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COMPUTER CONTROL OF THE ENERGY OUTPUT OF A KLYSTRON IN THE SLC*

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ABSTRACT

Hardware and software have been developed to permit computer control of the output of high power klystrons on a pulsed basis. Control of the klystron output is accomplished by varying the input drive via a pulsed RF attenuator. Careful power calibrations permit accurate calculation of the available energy, as seen by the beam, over the full range of the klystron output. The ability to control precisely the energy output allows for energy feed-forward as well as energy feedback applications. Motivation for this work has been the need to adjust the energy of beams launched into various regions of the SLC. Vernier klystrons play a crucial role in the energy delivered from the SLC injector, linac, and positron source. This paper discusses the hardware development, energy calculations, and software implementation. Operational results are presented.

Introduction

The SLC injector must provide beams to the damping rings whose energy is stable to within a few MeV. This stability is achieved through the control of a variable output high power klystron. The controls include a well characterized attenuator and a high speed analog controller, whose output may vary on a pulse to pulse basis. This allows stabilization of interlaced beams with different energies.

The high speed controller is a CAMAC based module, the Programmable Amplitude Unit (PAU)[1] which can set and monitor an analog voltage whose value is different for different beams. This drives an additional high power RF attenuator in the klystron's RF interface. Software has been developed to calculate a station's energy gain from analysis of the RF output, and to calibrate the high-power attenuator in terms of the energy gain. This calibrated energy control is then used by the energy stabilization feedback.[2-4]

A schematic of the vernier klystron RF is shown in Figure 1, where the additional high power attenuator required to pulse the klystron is indicated. Figure 2 depicts the overall control of a vernier klystron. The PAU drives a current source which controls the vernier attenuator. Output amplitudes on different beam codes are selected from the VAX and implemented by the local micro-processor. The PAU selects the appropriate output based on the beam code broadcast by the Master Pattern Generator.

Modifications to the RF Controls

The standard RF Drive controls for a klystron[5,6] include an attenuator, a rotary field Fox phase shifter, a linear amplitude detector and several RF isolators. Klystron output is measured with a calibrated Phase and Amplitude detector, which monitors the high power output from the SLED cavities upstream of the accelerator. The normal klystron attenuator is used by the conventional klystron controller to adjust the operating point of the klystron on the RF drive saturation curve. It is also used as a protection device for certain classes of klystron station faults. The vernier stations have a voltage controlled current source and an additional high power RF attenuator. An analog multiplier provides a square-law output from the input voltage, allowing

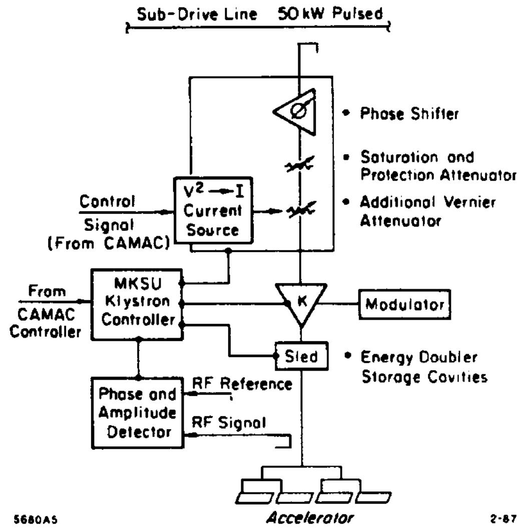

Fig. 1. Schematic of Vernier Klystron showing the RF path and the associate RF controls and monitors. K = Klystron, MKSU = Modulator and Klystron controller.

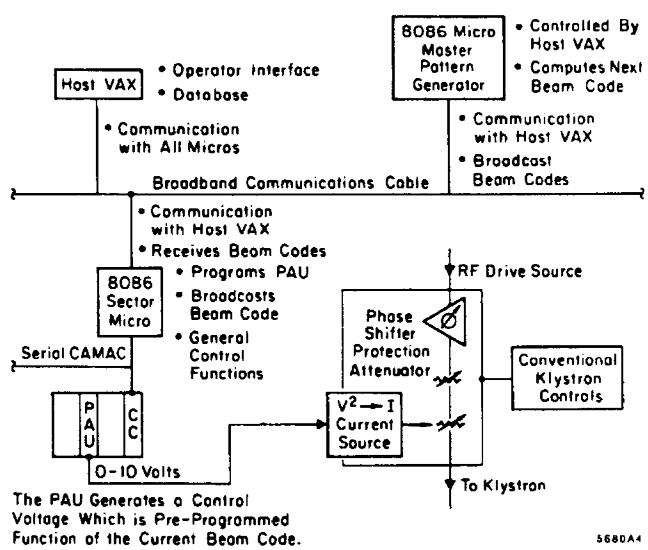

Fig. 2. Control System Schematic for the Vernier Attenuator.

finer control at low current. The input signal is referenced to a 10 volt offset so that the attenuator has a minimum insertion loss (resulting in maximum drive) when the external control cable is removed. This allows maintenance personnel the ability to effectively remove the attenuator by disconnecting the external control input. The control current supplied to the attenuator is given as

$$I_{attenuator}[ma] = \frac{(V_{input} - 10.)^2}{10.}$$

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where the V_{input} is the control voltage. The measured RF drive as a function of V_{input} is shown in Figure 3.

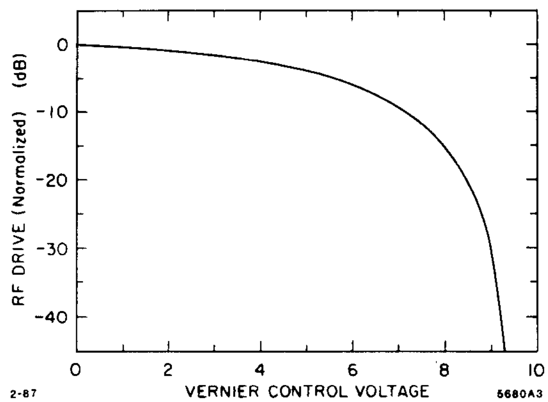

Fig. 3. Measured RF drive curve as a function V_{input}.

Special Properties of the Klystron

Although the normal operating point for klystrons is at full saturation, a large fraction of the standard SLAC high power klystrons have satisfactory performance at input drive levels substantially below saturation. Typically, klystrons which are under-driven have an acceptably smooth gain curve and reasonably constant phase shift. The vernier klystrons are typically operated at levels of 5% to 80% of the maximum power output, well below saturation. Operating a high power klystron at a reduced power level results in less RF energy, and a corresponding increase in the beam power at the collector. Although this can reduce the service life of a klystron, this has not been a problem to date.

Programmable Current Controls

The beam-dependent control of the attenuator is provided by the Programmable Amplitude Unit (PAU). This CAMAC module was developed at SLAC to receive the broadcast beam code number, and supply an appropriate voltage signal to a device needing pulse to pulse control. These devices, such as special klystrons and magnets, must accept a high speed analog input. The module contains both a 12 bit DAC and a 12 bit ADC. For each beam code, an appropriate value is written to the DAC and at beam time, the readback signal is sampled. This allows beam-specific control. For the implementation of the vernier klystrons, the read-back only monitors the request voltage, and the klystron output is monitored with the Phase and Amplitude Detector at each station.

On Line Analysis of Vernier Controls

Included in the normal klystron support software available to the operator is a variety of Fast Time Plot displays. These are displays of 64 data points acquired at different relative delays, on sequential pulses from the klystron. One of the waveforms available is the RF voltage output of the klystron near the entrance to the accelerator. Coupler constants, stored in the database, allow a quantitative prediction of the energy gain of a station from the analysis of the RF voltage waveform.

The peak RF power entering the accelerator is the primary data used in the calculation of the station's energy gain. Bandwidth limitations in the Phase and Amplitude Detector require analysis of the RF waveform to determine the "Peak" power. The peak RF power is defined by the intersection of a straight line fit to the data points following the SLED discharge time with a leading edge line. The Analysis of the peak RF from the Fast Time Plot data is shown in Figure 4.

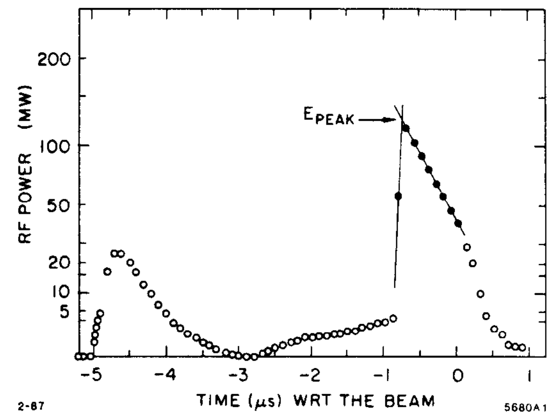

Fig. 4. Analysis of Peak RF from the Fast Time Plot. SLED discharge time is derived from a point on the leading edge, trailing points are used to determine peak value.

The no-load energy gain, E_{noload}, represents the maximum available, energy gain from a klystron without beam loading effects. It is computed for a configuration of (Disk Loaded Wave–Guide) accelerating sections (DLWG) driven by a particular station using the measured peak in the RF power delivered to the DLWG. For unSLEDed operation, E_{noload} is given as

$$E_{noload} = \left(Nr_0L(1-e^{-2\tau})\right)^{\frac{1}{2}}GP_0^{\frac{1}{2}}$$

with $\left(Nr_0L(1-e^{-2\tau})\right)^{\frac{1}{2}} = 20.0$ for typical SLAC RF parameters, where N = the number of sections powered by the klystron, r_0 = the shunt resistance, L = the section length, and τ = the attenuation parameter; G is a geometric factor to account for different configurations of DLWG ($G = 1.0$ for the usual four-way split of RF into standard SLAC 3 m sections; $G = 0.5$ when all the RF is delivered to a single section); and P_0 is the RF power level during the flattop of the klystron output. For the case of SLEDedoperation, E_{noload} is given by

$$E_{noload} = 20.0GM_{SLED}\left(\frac{2\beta}{1+\beta}(1-e^{-\tau_1})+1\right)^{-1}P_{peak}^{\frac{1}{2}}$$

wherein the factor of 20.0 and G are the same as above; M_{SLED} is the SLED energy gain multiplier, which is a function of RF pulse length; β = the SLED cavity coupling constant, 4.5; $\tau_1 = \frac{T_{RF}-T_{fill}}{2Q_0/(1+\beta)\omega}$ with T_{RF} = the RF pulse length, T_{fill} = the DLWG filling time, 825 ns, Q_0 = the unloaded Q of the SLED cavities, 10^5, and $\omega = 2\pi \times 2856$ MHz; and P_{peak} is the peak in the SLEDed RF power. For a range of RF pulse lengths from 3.5 μs to 5.0 μs, E_{noload} is well approximated by

$$E_{noload}[MeV] = (14.297 + .084T_{RF})GP_{peak}^{\frac{1}{2}}[MW].$$

Calibration

The characterization of the transfer function of E_{noload} to the control voltage is measured online as part of the standard SLC control software. For the data acquizition, the attenuator is stepped through its full dynamic range and the resultant E_{noload} measured at each step. A polynomial fit to the data (typically 40 points) gives the control voltage as a function of E_{noload}. This polynomial is deposited into the SLC database and is used by the software in the local micro-processor to compute the control voltage corresponding to the desired energy gain. The results of a typical klystron calibration are shown in Figure 5. A few data points at each end of the analysis are not used in the computation of the polynomial.

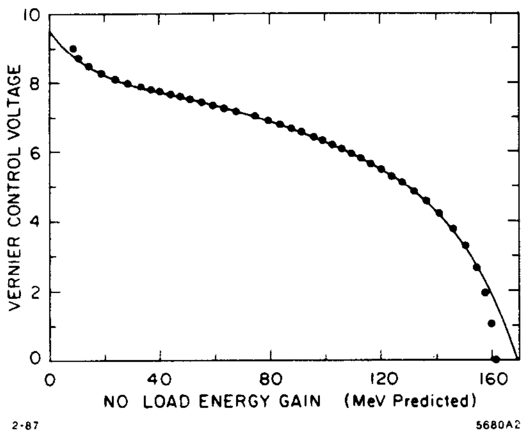

Fig. 5. Data and Results of E_{noload} Analysis.

Summary

Computer code has been implemented and hardware installed for beam-dependent control of the energy gain of two SLC klystron stations. The vernier klystron has proven to be a reliable, stable tool in the control of the energy of both electron and positron beams in the SLC injector. It has been used routinely throughout the commissioning of the SLC damping rings. In particular, the linearized control of the injector energy was a key part of the implementation of autonomous feedback loops to stabilize beam parameters at the entrance to the damping rings. Plans have been made for the implementation of a vernier control for the positron energy in the e^+ production region, if it is found that energy stability is a problem.

Acknowledgments

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