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ABSTRACT. -

We describe a calorimetric monitoring system for the LNF-LEALE low energy pion beams. The apparatus measures the energy dissipated by the photons in the pion source with thermometric techniques. Numerical manipulation of the source temperature yields a relative but very stable monitor.

1. - INTRODUCTION. -

The main features of the low energy positive and negative pion beams produced by the electron Linear Accelerator of the Frascati National Laboratories have been included in a previous paper[1]. In the present one we discuss the problems connected with a special monitoring system for such a low duty cycle ($\lesssim 10^{-3}$) type of beams. The resulting peak pion current during the duty cycle is about one pion per nanosecond, which makes impossible the individual counting of pions. The use of ionization chambers has been attempted, but the background radiation (soft gamma rays and neutrons) produces a current highly unstable and in absolute values many times larger than that expected from the pion beam itself. A Faraday cup, carefully guarded, has given some reasonable results, but it cannot be used in some experimental conditions, e. g. when the scattering spectrometer intercepts the primary pion beam.

For these reasons we had to devise a new monitoring system with the necessary short and medium term stability. This monitor has not to be an absolute one, since it can easily be calibrated versus the Faraday cup.

Our pion beam is obtained by photoproduction in a Carbon target. The photons are produced by the Bremsstrahlung of the primary electrons in a Tungsten Radiator (see Fig. 1).

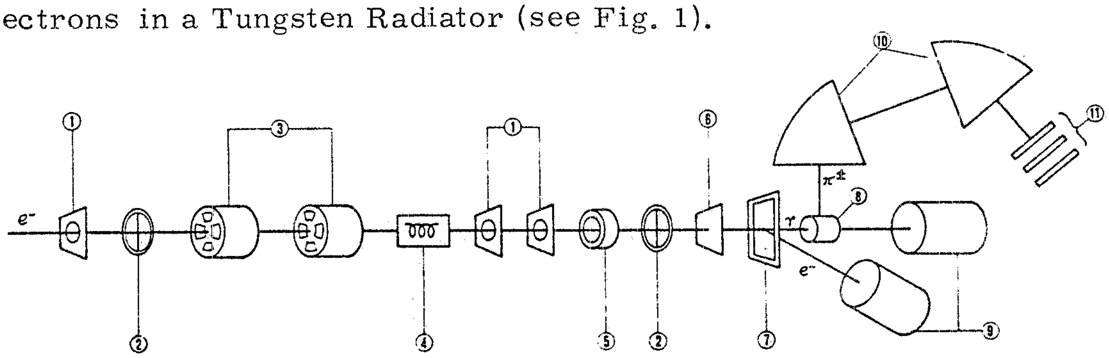

FIG. 1 - 1-Collimator. 2-Secondary Emission monitor. 3-Quadrupoles. 4-Steering Coils. 5-Ferrite Monitor. 6-Tungsten Radiator. 7-Sweeping Magnet. 8-Pion Source. 9-Beam Catchers. 10-Energy Loss Spectrometer. 11-Pion Detecting Apparatus.

Various alternatives have been examined with the aim of obtaining a stable relative monitor:

1) Measuring the current I_e of the primary electron beam with a secondary emission monitor or a toroidal pulse transformer(2);
2) Measuring the total power P of the gamma ray beam with a secondary emission quantameter(3);
3) Measuring the power W dissipated by the gamma ray beam in the pion source with thermometric techniques.

All these measurements, I_e, P and W, yield an output which is proportional to the number of photoproduced pions, provided that the energy of the primary electron beam remains constant. However, I_e and W are less sensitive than P to small fluctuations of the electron energy.

The measurement of the total power of the gamma ray beam is difficult with our experimental apparatus. With a thick radiator ($0.1 \div 0.3$ radiation lengths) the divergence of the gamma beam is such that the quantameter has to be very large or very close. A large quantameter beeing expensive and impractical, a close quantameter would produce too much neutron background in the experimental area.

The electron current is measured continuously during our machine runs, by means of a toroidal pulse transformer, followed by a linear gate (SEN FE 281), an RC integrating network and a current digitizer (ORTEC Model 439). This measurement however does not turn out to be a good monitoring method. Due to multiple scattering of the electrons in the radiator, the photon beam cross section, at the position of the pion source, is comparable with that of the source itself ($\emptyset = 10$ mm). Therefore any displacement of the electron beam from its position changes the fraction of high energy photons which impinges on the pion source. While the electron beam can always be brought back to its central position with high accuracy, unpredictable displacements due to uncontrolled changes in the conditions of the accelerator are hard to avoid.

The power W dissipated by the photon beam in the pion source can be calculated from a measurement of the source's temperature. Continuous monitoring of this temperature has been achieved by means of a Chromel-Alumel thermocouple connected to an integrating digital voltmeter (VIDAR 520 B) interfaced to a PDP-15 computer. Since the graphite source takes a fairly large time to reach its equilibrium temperature, when the beam is turned ON or OFF, temperature scanning has not to be very frequent. Measurements taken every 20 seconds are satisfactory. On the other hand, the heat left in the graphite at a particular instant must be calculable if we wish to know at any time the total energy deposited by the photon beam.

2. - TEMPERATURE EQUATION OF THE PION SOURCE. -

The pion source is a graphite cylinder 10 mm in dia. and 50 mm long. It is isolated in high vacuum, beeing suspended by thin Tungsten wires whose thermal conductivity can be neglected. The cooling of the source is so entirely due to thermal radiation. The external surface of the cylinder is much smaller than the internal surfaces of the vacuum system surrounding it. Furthermore we can assume that the heat production and temperature distribution inside the cylinder are uniform. With these approximations[4] we can write the differential equation governing the time behaviour of the graphite temperature as follows:

$$W(t) - \varepsilon(T) S \sigma (T^4 - T_e^4) = m\, c(T) \frac{dT}{dt}$$

where:

W(t) is the power deposited in the graphite by the gamma ray beam;

$\varepsilon(T)$ is the total emissivity of graphite. A slow varying function of T: $\varepsilon(T) = \varepsilon_o/(1+eT)$; $e \ll 1/T$;

S is the surface of the cilinder;

T_e is the (absolute) temperature of the vacuum system;

σ is the Stefan-Boltzmann constant;

c(T) is the specific heat of graphite. Its temperature dependence can be represented, in our region of interest, by the following function[5]:

$$c(T) = c_o (1 + c_1 T + c_2 T^{-2})$$

If we assume that W does not change with time, then we can re-write eq. (1) as:

$$\frac{c(T)\, dT}{B^4 - T^4} = k\, dt \qquad (2)$$

where:

$$A^4 = W/S\sigma\varepsilon(T); \qquad B^4 = A^4 + T_e^4; \qquad k = \varepsilon(T)\sigma S/m$$

The case more interesting for us is the ON-OFF case. The machine has been ON for some time and the source has reached the temperature T_o. At this point the machine is turned OFF and the temperature is measured while the source cools down to room temperature. We have now $B = T_e$ and eq. (2) can be easily integrated, giving:

(3)
$$k_o(t-t_o) = f(T) - f(T_o)$$

where
$$k_o = \frac{\varepsilon_o \sigma S}{m c_o}$$

(4)
$$f(T) = f_1(T) + f_2(T) + f_3(T) + f_4(T) + f_5(T)$$

and

$$f_1(T) = \frac{1}{2T_e^3}\left\{\frac{1}{2}\ln\left|\frac{T_e+T}{T_e-T}\right| + \mathrm{atan}\frac{T}{T_e}\right\}$$

$$f_2(T) = \frac{e+c_1}{4T_e^2}\ln\left|\frac{T^2+T_e^2}{T_e^2-T^2}\right|$$

$$f_3(T) = \frac{ec_1}{2T_e}\left\{\frac{1}{2}\ln\left|\frac{T_e+T}{T_e-T}\right| - \mathrm{atan}\frac{T}{T_e}\right\}$$

$$f_4(T) = \frac{ec_2}{T_e^4}\left\{\ln\frac{T}{\sqrt[4]{|T_e^4-T^4|}}\right\}$$

$$f_5(T) = \frac{c_2}{T_e^4}\left\{-\frac{1}{T} + \frac{1}{2T_e}\left(\frac{1}{2}\ln\left|\frac{T_e+T}{T_e-T}\right| - \mathrm{atan}\frac{T}{T_e}\right)\right\}$$

3. - RESULTS AND CONCLUSIONS. -

The cooling off curve (Fig. 2) has been measured and the experimental values of the temperature have been compared with the theoretical curve of equation (3). The parameters have been adjusted to obtain a best fit of the experimental data. These best fit parameters are compared in Table I with those obtained from textbooks (5, 6).

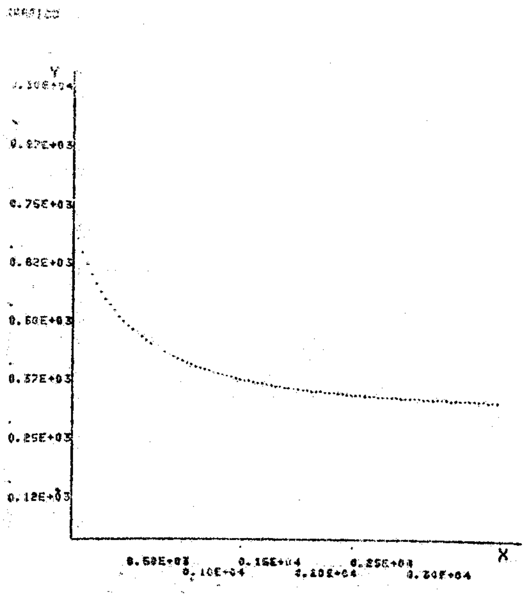

FIG. 2

TABLE I

	$e\,(^oK^{-1})$	$c_1\,(^oK^{-1})$	$c_2\,(^oK^2)$
ref. (5, 6)	$1,6 \times 10^{-4}$	$2,5 \times 10^{-4}$	$-5,1 \times 10^4$
our data	$2,2 \times 10^{-4}$	$3,4 \times 10^{-4}$	$-3,0 \times 10^4$

The agreement is very satisfactory, especially taking into account the amorphous and irregular structure of commercial graphite.

The aim of this method is to have a mathematical expression for the energy absorbed by the source up to any time instant. This is given by the sum of two parts:

$$U(t_1) = \int_{t_o}^{t_1} W(t)\,dt = S\,\sigma \int_{t_o}^{t_1} \varepsilon\,(T)\,(T^4 - T_e^4)\,dt + m \int_{T_o}^{T_1} c(T)\,dt \qquad (5)$$

with

$$T = T\,(t)\,.$$

The first term is the energy radiated by the graphite and the se cond its internal energy. The former is obtained by continuous numerical integration of the temperature-time series; worst case analysis has indicated that the error of integration can always be made negligible. The internal energy is computed by evaluating the analytical result of the integral for the relevant values of the initial and final temperatures. The error associated with this con tribution can also be made negligible by using our best fit parameters. To check this we used the following procedure.

We let the source reaching some high temperature (e.g. 700 °K) by keeping the beam on. We then switched the machine OFF and began reading the temperature at fixed time intervals (20 sec) until it approached the room temperature. Under these conditions:

$$U(t_1) = 0$$

and therefore

$$\int_{t_o}^{t_1} \varepsilon\,(T)\,(T^4 - T_e^4)\,dt = \frac{m}{S\,\sigma} \int_{T_1}^{T_o} c(T)\,dT \qquad (6)$$

Comparing the results of the two integrations for different values of t_1 and the corresponding T_1 yields an estimate of the maximum error incurred. It turns out that the difference between the two terms in eq. (6) becomes smaller by increasing the number of integration points and reaches a plateau value of about 2% for 80 data points. Since the energy left in the source when the beam is turned OFF is usually a very small fraction of the total energy absorbed, this error can completely be neglected.

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