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PROJECT M

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A SCHEME FOR DEFINING THE CORRECT OPERATING TEMPERATURE FOR AN ACCELERATOR

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The regulation of accelerator temperature to within $\pm \frac{1}{2}$ degree of some temperature appears to be accepted as a reasonable specification for Project M. But the definition of the standard temperature has still not been accomplished. The operating frequency, mechanical differences between pipes, average rf power level, beam loading and water-flow rate all appear to be involved in determining the proper water temperatures. On the other hand, the purpose of regulating temperature is to obtain synchronism between the beam and the wave in the accelerator. If the wave velocity can be determined directly, the proper temperature can immediately be found.

I have previously proposed that the rf power entering and leaving an accelerator section be sampled and compared in a phase detector. By cold test procedures, the phase detector can be adjusted for null output when the accelerator section is operating exactly in the $2\pi/3$ mode. During operation it is then only necessary to adjust the accelerator temperature to restore null output from the phase detector. The main difficulty with this system is that it uses two rf signals originating in the accelerator tunnel and therefore must either use rf detectors in the tunnel or two low-power rf transmission lines per section.

It is possible to use the electron beam instead of cold tests to determine when the wave is synchronous. Assume a square beam pulse with rise- and decay-time small compared to the filling time of the accelerator and pulse-length significantly longer than the filling time.

(This latter condition is convenient but not essential.) Assume also that a c.w. reference signal is also available, coherent with the beam. The signal radiated by the beam in an accelerator may be considered to be the sum of signals radiated into each element of length of the accelerator, corrected for delay-time and attenuation between the point of origin and the point of observation. If the wave travels synchronously with the beam, all elements of the signal will arrive at the end of the section in phase with the beam. If the wave is asynchronous, the elements of the signal will arrive at different angles and will add up to a signal of somewhat different phase from that of the beam. If this total signal is set to be in phase opposition to the rf acceleration power emerging from the section, we have the condition of "practical phasing adjustment" described by Loew in M.L. Report No. 740.

During an interval of one filling-time after the start and finish of the beam pulse, there is a transient; the signal observed contains elements radiated from part of the section. In particular, the initial portion of the signal contains only elements radiated at the load and of the section and is in phase with the beam at the output. The very last portion of the observed signal contains only elements radiated from the input end of the section. The phase difference of these two portions of the signal is equal to the phase error incurred by the rf signal as it traverses the section. Indeed, by taking appropriate derivations of the amplitude and phase angle of the observed transients, it would be possible in principle to determine the phase error of the wave at every point in the section.

In practice, the signal goes to zero amplitude at beginning and end and the phase at these points cannot be measured. But in a reasonably uniform accelerator operating at the wrong temperature, the phase varies progressively, as indicated in Fig. 1. During the initial transient, the first Signal 1 is unattenuated, in phase with the beam. To it is then added a slightly attenuated signal with a few degrees phase shift. The vectors 0-3, 0-4 represent further growth and 0-5 represents the steady-state radiation from the beam. The large signal from the load end is the first to disappear in the decay transient, giving vector 0-6. The signal then continues to decay to zero.

If the phase detector is adjusted for null output for the steady signal 0-5 in Fig. 1, its output during the transient will be just proportional to the vectors S_1, S_2 drawn perpendicular to 0-5. This vector is just $S = E \sin \phi$ where E and ϕ are the instantaneous phase and amplitude of the signal. In Fig. 2 are plotted E, ϕ and the phase detector output S as functions of time.

By inspection of Fig. 1 it is obvious that the second transient in Fig. 2 d is exactly minus the first transient, regardless of the distributions of phase errors in the section. It contains no information not contained in the first half, but does make the time average of S equal to zero if the phase detector is set for the proper null. If the rf input to the accelerator is reasonably free of phase modulations, the first transient is as easily abservable with the rf power on as is the steady-state phase error. This scheme is thus compatible with either of the currently favored plans for using beam-loading for phasing the accelerator(I: phase of beam-induced rf vs acceleration power, II: phase of loaded rf output vs unloaded rf output).

For a numerical example, let us refer again to Fig. 1. This diagram is plotted to scale for a uniform accelerator with $IL = 0.6$ and a 36 degree total phase slip between the wave and the beam. This corresponds to approximately 3°C temperature error for a 27-wavelength copper section with $C/v_g \approx 80$. In operation at optimum phasing, the input phase error will be about 20°, the output phase -16°, and the maximum error signal during the transient will be equivalent in magnitude to a steady-state error of 6°. The energy loss due to slip is about 1.8 per cent, the same as would be obtained with a constant phase error of 11 degrees.

In general, this scheme will allow the total slip to be held to a value no greater than six times the detectable phase error of the steady beam. If the phase error can be held to 1.5 degrees and the total slip to 9 degrees, the energy losses will be approximately equal for each error and will be under one tenth per cent. The temperature will be within 3/4°C of the best value.

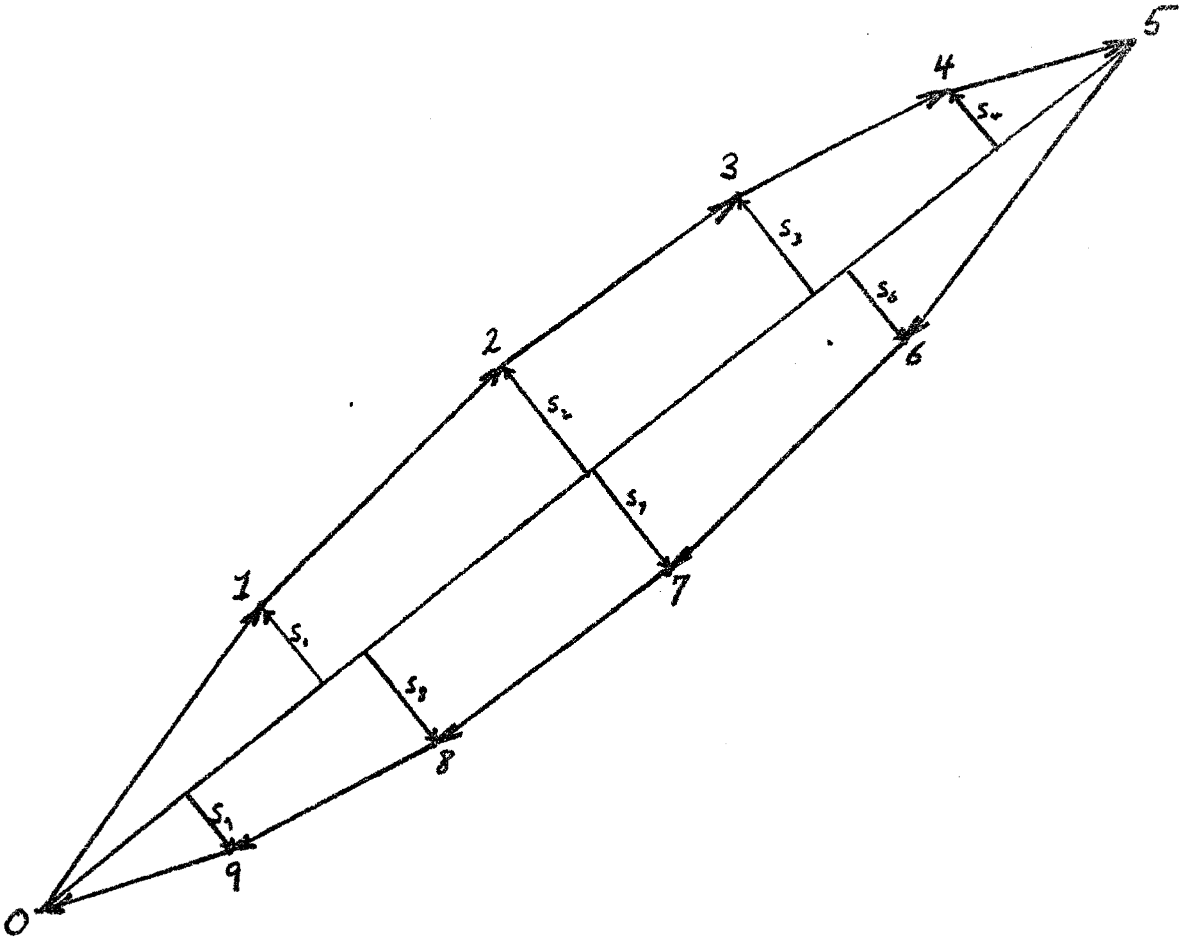

Figure 1. Vector addition of radiated signal elements.

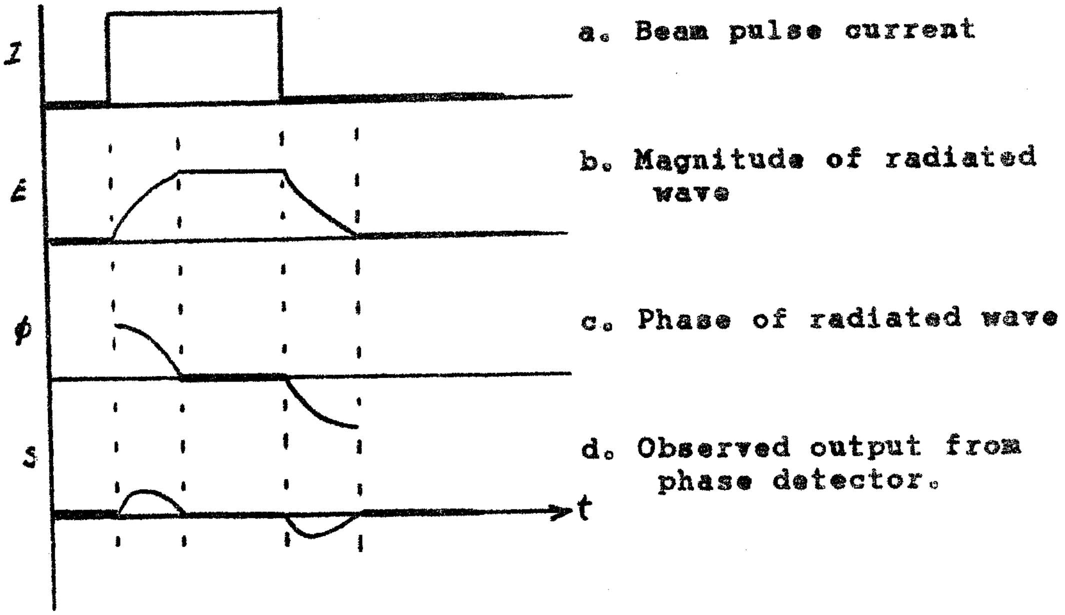

Figure 2. Time-variation of signals.