BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I., N.Y.

HW-1

ACCELERATOR DEPARTMENT
AGS
INTERNAL REPORT

MASTER

JAN 14 1966

A DEVICE FOR RELIABLE MEASUREMENTS OF CURRENT IN A LOW ENERGY,
HIGH INTENSITY ION BEAM

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

Harold Wroe

November 22, 1965

I. Introduction

The measurement of beam current immediately following an ion source is difficult for a number of reasons. It is difficult to take into account the confusing effects of secondary electrons when the beam is collected in a cup or target and the current measured electrically. If no precautions are taken to suppress them, the current due to secondaries can be several times that due to the incident ion beam, causing large errors in the measurement of the latter. Furthermore, it is difficult to devise really foolproof means of suppression because the beam is often diverging rapidly and the target has to be placed close up to the source. Nevertheless, an electrical method of measurement is essential when using pulsed beams so that an oscilloscope display can be used to study time dependent phenomena.

The most reliable method of measurement is the calorimetric one in which the heat delivered to a target by the beam is measured, because the secondary electrons, being of low energy, make a negligible contribution to the thermal power in the beam. However, some ion sources, e.g., the radiofrequency type, produce large numbers of fast neutral particles which contribute substantially to the beam current measured by a calorimeter, though they do not constitute useful beam. Also, the calorimeter measures the mean beam current only, and is rather slow in operation.

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.

The ideal device would seem to be one which combines a collector cup, with some means for suppressing secondary electrons, with a calibrated calorimeter, so that thermal and electrical measurements can be carried out simultaneously. This note describes such a device, which has been used to measure the output current of the MkI duoplasmatron source.

II. The Calorimeter Principle

The calorimeter is based on the one described by Harrison^{1,2} for pulsed beams and is illustrated in Fig. 1. A target, mass m , made from a material of specific heat, c , is attached by a stem of length L , cross sectional area A and conductivity K to a cooled base plate. The heat delivered to the target by the beam flows down the stem, producing a temperature difference which can be measured by thermistors as shown.

The rise in temperature of the target is analogous to the rise in voltage of a capacitor, shunted by a resistor, when pulses of current are fed in. The temperature rise, $\Delta\theta$, in a time, t , is given by

$$\Delta\theta = \frac{w}{J} \frac{L}{KA} (1 - e^{-\frac{t}{T}}) \text{ } ^\circ\text{C}$$

where w is the power input from the beam in watts, J is the mechanical equivalent of heat and T is the thermal time constant of the calorimeter, given by

$$T = \frac{mcL}{KA} \text{ sec.}$$

Thus, for a quick response, T should be small which requires a low mass target with a high conductivity stem. The time constant must not be so short, however, that there is a large drop in temperature between pulses. This is only significant when the pulse power in the beam is high and the repetition rate is very low. Also, a short time constant means a small

steady state temperature difference between the ends of the stem and this must not be so small that it becomes difficult to measure conveniently.

As a compromise, the calorimeter is made from copper with the stem 3 cms long and 0.1 cm^2 cross-sectional area. The target mass is estimated at 2 grms. Thus, taking the thermal conductivity of copper to be 0.92 calories/cm/ $^{\circ}\text{C}$ /sec and its specific heat to 0.093 calories per gram, the following figures result:

Time constant $T = 6 \text{ secs}$

Steady state temperature difference per watt = 7.8°C

III. Construction of the Device

The mechanical arrangement of the device is shown in Fig. 2. The target is in the form of a Faraday cup, half an inch in diameter and one inch long, made from 0.002-inch thick copper foil. It is mounted on a double stem which in turn is soldered to an oil-cooled copper flange. The double stem makes for mechanical rigidity and enables a small permanent magnet to be placed between the stems to provide a transverse magnetic field across the cup. This field is of the order of 100 gauss and is effective in turning back low energy electrons which try to leave or enter the cup. Since electrons deflected away from the cup by the magnetic field can easily find their way on to the magnet pole pieces, it is essential the latter be electrically insulated from the cup. The current collected by the cup is put through a 10 ohm resistor and the voltage drop produced is displayed on an oscilloscope.

The thermistors used to measure temperature differences are cemented to the stem with epoxy as shown in Fig. 2. They are connected to a simple Wheatstone bridge circuit, the out-of-balance current being measured by a microammeter.

The collector cup has a hollow base inside which is a small filament, so that a known amount of power can be deposited on the cup for calibration purposes. The advantage of using a radiant heater is that its mass does not contribute to the thermal capacity of the target. A very convenient filament can be obtained by breaking open a type G.E. 40 lamp. No special precautions are taken to stabilize the temperature of the cooling oil and a drift of this temperature would cause a change in the out-of-balance current in the bridge circuit even though the temperature drop down the stem remains constant. To avoid errors on this account, the method of making an accurate calorimetric measurement is to switch off the beam when steady conditions are achieved and then immediately switch on the heater, adjusting the heater current so as to preserve the same reading on the bridge microammeter. A measure of the heater power then gives a direct measure of the beam power.

IV. Results

The calorimeter has been very convenient in use, steady readings being observed after about 45 seconds. When the beam power has been measured, the mean beam current is given by:

$$\text{mean beam current } I = \frac{w}{VtR} \times 10^6 \text{ mA}$$

where w mean beam power in watts
V beam energy in kV
t pulse length in μ secs
R repetition rate

A major source of error is in the measurement of the beam energy, i.e., the source extraction voltage which being a pulsed voltage, has to rely on a compensated potential divider and oscilloscope. Also, not all the filament power finds its way into the calorimeter, a small fraction is lost by conduction down the connecting wires. An estimate of this loss was made

by running a filament in a bell jar in vacuum and making a visual estimate of the color temperature of the filament near the ends, which gave a crude estimate of the temperature gradient. For a filament power of 0.26 watts, the conduction loss was about 10%. For a power of 0.68 watts, the loss was 5%. With care, the mean beam current should be found to an accuracy of $\pm 5\%$.

A plot of beam current against extraction voltage for the MkI duoplasmatron is shown in Fig. 3. The beam current measured electrically by the collector cup agrees well with the calorimetric values, though in making the comparison, an allowance has to be made for the fact that the current waveform is not flat-topped. A typical waveform is shown in Fig. 3 and an estimate of the mean current (made by eye) was used to compare with the calorimetric value, the two being usually well within 10% of each other.

V. Conclusions

The device is a reliable, compact and convenient instrument for measuring the beam current from an ion source.

When used with the duoplasmatron source, the fact that the electrical and calorimetric measurements are in close agreement, suggests that there are few fast neutral particles in the output beam.

Acknowledgment

The author wishes to acknowledge the assistance of Mr. G.E. Rackett and Mr. R.L. Lane in the construction and operation of the device.

References

1. Harrison, E.R. Design of Calorimeters for Pulse Ion Beam Current Measurements, J. of Sci. Instr., Vol. 30 pp. 242-244, June 1957.
2. Wroe, H. MURA Linac Conf., 1964 p. 480

Distribution: B1, B2

HW/ah

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

BROOKHAVEN NATIONAL LABORATORY

BY _____ DATE _____ SUBJECT _____ SHEET No. _____ OF _____
CHKD. BY _____ DATE _____ JOB No. _____
DEPT. OR PROJECT _____

FIG.1. Diagram of Calorimeter

BROOKHAVEN NATIONAL LABORATORY

BY _____ DATE _____ SUBJECT _____ SHEET NO. _____ OF _____
 CHKD. BY _____ DATE _____ JOB NO. _____
 DEPT. OR PROJECT _____

FIG 2. A small collector cup-calorimeter assembly for beam current measurement

H. Wroe
 B.N.L. Sept 65

Fig 3.

H. Wroe B.N.L. Nov 65.