phase stability necessitated an interactive process of looking at the captured scope trace and adjusting each arbitrary waveform generator in such a manner as to modify the pulses so that they conformed to the required specifications. The resultant oscilloscope trace as depicted in figure 3. indicates that ±0.22% was achieved for pulse flatness at the 65 MW and 10 pps operating point.

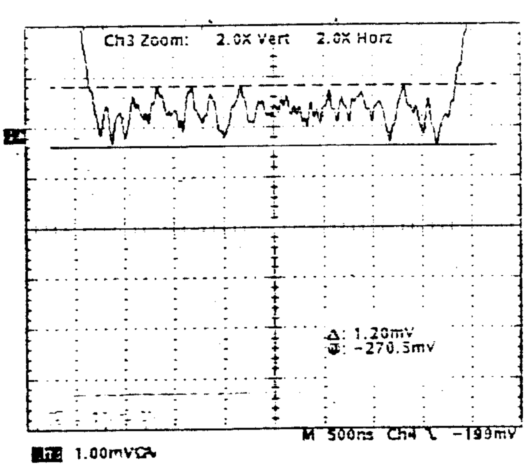

Figure 3. Oscilloscope trace depicting rf pulse flatness at the 65 MW and 10 pps operating point.

The phase variation across the pulse was measured at ±1° as depicted in figure 4.

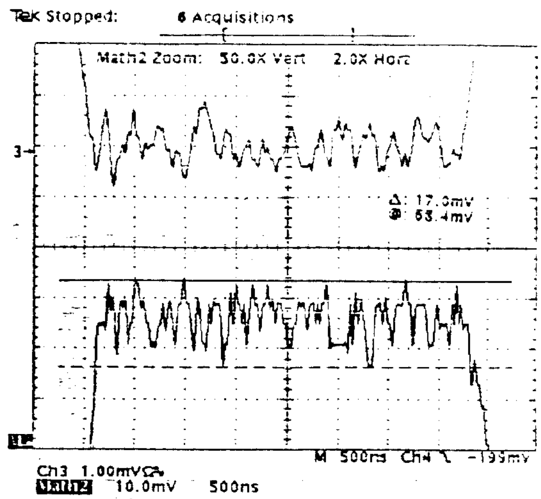

Figure 4. Oscilloscope trace depicting a) rf pulse flatness (top trace) and b) rf pulse phase stability (bottom trace) at the 65 MW and 10 pps operating point.

The heat run was performed with reduced pulse width using the klystron in diode mode and lasted just short of the required 6 hour test.

V. REFERENCES

[1] M. Lampel et.al., these proceedings.
[2] R. A. Cover et. al., SPIE Proceedings Vol. 1868, Los Angeles, CA (January 1993)