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Authors
Jackson, Horace G.
Mack, Dick A.
Wiegand, Clyde.

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ABSTRACT

This paper describes an instrument for displaying intensity profiles of charged-particle beams that emerge from high-energy accelerators. The intensity versus position on a strip of 21 scintillation counters each 1 by 1 cm appears as a histogram on an oscilloscope. The display is accomplished by employing transistor circuits to amplify and integrate the outputs of the multiplier phototubes. The accumulated charge associated with each counter element is then read out in sequence by means of a blocking oscillator commutator. The output signal is further amplified logarithmically for oscilloscope deflection.

BEAM PROFILE INDICATOR[°]

Horace G. Jackson, Dick A. Mack, and Clyde Wiegand

Radiation Laboratory
University of California
Berkeley, California

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At the Radiation Laboratory in Berkeley we have constructed a device to aid in aligning the external beams of charged particles emitted by the Bevatron. Typical experiments require beams up to 100 feet in length from the primary target in the machine. Such beams are directed through bending and focusing magnets to determine the momenta of their particles and to concentrate the particles onto special targets. A problem is to align the beams along predetermined trajectories with a minimum of time and effort. The intensity of the beam is too low for practical detection by the darkening of photographic film or by a cluster of ionization chambers. We could expose photographic emulsions, but the time required to develop them and count the individual tracks would be prohibitive.

We have designed an array, which is placed normal to the beam, consisting simply of a row of 21 scintillation counters each 1 cm by 1 cm in cross section. Transistorized circuits are used to amplify and equalize the pulses from each counter and to indicate the number of pulses by electrical integration. An electronic commutator allows the accumulated charge associated with each element to be read out and displayed as a histogram on an oscilloscope. With this apparatus we are able to observe the intensity profiles of the beams and to adjust the various magnet currents to optimum bending and focusing conditions.

Figure 1 shows the photomultiplier assembly and one of the three similar bin assemblies which hold the printed circuit cards for amplifying and integrating the photomultiplier signals, along with commutator cards and gating cards.

Light from the plastic scintillator, 1 cm square, is transmitted by the Lucite light pipes to the side-window photocathodes of 1P21 photomultiplier tubes. From noise considerations it was decided to limit the high voltage

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across the phototube to a maximum of 1000 v. Approximate design conditions,
therefore, were for scintillation-counter output pulses of 10-mv amplitude
with rise times of 1 milli-microsecond and width at half amplitude, 10 mμsec.
Counting rates were expected to vary from 10 to 1000 counts per Bevatron
pulse. The Bevatron produces a beam pulse once every 6 seconds, and the
duration of the beam can be adjusted from 30 to 300 milliseconds.

A block diagram of the system is shown in Fig. 2. There are twenty-
one channels, one for each scintillator. The output from the scintillation
counter is amplified by a three-stage amplifier, thence goes to a discriminator
which feeds pulses, equalized in amplitude and duration, to a diode pump
circuit for integration. The output of the integrator is amplified by a single-
stage vacuum-tube amplifier which also serves as an output gate. The 21
vacuum-tube amplifiers have a common anode load resistance, and are turned
on in sequence by a blocking oscillator commutator. The output across this
common anode load is transmitted to a logarithmic amplifier and thence to the
amplifier input of a Tektronix 531 oscilloscope. The horizontal sweep of the
scope is triggered from the blocking-oscillator commutator, so that time
synchronization is maintained between the sweep and the reading out of in-
formation from the integrators. The intensity profile of the beam of charged
particles therefore appears on the face of the scope in a histogram form.

To gate out noise and background counts from the scintillation counter,
additional circuits were needed to allow charge to build up in the integrator
only during the time of the Bevatron beam. Also circuits were needed to clear
the integrator at the termination of the Bevatron pulse. Normal operation is
for charge to accumulate in the integrator during one Bevatron pulse, but
means are also provided for integrating for a longer time of 30 seconds.

The circuit diagram of the amplifier-integrator is shown in Figs. 3
and 4. The input to the amplifier is the 10-mμsec 10-mv pulse from the
scintillation counter, and a minimum trigger level for the discriminator
was set at 0.1 v, with a width at half amplitude of 0.3 μsec. The amplifier
performs the combined function of amplifying and stretching the pulses. The
2N247 drift transistor was chosen for the amplifier section because it was an
economical unit with a gain-bandwidth product of 15 Mc in the common emitter
configuration. It can be shown, for a pulse whose width is shorter than the
rise time of the amplifier, that the gain of the amplifier is reduced in
proportion to the ratio of the amplifier rise time to input pulse width. In
the circuit shown the gain for an input-step function is approximately 420,
with an output rise time of 0.4 μsec. With a pulse whose half width is

10 mμsec the gain is 10, and the width at half amplitude is 0.3 μsec. The bias resistances in the amplifier were determined following the method suggested by Ghandi.[1] These signals trigger a discriminator which has the dual function of discriminating against noise and presenting equalized pulses to the integrator. The millivolt discriminator principle described by Kandiah[2] is used. Here the transistors are biased so that the circuit is potentially unstable, but the collector load of transistor Q4 is shorted out because diode CR2, is normally conducting. Application of a positive pulse to the base of transistor Q4 causes it to conduct heavily, making the diode present a high impedance, and the circuit becomes regenerative. The choice of the time constant in the univibrator was made consistent with the maximum counting rate. For 1000 counts to occur in 30 msec required a maximum resolution time of 30 μsec; the duration of the pulse out of the discriminator is 10 μsec; the amplitude, 10 v positive. The switching times now involved are slow enough that general-purpose transistors can be used, namely the 2N35. Attempts at varying the trigger sensitivity by changing the bias on the diode D2 were unsuccessful because the voltage across the timing capacitor C13 also varied directly with the diode bias. Thus the duration of the output pulse varied with the sensitivity setting. A simple form of biased diode discriminator was therefore incorporated between the amplifier output and univibrator input. The circuit responds to a minimum signal of 10 mv at the amplifier input.

The gating transistor Q6 permits the univibrator pulse to accumulate charge in the integrator. A trigger pulse is available from the Bevatron control that is coincident in time with the beginning of the Bevatron beam pulse. This trigger pulse is made to actuate a univibrator circuit, whose output signal is adjustable from 10 msec to 300 msec. The trigger pulse is applied to the emitter of transistor Q6, causing it to saturate and thereby allow the pulse from transistor Q5 to be fed into the integrator.

[1] S. K. Ghandi, Bias Considerations in Transistor Circuit Design, IRE Trans. on Circuit Theory, Vol CT-4, p 194, Sept. 1957

[2] K. Kandiah, A Sensitive Pulse Trigger Circuit With a Stable Threshold, Proc IEE, p 239, June 1954.

The integrator is a simple diode pump circuit as described by Elmore.[3]
The negative square pulse at the collector of transistor Q5 charges capacitor
C15; arrival of the trailing edge of the pulse from the collector causes the
charge across C15 to be dumped into C16 or C17. Two integrating time
constants are used: 2.5 seconds for integrating one Bevatron pulse and 30
seconds for integrating up to five Bevatron pulses. Low leakage in the reservoir
capacitors is important, and Mylar dielectrics are used. Physical considerations
limited the size of this capacitor to 6 μf, thus a 5-meg resistor was necessary
to achieve the desired time constant.

Cascaded emitter-followers were considered for reading out the in-
formation in the integrator, but it appeared more practical to make use of the
high input impedance of a vacuum tube. The subminiature CK5702 is used.
Diode CR-3 is a high-conductance diode, 1N56A; and CR-4 is a low-reverse-
current silicon diode, H-P G111A. One thousand counts into the integrator
yields a positive potential of 1.5 v across C16. Resetting is accomplished by
rendering diode CR-6 conductive just prior to the onset of the Bevatron beam.
A pulse is obtained from the Bevatron control that effectively grounds the
cathode of CR-6, canceling any charge left on the reservoir capacitors.

Normally there exists a 6 v negative bias at the grid of V1. This is
due to the 4V Zener diode CR-5, whose cathode is at +2V. Storage capacitor
C19 holds this cathode at 2 v when CR-5 becomes forward biased. With 85 v
on the plate and screen of the pentode V1, the anode current is normally less
than 0.1 μa. Now the application of a negative gating pulse from the commutator
circuit on the base of transistor Q7 causes this transistor to conduct, and
diode CR-5 becomes forward conducting. With no charge in the integrator the
grid-to-cathode bias on pentode V1 is reduced to 2 v and the tube operates in
the linear region, drawing an anode current of approximately 0.5 ma. As noted
earlier, the anode load of V1 is common to all 21 channels. Therefore, as
transistor Q7 on each card is gated on sequentially by the blocking-oscillator
commutator, the information stored in the integrators is likewise read out
across resistor R38.

The blocking-oscillator commutator is shown in Fig. 5. This consists
of a series of blocking oscillators, 21 in all, each unit triggering the succeeding
one. A delay is introduced at the end of the train of 21 pulses to allow for the
retrace time of the beam in the oscilloscope. This is accomplished by the delay

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[3]W. C. Elmore, Electronics (McGraw-Hill, New York, 1949), p. 250.

multivibrator Q8 and Q9. Coincident with the trigger to the first blocking
oscillator, a pulse is produced to trigger the oscilloscope sweep. Type
2N34 PNP transistors are used to yield negative square pulses of 10 v
amplitude and 100 µsec duration. Thus a horizontal sweep speed of 200 msec/cm
is used on the oscilloscope.

Three bin assemblies are used, each holding seven of the amplifier in-
tegrator cards and one blocking-oscillator card. The outputs of the amplifier
cards are all joined in parallel by connecting cables.

The output of the scintillation counters are fed to the amplifier through
coaxial cables which are terminated at the amplifier input. The signals from
the plates of the pentodes in the amplifier integrator cards must be transmitted
150 feet by cable to the oscilloscope located in the Bevatron control room. An
emitter follower is therefore used to obtain the low output impedance.

In Fig. 6 is shown the emitter follower and the logarithmic amplifier
which compresses the counting rate, or intensity scale for convenient viewing
on the oscilloscope. The pedestal due to the commutated signal is removed by
the biased diode CR-1, and the information from the integrator is further
amplified by the transistor Q2 which has a gain of three. The signal level at
this point due to 1000 counts at the input of the integrator is + 30 v. Finally,
an emitter follower is used to develop the signal across a logarithmic element
which is a type G-7A diode. This signal is coupled directly to the input channel
of a Type 53/54C plug-in unit of a Tektronix 531 'scope. The vertical deflection
sensitivity used is 0.1 v/cm, and 1000 counts at the input of the integrator yields
0.52 v vertical deflection on the 'scope face. For 100 counts the deflection is
0.25 v and for 10 counts, 0.02 v.

A comment might be added about the transistor used in the logarithmic
amplifier section, where the signal is approximately 30 v maximum. This
indicates a supply voltage of 40 v or more. Tests on about 80 2N247 transistors
showed that about one-half of them had a collector leakage current of less than
10 µa when 100 v was applied between the collector and base; about 25% had a
leakage current of less than 5 µa at this same voltage. By comparison all
2N34 and 2N35 transistors tested had collector leakage currents of more than
20 µa when 100 v was applied. Some 2N398 were also checked, and all had
leakage currents of more than 5 µa with 100 v applied. Therefore 2N247
transistors were used in this high-level section, and the collector supply
potential was arbitrarily set at 65 v.

There are three main power supplies for the unit, +85 v, +12 v, and
-12 v. By means of a meter-insertion switch the current to each of the bins
at all three voltages is easily monitored. Disregarding the heater supply to the
vacuum tubes, the total power dissipation of the unit is less than 5 w. The
heater power is about 25 w.

Figure Captions