MASTER

CEAL-

1022

CONF-650636-2

BEAM MONITOR
CALIBRATION MEASUREMENTS WITH THE
6-Gev EXTERNAL ELECTRON BEAM OF THE
CAMBRIDGE ELECTRON ACCELERATOR

James de Pagter
Mircea Fotino

June 30, 1965

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

There is no objection from the patent
point of view to the publication or
dissemination of this document:
NY Patent Group
By.....
.....1965

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 research work described in
this report was performed under
Contract AT(30-1)-2076 between
the U.S. Atomic Energy Commission
and the President and Fellows of
Harvard College.

CAMBRIDGE ELECTRON ACCELERATOR

HARVARD UNIVERSITY
42 OXFORD STREET
CAMBRIDGE, MASS. 02138
♦

CEAL - 1022
James de Pagter
Mircea Fotino
June 30, 1965

BEAM MONITOR

CALIBRATION MEASUREMENTS WITH THE

6-Gev EXTERNAL ELECTRON BEAM OF THE

CAMBRIDGE ELECTRON ACCELERATOR

(Presented at the "International Symposium on Electron
and Photon Interactions at High Energies", Hamburg,
Germany, June 8-12, 1965)

In this report we discuss problems related to beam monitoring and calibrations pertinent to experiments performed with photon or electron beams in the multi-Gev range. As has been known for some time, absolute measurements with quantimeters and their reproducibility are relatively uncertain and sensitive to unaccountable fluctuations. The availability of a stable extracted electron beam^{1,2} of accurately known energy³ at the Cambridge Electron Accelerator makes it possible to refer all such measurements to a Faraday cup, considered at the present time to be the best final absolute monitor. The behavior of the Faraday cup and that of quantimeters normally used for determining the total energy contained in a photon beam were studied in the electron beam with a secondary emission monitor as an intermediate standard. It is shown that accuracies of the order of 1-1.5% can be obtained provided care is taken in identifying and controlling all relevant parameters such as spill length (time during which the beam is extracted at the end of the acceleration cycle) and uniformity, spot size, beam intensity and stability, beam contaminations and their changes in time.

We shall first describe briefly the characteristics of these monitors.

Faraday Cup. The design of the 6-Gev Faraday cup in use at CEA incorporates⁴ the main features discussed by Brown and

-
1. F. W. Brasse, G. E. Fischer, M. Fotino and K.W. Robinson, Proceedings of the "International Conference on High-Energy Accelerators, Dubna, Aug. 1963," pp. 718-22, 1964.
 2. J.M. Paterson, Proceedings of the Particle Accelerator Conference, Washington, Mar. 1965, IEEE Transactions on Nuclear Science, NS-12, No. 3, 931 (1965).
 3. H. Winick, CEAL-1015, Feb. 1965.
 4. P. H. Burr, CEAL-1008, Jan. 2, 1964.

Tauftest⁵ and Isabelle⁶ (Fig. 1). The shower develops and is totally absorbed in a Pb block, 11 in. long ($55X_0$) and 27 in. diameter ($135X_0$), preceded by a tungsten heat plug, 2 in. long ($15X_0$) and 6 in. diameter ($46X_0$). A 9 in. diameter re-entrant hole, 10.5 in. deep, was added in the earlier stages of these measurements in order to improve beam capture. The entrance window is 0.005 in. thick stainless steel foil. Two toroidal permanent Alnico V magnets (2 in. long, $B=350-400$ gauss) are located coaxially with the beam. Their transverse fields eliminate (i) contamination due to secondary emission from the window foil and (ii) loss of charge through low-energy back-scattering. An aluminum jacket, 0.5 in. thick, surrounding the Pb block is supposed to reduce the loss of charge through photoelectric emission ($\sigma_{ph.el.} \propto Z^4$) and Compton effect ($\sigma_c \propto Z$) because of its lower Z . During operation the pressure was about 10^{-8} torr. A biased grid on the pumping path prevented ion collection and possible photoemission caused by the titanium - discharge Drivac pump. The dark current was below our lowest measuring range ($<10^{-11}$ a.). The design mentioned above was chosen for an expected 0.1% accuracy.

Secondary Emission Monitor (SEM). It contained 21 aluminum foils (each of thickness $8/\mu$ or 2.3 mg/cm^2) stretched on 6 in. diameter rings (Fig. 2). The foils were never replaced nor the monitor opened to atmosphere during the measurements. The pressure was maintained at about 5×10^{-7} torr.

Quantameters. They are an enlarged version of the first instrument proposed by Wilson⁷. Fig. 3 shows schematically their structure. A major fraction of the photon-induced shower is absorbed in 18 copper plates (each 1cm. thick) totalling $12.5X_0$. They are spaced alternately

5. K.L. Brown and G.W. Tautfest, Rev. Sci. Instr., 27, 696 (1956).

6. D. Isabelle, L'Onde Electrique, XLII, No. 421, 354 (1962).

7. R.R. Wilson, Nuclear Instruments 1, 101 (1957).

2mm and 1mm apart so that Simpson's rule for directly integrating the shower curve is applicable. Compensating gaps (lateral: 6.5mm. average width, and back: 7.0mm. deep) contribute the fraction of ionization which otherwise would be lost because of the finite dimensions of the quantameter. An accuracy of better than 1% is expected in measuring beam energy.

Integrators. Throughout the measurements we used integrators of a type developed⁸ at CEA and carefully calibrated to give accuracies of better than 0.3% for the ranges 10^{-8} - 10^{-5} coul. and 0.5% for the range 10^{-9} coul.

Beam Problems. The geometry and parameters of the experimental layout are shown in Fig. 4. The electron beam was designed² to have a minimum spot size (about 1mm vertical, 2mm horizontal) at the pivot of the electron-proton scattering platform. It emerged from the transport system through a 0.002 in. Al window and after a 30-ft. trajectory through a He-filled polyethylene bag entered a shielding hut through an 8 in. x 4 in. opening. The spot size at the monitors was kept at about 1 1/4 in. x 7/8 in. by changing the focal length of the transport system. In all runs pictures (glass plates) were taken before measurements in order to ascertain the alignment and cleanliness of the beam. Occasional checks for beam performance were made by means of an additional remotely controlled secondary emission monitor (9 Al foils each 4 μ thick) located about 20 ft. upstream from the focal point.

The details of the setup used during the measurements are shown in Fig. 5.

8. L.A. Law and J. Weinstein, CEAL-1021, May 14, 1965.

DISCUSSION OF RESULTS

1. Secondary Emission Monitor

At the intensity levels (5×10^6 to 5×10^{10} el/pulse) available in the external electron beam, the secondary emission monitor provided a satisfactory standard of comparison. For short term stability, after initial conditioning of the foils had been attained, measurements could be reproduced to within $\pm 0.3\%$. For long term performance it appeared that the surface emissivity increased by 2% over a period of 4 months. This is attributed to surface changes and to beam fluctuations enlarging the conditioned area of the foils. The behavior of long and short term stabilities is illustrated in Fig. 6; where we occasionally indicated the existing pressure.

The independence of the secondary yield on beam intensity within the short term mentioned above was verified in the Gev range up to maximum densities of about 10^{11} el/(sec.cm²). This important feature for monitoring purposes is thus in agreement with what previous investigators^{6,9-13} had reported for energy ranges up to 600 Mev.

Without discussing the mechanism involved (thickness dependence, density effect, surface condition, etc.), we note that the yield from the secondary emission monitor increases by 4.5% with energy in the range 1-5 Gev (Fig. 7). This is to be compared with an increase of about 7.5% from extrapolating to this energy range the theoretical yield $Y(E, \xi)$ calculated by Vanhuyse and van de Vijver¹⁴. The effi-

-
9. G.W. Tautfest and H.R. Fechter, Rev. Sci. Instr., 26, 229 (1955).
 10. S.I. Taimuty and B.S. Deaver, Jr., Rev. Sci. Instr. 32, 1098 (1961).
 11. S.A. Blankenburg, J.K. Cobb and J.J. Muray, Proceedings of the Particle Accelerator Conference, Washington, Mar. 1965, IEEE Transactions on Nuclear Science, NS-12, No. 3, 935 (1965).
 12. F.A. Bumiller and E.B. Dally, "Proceedings of the International Conference on Instrumentation in High Energy Physics." (Berkeley, Cal., 1960), Interscience Ed., New York 1961, p. 305.
 13. C.J. Karzmark, Rev. Sci. Instr., 35, 1646 (1964).
 14. V.J. Vanhuyse and R. E. van de Vijver, Nucl. Instr. Methods 15, 63 (1962).

ciency of the secondary emission monitor being hard to predict for higher energies, mainly because of factors depending on surface condition, it is necessary that the nature of this discrepancy be better understood if an extrapolation to even higher energies (e.g. at SLAC) is to be safely made without reference to an adequate Faraday cup¹⁵.

2. Quantameters.

The difficulties encountered with quantameters at the present time should be of concern in most experiments performed in the GeV range. Their reliability, saturation effects and linearity of response must be well understood before conclusions involving absolute measurements can be formulated.

For intercalibration purposes, and following the original choice of Wilson, we chose A(95%) + CO₂ (5%) as initial gas mixture in CEA quantameters. When saturation and recombination problems became serious, exploratory measurements were performed with various mixtures of He and N₂. Fig. 8a shows ion collection plateaus for various He+N₂ mixtures in a 4 GeV photon beam referred to an ion chamber. In order to combine a reasonably long voltage plateau, low gas density and stability of response against small variations in gas composition, He(90%) + N₂(10%) was chosen as the alternate mixture for CEA quantameters. Typical ion collection plateaus for the two different CEA mixtures measured in the external electron beam are shown in Fig. 8b. The fact that they are not flat, and hence that one cannot be certain about total ion collection within the gap for a given voltage, remains unexplained as yet. A 400 v. bias has been arbitrarily adopted.

The availability of a stable and nonsaturable monitor as well as

15. D.B. Isabelle, SLAC-25c, Summer 1963.

vastly improved beam stability has made it possible, with the electron beam, to determine the dependence of recombination effects on beam intensity. Fig. 9 shows the saturation curves at 3 and 5 Gev for both A + CO₂ and He + N₂ mixtures in terms of average current collected in the secondary emission monitor. It should be borne in mind that the ionization phenomena in the gas are sensitive to fluctuations in beam intensity, spill length and types of particles in the beam. Great care was therefore taken to establish good beam stability. It is seen that, over the intensity range available and for spill lengths of about 300-400 μ sec., the percentage changes due to recombination effects in He + N₂ are about 6 times smaller than in A + CO₂.

To ascertain the validity of the shower method upon which the design of the quantameter is based, we determined the energy dependence of the total number of ion pairs collected for each incident electron. The curves in Fig. 10 were obtained with beams of very small intensity so as to avoid recombination as much as possible. They seem to indicate that between 0.9 Gev and 6 Gev the CEA quantameters integrate the entire shower and that the compensating gaps contribute as expected for radiation escaping longitudinally and radially. The contribution from the first 0.5mm "missing gap" (which must be taken into account in evaluating a photon rather than an electron beam¹⁶) can be neglected with an estimated error of less than 0.5%. The slight irregularity of points for A + CO₂ could be explained by the fact that this mixture is more sensitive to beam instabilities.

At the beam power levels available at CEA and other large accel-

16. R. Gomez, J. Pine and A. Silverman, Nucl. Instr. Methods 24, 429 (1963).

erators in the Gev range, thermal effects as well as induced radioactivity must be taken into consideration. Although we were not in a position to determine local thermal changes, we irradiated a quantameter (Q1E with He + N₂) for 12 min. with a 600-watt beam, or a total of about 4.6×10^5 joules. When thereafter we immediately returned to a weak beam, the observed variation with time of the quantameter response q_Q/q_{SEM} was reminiscent of Cu radioactive decay with 6-min half-life (Fig. 11).

We have sought to determine the reproducibility of quantameter performance and to establish the dependence of the quantameter constant on energy, time and filling pressure for various instruments. All pertinent data are summarized in Table I for A + CO₂ and in Table II for He + N₂. Although for a given mixture p/T is not the same for all quantameters, we left the initial fillings unchanged.

Fig. 12 shows the variation of quantameter pressure with time. The filling pressure was initially slightly above atmospheric. However, a strange behavior was displayed by two different quantameters each filled with a different mixture. A small selective leakage or diffusion of gas could account for the pressure drop below atmospheric. Another quantameter (Q1C) filled with A + CO₂ displayed an opposite trend when surrounded by an A + CO₂ atmosphere. It is interesting to note that quantameter Q1A, for which observations have been carried out with the same filling for two years, maintained constant pressure for about one year before starting the above mentioned trend. One may suspect a progressive porosity, produced by slow precipitations in the metal lattice or perhaps radiation-induced effects, to be responsible for this behavior.

We write the total energy content in the beam as:

$$U = U_q \cdot q$$

where q is the charge collected and U_q is the quantameter constant expressed in Mev/coul.

We put:

$$U_q = \frac{C_Q}{(p/T)} \quad \text{where } C_Q \text{ is in } \frac{\text{Mev}}{\text{coul}} \frac{\text{torr}}{^\circ\text{K}}$$

For a given quantameter C_Q should be only a function of gas mixture.

From the data in Tables I and II we obtain the following average values and errors (standard deviation):

Q1A, filled with He + N ₂ :	$\bar{C}_Q = 7.23 \times 10^{19} \frac{\text{Mev}}{\text{coul}} \frac{\text{torr}}{^\circ\text{K}}$	
	$\sigma = 0.18$	or $\pm 2.5\%$
Q1D, filled with A + CO ₂ :	$\bar{C}_Q = 12.15 \times 10^{18}$	
	$\sigma = 0.18$	or $\pm 1.5\%$

The value for 0.866 Gev has not been incorporated because of uncertainty in beam stability and synchrotron performance.

The calculated quantameter constant U_q is given only for A + CO₂ assuming a value of 26.0 ev for the energy required to form an ion pair¹⁷. The measured values of U_q are all lower by an amount of about 6% which seems independent of energy.

The time variation of C_Q (see Fig. 13) indicates, however, that the pressure drop is accompanied by a change in sensitivity. On comparing the measured sensitivities of Q1A (during the time of stable p/T) and Q1E (which did not show a change in p/T), one finds that they are in the same ratio as their calculated sensitivities within 0.9%. With this in mind it is clear that accuracies of $\pm 1\%$ can readily be obtained with a quantameter for time periods during

17. J.R. Rees, private communication quoted in Ref. 15.

which it is known that C_Q does not change. The quantameter constant, at a given time, seems to be independent of energy within the normal accuracy mentioned above (see Fig. 14).

3. Faraday Cup

It was assumed throughout the present investigation that the response R_0 of the unbiased Faraday cup can be taken as an absolute standard. However, the response R for variable bias was found to display a characteristic symmetric spread between two plateaus (Fig. 15), in agreement with previous measurements^{5,12,18} at energies up to 600 Mev. The total spread $S = \frac{R_{\max} - R_{\min}}{R_0}$ and the ratio $q_{\text{SEM}}/q_{\text{FC}}$ have been taken as criteria of beam performance. It was established that the reduction of transmission efficiency in the transport system (a consequence of requiring, at high energies, a sufficiently small beam spot size at the monitor location) has no effect on the total spread or on the ratio $q_{\text{SEM}}/q_{\text{FC}}$. The energy dependence of the total spread S (Fig. 16) suggests that the reliability of the Faraday cup as an absolute standard diminishes at higher energies. It would therefore be desirable to have available for comparison some other method of absolute calibration.

In view of the calibration problems just described, and because of doubts stemming from unexplained discrepancies, it is perhaps appropriate to reevaluate the necessity of establishing a normalization procedure common to all laboratories using high-energy photon and electron beams.

18. W.C. Barber, Phys. Rev. 97, 1071 (1955).

ACKNOWLEDGMENTS

The substantial help of Dr. J.R. Rees during the measurement program is hereby heartily acknowledged. We are also greatly indebted to the CEA Operations Division under Dr. G.A. Voss for excellent synchrotron performance and cooperation, and particularly to Dr. J.M. Paterson and Dr. R. Little for their effective assistance in setting up and stabilizing the extracted electron beam. The quantameters in use at CEA were designed by Dr. H.R. Myers. The initial Faraday cup design was the responsibility of Dr. G.E. Fischer and Dr. R.C. Smith.

TABLE I Data for A(95%) + CO₂ (5%)

Date	Location	Quantameter	Energy (Gev)	P/T($\frac{\text{torr}}{^\circ\text{K}}$)	Ion Pairs per incident electron	U _q (theor) (Mev/coul)	U _q (meas) (Mev/coul)	Difference (%)	C _q (meas) ($\frac{\text{Mev}}{\text{coul}} \cdot \frac{\text{torr}}{^\circ\text{K}}$)
April 9, 1964	T.A.	Q 1 D	0.866	2.640	1238	4.93×10^{18}	4.37×10^{18}	-11.3	11.54×10^{18}
April 9, 1964	T.A.	Q 1 D	2.50	2.640	3346	4.93	4.66	-5.5	12.30
April 9, 1964	T.A.	Q 1 D	2.50	2.640	3363	4.93	4.64	-5.9	12.25
Dec. 16, 1964	E.A.	Q 1 G	3.00	2.689	4128	4.77	4.54	-4.8	12.21
April 9, 1964	T.A.	Q 1 D	4.00	2.640	5405	4.93	4.62	-6.3	12.20
April 7, 1965	E.A.	Q 1 G	5.00	2.702	7144	4.78	4.37	-8.6	11.80
April 9, 1964	T.A.	Q 1 D	6.00	2.640	8144	4.93	4.59	-6.9	12.12

T. A. = Target Area

E. A. = Experimental Area

TABLE II Data for He (90 %) + N_2 (10 %)

Date	Location	Quantameter	Energy (Gev)	P/T ($\frac{\text{torr}}{\text{°K}}$)	Ion Pairs per incident electron	U_q (meas) (Mev/coul)	C_q (meas) ($\frac{\text{Mev}}{\text{coul}} \cdot \frac{\text{torr}}{\text{°K}}$)
April 9, 1965	E.A.	QIA	1.5	2.567	343	2.73×10^{19}	7.01×10^{19}
April 9, 1964	T.A.	QIA	2.5	2.700	563.8	2.77	7.48
Dec. 16, 1964	E.A.	QIA	3.0	2.620	666	2.82	7.39
Jan. 22, 1965	E.A.	QIE	3.0	2.677	691	2.71	7.25
Feb. 4, 1965	E.A.	QIE	3.0	2.678	693.3	2.70	7.23
Feb. 4, 1965	E.A.	QIA	3.0	2.595	676.7	2.77	7.18
Feb. 8, 1965	E.A.	QIA	3.0	2.594	678.1	2.76	7.16
Feb. 8, 1965	E.A.	QIA	3.0	2.594	682.6	2.74	7.11
Feb. 8, 1965	E.A.	QIA	3.0	2.594	683.0	2.74	7.11
Feb. 8, 1965	E.A.	QIA	3.0	2.594	678.4	2.76	7.16
March 11, 1965	E.A.	QIA	3.0	2.580	679.9	2.75	7.10
March 26, 1965	E.A.	QIA	3.0	2.574	686.1	2.73	7.02
March 26, 1965	E.A.	QIE	3.0	2.683	698	2.68	7.20
April 9, 1964	T.A.	QIA	4.0	2.700	894	2.79	7.53
April 7, 1965	E.A.	QIA	5.0	2.568	1130	2.76	7.09
April 9, 1964	T.A.	QIA	6.0	2.700	1325	2.83	7.64

T.A. = Target Area

E.A. = Experimental Area

FIG. I SCHEMATIC DIAGRAM OF FARADAY CUP

FIG.2 FOIL ASSEMBLY OF THE SECONDARY EMISSION MONITOR. RING AT LEFT HAS BEEN REMOVED TO SHOW CONSTRUCTION DETAIL.

FIG. 3 - QUANTAMETER STRUCTURE

FIG. 4 - EXPERIMENTAL LAYOUT

FIG. 5 SCHEMATIC DIAGRAM OF MEASURING ARRANGEMENT

FIG. 6 LONG AND SHORT TERM STABILITY OF SECONDARY EMISSION MONITOR

FIG. 7 ENERGY DEPENDENCE OF SEM EFFICIENCY

(a)

(b)

FIG.8 ION COLLECTION PLATEAUS FOR CEA QUANTAMETERS

FIG.9 QUANTAMETER RESPONSE FOR A+CO₂ AND He+N₂ WITH BEAM INTENSITY. QUANTAMETER CURRENT ALSO SHOWN AS ADDITIONAL ABSCISSA IN EACH CASE.

FIG.10 NUMBER OF ION PAIRS COLLECTED IN THE QUANTAMETER PER INCIDENT ELECTRON

FIG. II QUANTAMETER RESPONSE (FOR SMALL STEADY BEAM) AFTER IRRADIATION WITH 4.6×10^5 JOULES.

FIG. 12 VARIATION OF $\frac{P}{T}$ WITH TIME

FIG. 13 VARIATION OF C_Q FOR $\text{He} + \text{N}_2$ WITH TIME

FIG. 14 ENERGY DEPENDENCE OF C_Q

FIG. 15 RESPONSE OF 6" FARADAY CUP WITH BIAS.

$$R = \frac{q_{FC}}{q_{SEM II}} \quad R_0 \text{ IS FOR ZERO BIAS.}$$

FIG. 16 ENERGY DEPENDENCE OF TOTAL SPREAD S

LEGAL NOTICE

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

- A. Makes any warranty or representation, express 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 to the extent that such employee or contractor prepares, handles or distributes, or provides access to any information pursuant to his employment or contract with the Commission.

The research work described in this report was performed under Contract AT(30-1)-2076 between the President and Fellows of Harvard College and the U.S. Atomic Energy Commission.