BNL 6438

1/5/62

IHR-112

JAN 5 1962

Facsimile Price \$ 2.60

Microfilm Price \$ 1.83

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

BEAM CURRENT INTEGRATOR

J. Jacobs

MASTER

Object

The object of this report is to acquaint the operator with the operational and technical aspects of this instrument as well as the theory of the system operation.

Introduction

This instrument has two purposes. One phase, the console channel is designed to measure the accumulation of charge received by a target during a period of a day no matter what the range used in the experimenter's channel. The console will make about 1500 counts in a day if 100 μ a of beam current is supplied all day long. This channel has a manual reset switch on the experimenter's chassis which sets the console counter to zero and shorts the console integrating capacitor. The second phase consists of the experimenter's channel. This channel consists of a much more accurate counting setup and controls to reset, start, and stop-run the experimenter's counter. The reset and start are self explanatory and only apply to experimenter's setup. The "stop-run" control allows the experimenter to interrupt his count at any point and resume the count at the same point he stopped at.

The range on the experimenter's channel is from 1/2 μ a to 500 μ a and the accuracy to 0.1%. The console has a constant charge/count ratio no matter what range is selected on the experimenter's channel and the accuracy is 5%.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

System Operation

The 18 in. cyclotron beam current is fed into a Philbrick P2 Solid State Differential Operational Amplifier with various feedback resistors which accomplish the ranging of the experimenter's counter. The output of this amplifier is then fed to both channels, the experimenter's and the console's. The polarity is inverted by this amplifier.

The experimenter's channel is a rapid counting circuit giving a few thousand counts during the run. The resistors used in this channel as well as the input circuit are 0.1% precision components. The output of amplifier (1) (input amplifier) is fed to the experimenter's integrating P2. When the output reaches a predetermined level, the trigger circuit flips (bistable flip-flops) and turns on a 2N586 transistor which allows a 500 μ f condenser to discharge through the impulse coil of the Sodeco predetermined counter and makes it count once. At the same time, the feedback capacitor of the P2 is shorted and the cycle repeats. The components and circuit parameters were chosen such that the Sodeco trips every time a particular charge is accumulated, which varies with the range selected. This channel also has reset, stop-run and start controls. The reset control shorts the feedback capacitor of the amplifier, opens the input to the amplifier and sets the Sodeco to the present number. The input is held open until the start button is depressed. This closes the input and the channel starts to count. The stop-run control just opens the input to the amplifier, thus resuming the count at the exact charge accumulation up to the point of stop when the control is again placed in the run position. When the Sodeco reaches the zero point it trips a relay that opens the input, thus stopping the count and rings a single stroke gong that

warns the experimenter that the run is completed.

The reasons for choosing the particular components are clearly seen in the following analysis. Point A is held at ground by the negative feedback of the amplifier thereby making the current in the feedback loop equal to the input current. This allows the following analysis:

$$E_1 = R_1 I_1 \quad I_2 = \frac{E_1}{R_2} = \frac{R_1}{R_2} I_1 \quad I_1 = \frac{dQ}{dt}$$

$$E_2 = \frac{1}{C} \int \frac{R_1}{R_2} I_1 dt = \frac{R_1}{C R_2} \int dQ = \frac{R_1}{C R_2} Q$$

$$\Delta E_2 = \frac{R_1}{C R_2} \Delta Q \quad \Delta E_2 \text{ set at } 8 \text{ volts}$$

$$\therefore \Delta Q / \text{count} = \frac{8(1.25 \times 10^6)(1 \times 10^{-6})}{R_1} = \underline{\underline{\frac{10}{R_1} \text{ coulombs}}}$$

example: at 100 μa of beam current, the appropriate range is $R_1 = 100K$

$$\Delta Q / \text{count} = \frac{10}{R_1} = \frac{10}{100 \times 10^3} = 1 \times 10^{-4} \text{ coulombs}$$

The console channel is designed such that the charge per count is a constant at all times, no matter what range the experimenter is utilizing. This Philbrick Amplifier (P2) is also used as an integrator and operates in the same fashion as the experimenter's channel. The bistable flip-flop trigger flips at 5 volts and the components are chosen such that the channel counts at the rate of one count per 2000 μcoul accumulation of beam charge. This channel has a manual reset control only. This control merely shorts the 20 μf capacitor and resets the console counter. This counter measures the charge received by targets during a whole day.

The reasons for choosing the particular components are clearly evident in the following analysis:

$$E_1 = R_1 I_1 \quad I_2 = \frac{R_1}{R_3} I_1$$

$$R_3 = 20 I_1$$

$$I_2 = \frac{1}{20} I_1 \quad E_2 = \frac{1}{20C} \int I_1 dt = \frac{1}{20C} \int dQ$$

$$E_2 = \frac{1}{20(20 \times 10^{-6})} Q$$

$$E_2 \text{ set at 5 volts}$$

$$\therefore Q = 2 \times 10^{-3} \text{ coulombs/count (constant)}$$

at 100 μ a of beam current,

$$\begin{aligned} Q \text{ in 8 hrs} &= 8(3600)(100 \times 10^{-6}) \\ &= 2.88 \text{ coulombs} \end{aligned}$$

$$\# \text{ of counts/day} = \frac{2.88}{2 \times 10^{-3}}$$

$$= 1440 \text{ counts in 8 hrs @ } 100 \mu\text{a}$$

Maximum error due to discharge time of condenser

There is a time lag and a consequent loss of charge due to the fact that the condenser must be discharged to restart the cycle. The discharge time or the time the condenser of the experimenter's integrator is shorted

is 2 msec. The minimum count time is ~ 1 second. Therefore the maximum error is:

$$\frac{2 \times 10^{-3}}{1} \quad \text{or } 0.2\% / \text{count}$$

Therefore the charge accumulated is:

$$Q = (N)(T)(q)(1 + \epsilon) \quad \epsilon = 2 \times 10^{-3} N$$

where N = counts / second = 1 minimum

T = time of run in sec.

q = coulombs / count

E = % error = .2% (Max.)

The time of charge loss for the console integrator is about 40 msec and the minimum time / count is about 4 seconds at 500 μ a of beam current.

Therefore the maximum error is:

$$\frac{40 \times 10^{-3} \times 10^2}{4} = \% = 1\% / \text{count}$$

Inherent error in circuitry

There is a first order error due to the fact that the gain of the amplifier is finite.

$$i = \frac{e_1 - \varepsilon}{R}$$

$$i = \frac{d}{dt} C [\varepsilon - e_0]$$

$$e_0 = -\varepsilon A$$

$$\frac{A e_1 + e_0}{A R C} = \frac{d}{dt} \left[-e_0 \left(\frac{1}{A} + 1 \right) \right]$$

$$\frac{1}{A} + 1 = 1$$

$$e_0 = -\frac{1}{RC} \int e_1 dt - \frac{1}{ARC} \int e_0 dt$$

difficult to evaluate

Let $e_1 =$ a constant for ease
of evaluation
and $D = \frac{d}{dt}$

$$\left(D + \frac{1}{ARC} \right) e_0 = -\frac{e_1}{RC}$$

of the form

$$e_0 = B_1 e^{st} + \text{particular solution}$$

$$\text{Particular Solution} = -e_1 A$$

$$s = -\frac{1}{ARC}$$

$$e_o = B_1 e^{-t/ARC} - e_1 A$$

$$@ t=0 \quad e_o = 0$$

$$B_1 = e_1 A$$

$$e_o = -A e_1 (1 - e^{-t/ARC})$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots$$

$$e_o = -A e_1 \sum_{n=1}^{\infty} (-1)^{(2n-1)} \frac{t^n}{n! (ARC)^n}$$

$$e_o = -\frac{e_1 t}{RC} + \frac{A e_1 t^2}{2 (ARC)^2} - \frac{A e_1 t^3}{6 (ARC)^3} + \frac{A e_1 t^4}{24 (ARC)^4} - \dots$$

dividing by $-\frac{e_1 t}{RC}$

$$e_o = -\frac{e_1 t}{RC} \left[1 - \underbrace{\left(\frac{t}{2(ARC)} - \frac{t^2}{6(ARC)^2} + \frac{t^3}{24(ARC)^3} \right)}_{\text{error}} \right]$$

error for the longest practical integrating period:

$$\varepsilon = \frac{t}{2ARC} \times 100 = \frac{2.5 \text{ sec} \times 10^2}{(2 \times 10^4)(1.25)} = 0.01\%$$

assuming a gain of 10000

Error in input circuit due to loading and finite gain.

The P2 amplifier pulls 2×10^{-11} amps in operation. Therefore the maximum error due to this current drain is when the unit is measuring the charge from $1/2 \mu\text{a}$ of beam current.

$$\frac{2 \times 10^{-11}}{.5 \times 10^{-6}} = 4 \times 10^{-5} \text{ or } 4 \times 10^{-3} \% \text{ error in current}$$

Max. error

$$e_o = RI [1 - 4 \times 10^{-5}] \text{ due to leak current.}$$

Another error due to the gain being finite is introduced as follows:

$$e_o = -A(e_o - R_2 I)$$

$$e_o (1 + A) = R_2 A I$$

$$\frac{e_o}{I} = \frac{R_2 A}{1 + A} = \frac{R_2 (A)(1 - A)}{A^2 + 1}$$

$$\frac{e_o}{I} \sim = R_2 \left(1 - \frac{1}{A}\right)$$

$$\frac{1}{A} = 5 \times 10^{-5}$$

Therefore the complete expression is:

$$e_o = R_2 I (1 - 4 \times 10^{-5} - 5 \times 10^{-5})$$

$$e_o = R_2 I (1 - 9 \times 10^{-5})$$

Total error:

$$\varepsilon_T = \frac{9 \times 10^{-5}}{1} \times 100$$

$$\varepsilon_T = 0.009 \%$$

The trigger circuit is a bistable multivibrator used as a monostable system and is regenerative through the coupled emitters. In the normal state, t_2 is in conduction and t_1 is fully off as well as t_3 . When the base of t_1 reaches the same level as the base of t_2 (8v) the system flips and t_1 now goes into conduction which turns on t_3 which in turn drives the counter and the relay that shorts the integrating condenser. The diodes are necessary to prevent the shorting of the integrator from yanking off t_1 too soon. The drift in the base potentials due to temperature variation is within .2 mv

Trigger Circuits per 10°C change in temperature. This drift will constitute an error of

$$\text{error} / \text{ }_{10^\circ\text{C}} = \frac{20 \times 10^{-5}}{8} \times 100 \%$$

$$\text{error} / \text{ }_{10^\circ\text{C}} = .0025 \%$$

Operation

The 18 in. cyclotron beam current is fed into the unit from a shielded cable at the BNC connector on the rear of the chassis. Depending on the magnitude of the beam current, the appropriate range is selected by means of the push button range switch. (The red mark on the local beam current meter shall not be exceeded as this will indicate a saturation of the input amplifier and an incorrect count will be obtained.) The number of counts desired is preset by the operator by pushing the black button on the experimenter's counter and giving it a half turn and then setting the number on the dial. This button is then returned to the operating position. The

local reset button shall be pushed momentarily and the "run-stop" switch placed in the "run" position. When the operator wishes to begin a count, the start button is pressed. When the counter reaches zero, the input to the experimenter's counter is opened and a bell rings at this point, a relay closes a 5 amp circuit at the "jones-strip" which may be used as desired.

If at any point during the experiment the operator wishes to interrupt the count, the "run-stop" switch shall be put in the stop position. This only opens the input to the experimenter's integrator and doesn't disturb the rest of the system.

An external 110v a.c. line shall be connected to the proper terminals on the "jones-strip" at the rear of the chassis for the console position operation of the experimenter's controls. The "local-remote" switch is then operational.

The console counter shall be wired to the "jones-strip" and will be mounted in the console. The "console manual reset switch" resets only the console counter and integrator.

Conclusion

In conclusion, it can be seen from the preceding analysis of the entire system that this unit will measure the accumulation of charge by a target to an accuracy of 0.1215% assuming that the constant error due to shorting the integrating capacitor is accounted for. The accuracy of the console circuit is well within 1% if the error due to shorting this integrator's capacitor is taken into account. The instrument is ranged to handle from 0.5 μ a to 500 μ a of beam current.

Acknowledgements

J. P. Palmer and W. A. Higinbotham

both of whose engineering knowledge and experiences were invaluable.