VI-9. THE AUTOMATIC PHASING SYSTEM FOR THE STANFORD TWO-MILE LINEAR ELECTRON ACCELERATOR*

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The Stanford 2 mile linear electron accelerator, now under construction, will consist of a straight line array of two hundred and forty 24-megawatt klystron amplifiers, operating at 2856 mc, each feeding four 10-foot accelerator sections made of disk-loaded waveguide. A relativistic bunched electron beam injected at the beginning of the machine will be accelerated to energies up to 20 billion electron volts. The acceleration is achieved through the process of energy transfer from the electromagnetic waves launched by the klystrons in the accelerator sections to the electrons riding on this wave. For maximum energy transfer, two conditions must be satisfied:

1 The dimensions of the 10-foot accelerator sections must be chosen so as to cause the waves to have a phase velocity equal to the electron velocity, i.e., approximately the velocity of light.

2 The phase of each klystron must be adjusted so that the bunched electrons entering each section ride on the crest of the wave in that section.

The purpose of this paper is to describe a system designed to automatically produce this phase adjustment on every one of the 240 klystrons in less than 30 minutes. Conventional techniques used in linear electron accelerators would require a prohibitive length of time and would fail to yield the specified accuracy.

The principle of the phasing method is illustrated in Figure 1. It is based on the fact that when a klystron is correctly phased, the rf wave (E_K) set up by the klystron output in the accelerator section is 180 degrees out of phase with the rf wave (E_B) which would be induced by the bunched electron beam in the absence of the klystron output wave (Figure 1a). If this relation is not fulfilled (as shown in Figure 1b), less than the maximum energy transfer is achieved. The goal of the phasing system is to phase each klystron with an error of less than 5 degrees.

Figure 2 shows the place of one automatic phasing system in the overall microwave circuitry of the accelerator. There will be 30 of these phasing systems along the machine, each controlling eight klystron-accelerator modules as the one shown in the illustration. Each klystron amplifier K receives its input signal from a drive line through an isolator I, a continuously variable phase shifter ϕ_K, and a variable attenuator α. The drive signal is pulsed at 360 pulse pairs/second, each pulse being 2.5 μsec long. A trigger signal triggers the high voltage modulator M at a repetition rate adjustable in multiples of 60 pps up to 360 pps. The four S-band waveguide runs feeding from the klystron to the four accelerator sections are rigid and temperature stabilized, and their lengths are permanently adjusted so as to cause the four input signals to be in phase with each other. The proper adjustment of ϕ_K puts them in phase with the electron beam. A directional coupler at the output of one of the sections permits the abstracting of a sample signal proportional to either E_K or E_B (or their vectorial sum). This signal is compared in phase with a fixed reference signal E_R.

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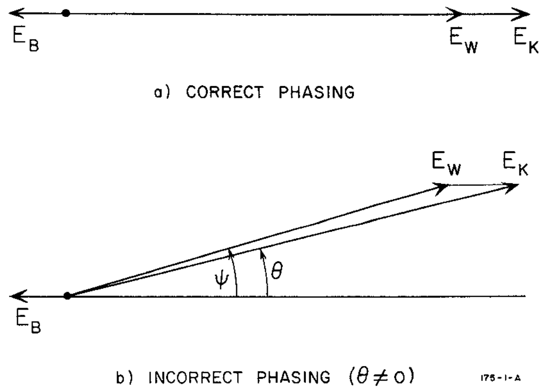

Figure 1. Relative Orientation of Electric Field Vectors Inside Accelerator Structure

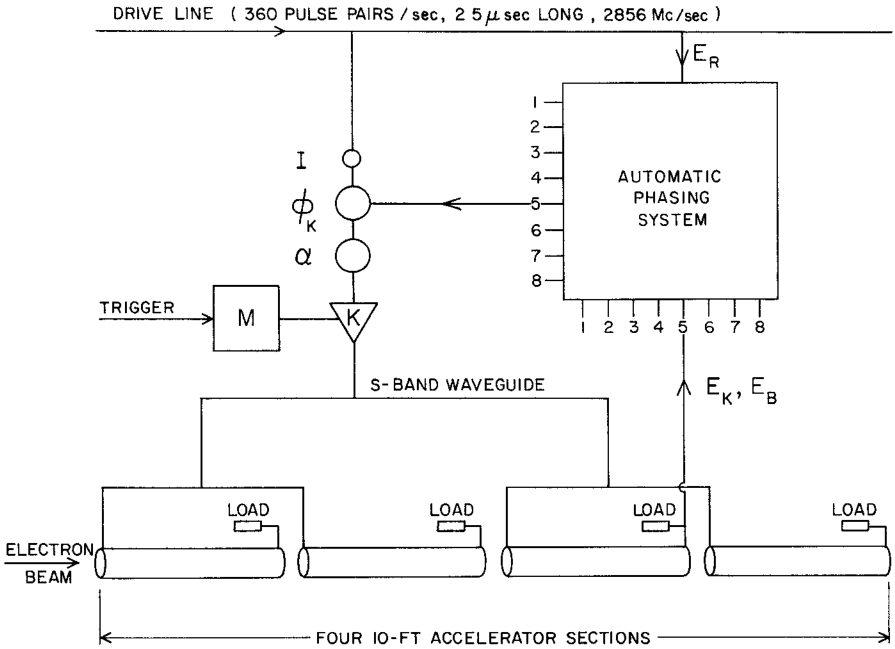

Figure 2. Block Diagram Showing Relation Between Automatic Phasing System and a 40-Foot Accelerator Module

The succession of steps involved in phasing a given klystron is illustrated in Figure 3. First, in the absence of the klystron signal E_K, the phase of E_B is compared with that of the reference signal E_R by means of the 3 db hybrid. By adjusting the phase shifter ϕ_C, a null is obtained at the output of the rf phase detector. This output consists of a pair of linear thermionic diodes followed by a sample-and-hold circuit called a gated voltmeter. Then, in the presence of E_K and with ϕ_C fixed, the phase of E_K is compared with that of E_R. A second null out of the rf phase detector is obtained, this time by adjusting ϕ_K. Hence, the vector relation illustrated in Figure 1a is achieved.

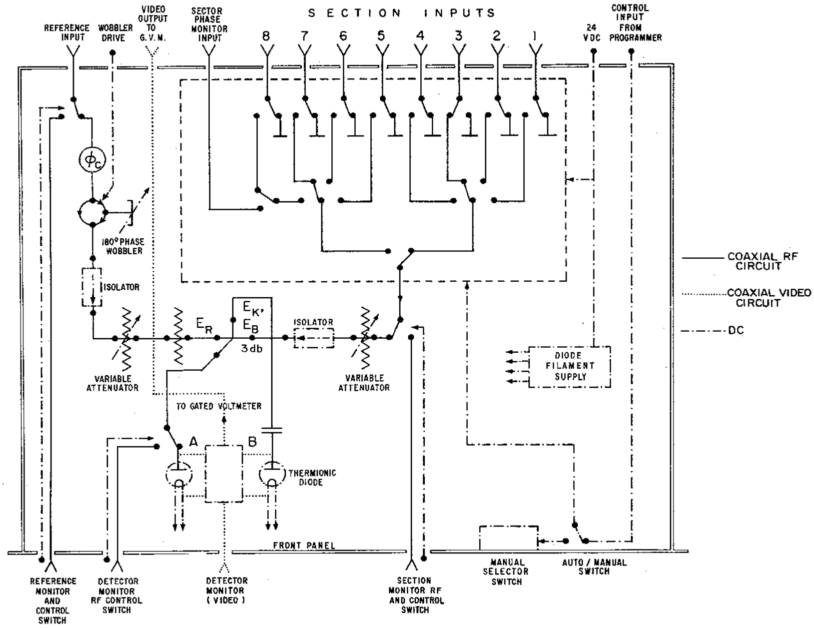

Figure 3. Schematic RF Detector Panel

There are two principles used in this system which combined enable the system to work fully automatically and over a dynamic power range of 50 db for E_K and E_B. One is the principle of the phase wobbling achieved by causing the phase of the reference signal E_R to shift by 180 degrees on alternate sampled pulses. The other is the principle of linear detection achieved with two thermionic diodes (RCA pencil diodes No. 6173). It can be shown that by keeping E_R small as compared with both E_K and E_B, the detected video signals A and B are of the form:

$$A \approx \frac{1}{2} (E_{B,K} + E_R \cos \phi)$$

$$B \approx \frac{1}{2} (E_{B,K} - E_R \cos \phi) .$$

By taking the difference,

$$A - B = E_R \cos \phi .$$

This signal is independent of the magnitudes of E_B or E_K and depends only on the constant amplitude of E_R and the relative phase ϕ. The wobbler changes the sign of cos ϕ; hence, the signal fed by the diodes to the gated voltmeter generates a square wave whose amplitude depends on E_R and ϕ. Null positions occur at $\phi = +\frac{\pi}{2}$ and $\phi = -\frac{\pi}{2}$. The circuit seeks stability at one null for the comparison between E_B and E_R and stability at the other null for the comparison between E_K and E_R.

Figure 4 shows a complete block diagram of the system illustrating how the above sequence of operations is achieved automatically. The phase shifter ϕ_C and all phase shifters ϕ_K are driven by two-phase motors. The two servoamplifiers are in phase quadrature. One is fed by a fixed signal;

its output drives the reference winding of the motor. The other is fed by the gated voltmeter; its output drives the control winding, and thus determines the sense of rotation, the speed, and the ultimate rest position of the motor. The null detector tells the programmer when the rest position has been attained. The programmer, which consists of an internal pulser and some relay circuitry, controls the whole sequence of operations.

Figure 5 shows a photograph of a typical isolator, Fox-type phase shifter (ϕ_K), and attenuator assembly.

Early tests of the entire system have been performed on a phasing simulator. It is expected that at the time of delivery of this paper, experimental results will have been obtained with the first 666 feet of the 2-mile accelerator.

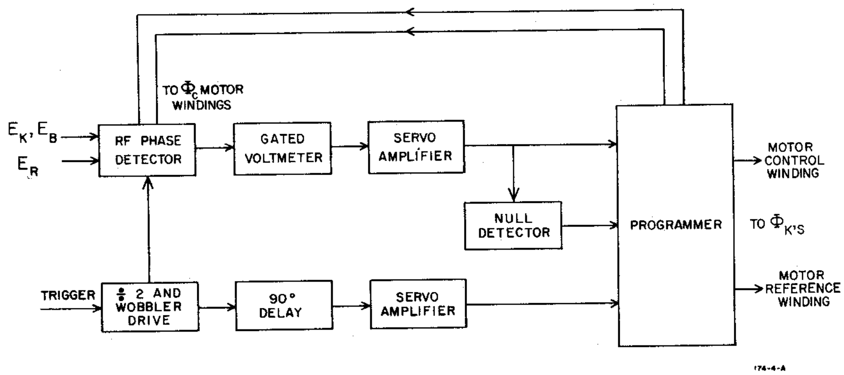

Figure 4. Complete Block Diagram of Automatic Phasing System

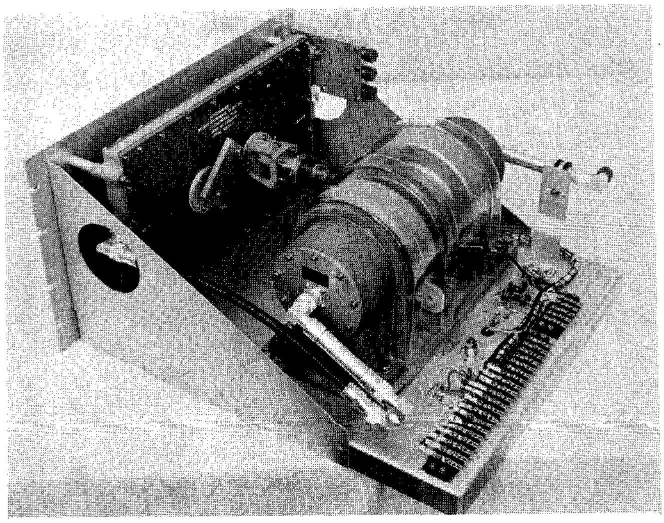

Figure 5. Photograph of Typical Isolator, Fox-Type Phase Shifter (ϕ_K) and Attenuator Assembly