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CALIBRATION OF THE BEAM-SPILL CONTROL SYSTEM AT LAMPF

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Summary

A technique is described for in-situ calibration of the beam-spill control system at LAMPF. Radiation produced by intercepted beam at the wire scanners is employed as a test source. It is shown that the secondary emission current from the wire scanner is a useful measure of the intercepted beam. The wire scanners are inserted into the beam by a digital-data servo system until the desired level of radiation is produced. Interesting digital-data servo-loop responses are displayed. The entire calibration procedure is programmed by the accelerator control computer and can be repeated as often as required without turning off the beam. The calibration programs have been written so that the conditions of the detectors and signal cables are determined and recorded.

Introduction

Activitation of the beam channel at LAMPF is the governing limit[1] on "allowed" beam spill. Control of the beam-spill is exercized by detectors[2] located along the accelerator so as to sense the radiation produced by beam-spill. When the spill is excessive, the injector is turned off by the detectors long enough to hold the average spill to the "allowed" level. The sensitivities of the detectors are adjusted or "calibrated" so as to accomplish the limiting without unduly hampering operation of the accelerator.

Preliminary Calibration

At the wall of the beam channel where the detectors are located the predicted[3] average neutron fluence is 4×10^5 neutrons/cm^2-sec and the gamma dose rate is 80 R/hr. The detectors have far more sensitivity to gammas. Provisionally therefore each detector was calibrated over Co^{60} and the trip-off sensitivity set at 80 R/h prior to installation.

Initial Calibration Efforts in the Beam Channel

The proton energy dependence of the radiation and the unknown energy dependence of the detector response to radiation make it imperative that the final calibration of the detectors be made in-situ. In the actual installation there is also a geometry problem that may not correspond with the assumption of uniform beam spill employed in calculating "allowed beam-spill".[1] The detectors are discrete and are located at the walls in the space between the accelerator modules as shown in Fig. 1a. Since the beam is continually refocused by the succession of quadrupole doublets along the machine, the beam is expected to be largest in cross section at the entrance to these quads and it is here that the likelihood of spill is greatest.

Calibration in place has been attempted by missteering the beam to cause spill as near the quadrupole region as possible. The location of the spill was checked by the use of TLD's distributed along the beam channel wall. Results to date show it is difficult to control the spill at or near the quadrupoles. A typical spill radiation pattern shown in Fig. 1b appears to be produced by a localized spill 3 to 4 meters upstream of the quadrupole. However, the relation between the

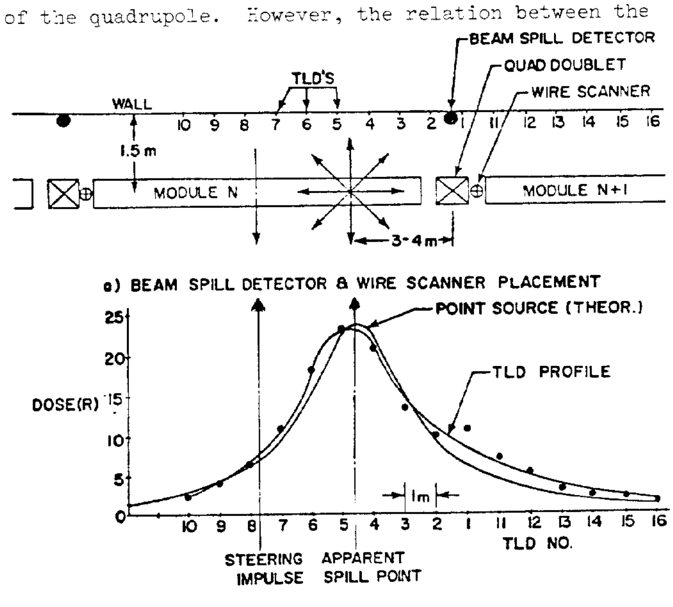

Fig. 1. Calibration Geometry Using Misteered Beam.

source and detector was not easily repeatable without producing undesirable beam channel activation. Furthermore, the spill location would have to be redetermined for each calibration. It became apparent that a calibration technique which did not mis-steer the beam and produce excessive activation problems was needed.

Calibration Using the Wire Scanners

Early in the beam diagnostics program it had been noted that insertion of the wire scanners in the beam even at relatively low duty factor sometimes produced sufficient radiation to turn off the injector by actuating the beam spill monitor near the wire scanner. Don Swenson[4] suggested that since the detectors are located very near the wire scanners between the modules, the wire scanners could possibly be used to make a relative calibration of the beam-spill monitoring system. The calibration would be relative because of the differing radiation patterns caused by the beam passing through thin wires as opposed to that generated by the thick metal structure of the accelerator. If the fraction of the beam which interacts with the wires to produce radiation can be related to an equivalent beam-spill, then an indirect measure of the dependence of beam-spill produced radiation on proton energy can be obtained by simply repeating the measurement at several locations along the accelerator. Such a calibration procedure has the advantage that it does not harm the accelerator even though repeated periodically. This makes it an ideal system operational check.

Interception of the beam by the wire scanners produces currents in the wires, due to secondary emission electrons, which are linearly related to beam current even for high beam current densities[5]. These currents by themselves are not useful for calibration in terms of beam-spill until an equivalence is established. Where it is possible to insert a target which absorbs all, or a known fraction, of the beam, the radiation resulting from this interception can be employed to establish the desired relation, even though the spectrum and spatial distribution of the radiation field produced by the wire scanner differs from that of a thick target. The rationale utilized here is that for the purpose of calibration it is only necessary that the two fields produce the same signal output from the detector, or that the field to current relations and the detector response are linear.

Analysis of Wire Scanner Currents and Detector Sensitivity

The wire scanner currents are proportional to the fraction of the beam current Δi_b which is incident on the horizontal (X) and vertical (Y) wires, i.e.:

$$
\begin{aligned}
i_x(y) &= K_H \Delta i_{bx}(y) \\
i_y(x) &= K_V \Delta i_{by}(x) \qquad (1) \\
i_{ws} &= i_x(y) + i_y(x) = \text{total current for both wires}
\end{aligned}
$$

The currents $\Delta i_{bx}(y)$ and $\Delta i_{by}(x)$ are not directly measurable. As illustrated in Fig. 2 they are functions of wire position in the beam and the beam intensity $j(x,y)$ along each wire.

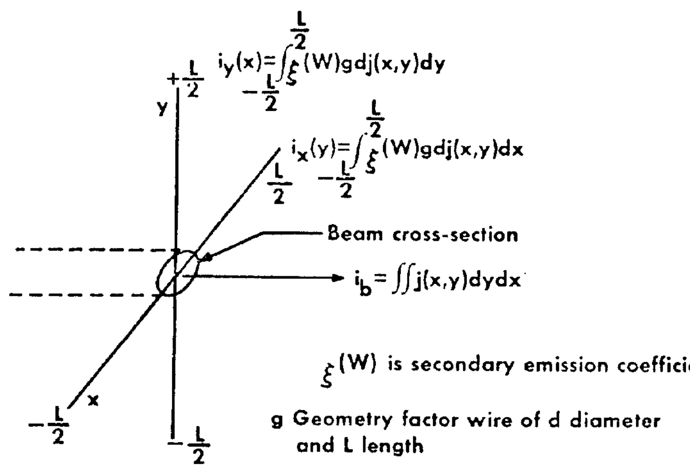

Fig. 2. Wire Scanner-Beam Relation.

The radiation arriving at the detector and the signal current, i_s, at the detector output are proportional to the portion of beam current incident on both wires, i.e.:

$$i_s = K_R i_{ws}. \qquad (2)$$

With a totally absorbing copper target inserted in the beam so as to preserve essentially the same geometric relation to the detector as the wire scanner, the detector output i_T will be proportional to total beam current, i.e.:

$$i_T = K_T i_b. \qquad (3)$$

When $i_T = i_s$, $i_b = i_{be}$ is the beam-spill current equivalent to that interacting with the wire scanners. For this condition:

$$i_{be} = \frac{K_R}{K_T} i_{ws}. \qquad (4)$$

Obviously, K_R and K_T are dependent on the proton energy W. Therefore, i_{be} will be energy dependent which makes eq. (4) assume the following form:

$$i_{be}(W) = \frac{K_R(W)}{K_T(W)} i_{ws} \qquad (5)$$

Eq. (5) is all that is needed to determine the energy dependence of the wire scanner current relative to the beam current. This measurement would not have to be repeated frequently to retain assurance of energy dependence. The relation which should be checked often is eq. (2) to verify the stability of K_R. This is a convenient operations measurement when drifting a low energy beam, for example 100 MeV or 211 MeV, through the accelerator to the switchyard. In this case the proton energy is constant and K_R should be the same for all beam-spill monitors in the drift region of the machine. A display of typical data is shown in Fig. 3.

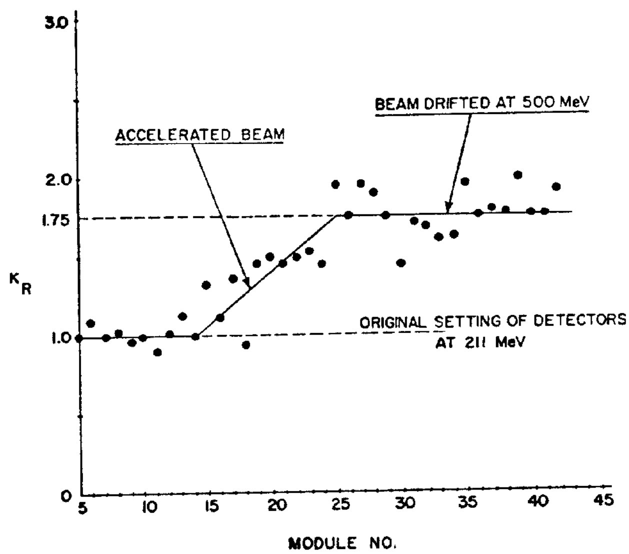

Fig. 3. Spill Monitor Sensitivity vs. Energy.

Control of the Coefficients K_R and K_T

The constants K_R and K_T determined above are functions of the detector sensitivity to both gammas and neutrons produced. Ignoring the neutron sensitivity these relations can be described as follows:

$$K_R = \frac{Gg}{i_{ws}}\int_0^W [S_\gamma(E)\dot{\gamma}_s(E,W)]\, \mathbf{dE} \qquad (6)$$

$$K_T = \frac{Gg}{i_b}\int_0^W [S_\gamma(E)\dot{\gamma}_T(E,W)]\, \mathbf{dE} \qquad (7)$$

where G = current gain of photo-multiplier (volt-sec/coul.)

g = charge to voltage conversion gain of the detector station unit (coul/volt-sec)

$S_\gamma(E)$ = Sensitivity of scintillator and photo cathode combination to gammas. Energy dependent in E(coul/photon).

$\dot{\gamma}_s(E,W)$ = rate of gamma photons arriving at the detector with energy E resulting from protons, having energy W, which interact with the scanner wires (photons/sec-MeV).

$\dot{\gamma}_T(E,W)$ = same as $\dot{\gamma}_s(E,W)$ but for thick target.

The value of g is fixed so that all station units are interchangeable. The value of G varies as the seventh power of the voltage applied to the photomultiplier hence can be changed over an extremely wide range. The applied voltage is the only control of detector system sensitivity employed.

A Computerized Closed-Loop Technique to Test the Beam-Spill System

The signal current i_s received at the detector station unit is comprised of several components other than the radiation produced phototube current, that is

$$i_s = i_{bs} + i_a + i_c + i_d \qquad (8)$$

where i_{bs} = radiation produced phototube current

i_a = a purposely introduced bleed off current representing the "allowed" beam-spill.

i_c = cable leakage current, possibly radiation induced. Can be plus or minus.

i_d = dark current phototube

In Fig. 4a is the circuit used to read the phototube. The integrator (charge to voltage converter of Eq. 8) receives the four currents. Thus, a convenient programmatic measure of the sensitivity and condition of the Beam-Spill Control system with the Central Control Computer at LAMPF can be based on a simple measure of K_R as defined in Eq. 2. During a pulse of time-width τ, the voltage increment ΔV is linearly proportional to time and the currents at the integrator summing junction:

$$\Delta V = [\frac{i_{bs}}{C} - \frac{i_a}{C} + \frac{i_c}{C} + \frac{i_d}{C}]\tau \qquad (9)$$

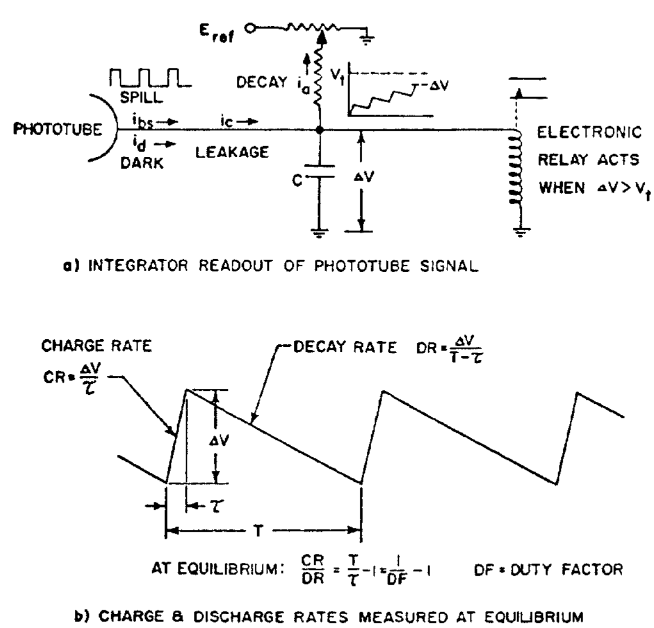

Fig. 4. Integrator Action at Equilibrium.

The charging and discharging rates can be expressed from Fig. 4b as follows:

$$\left.\begin{aligned} CR &= \frac{\Delta V}{\tau} = \text{charging rate} \\ DR &= \frac{\Delta V}{T-\tau} = \text{discharging rate} \end{aligned}\right\} \qquad (10)$$

Since the beam-pulse duty factor DF is τ/T, Eqs. (10) can be combined in the following way:

$$\frac{\Delta V}{\tau} = DR\left(\frac{1}{DF} - 1\right) \qquad (11)$$

this allows i_{bs} from Eq. (9) to be written in terms of directly measurable quantities

$$i_{bs} = (DR)(C)\left(\frac{1}{DF} - 1\right) + (i_a - i_c - i_d) \qquad (12)$$

thus, the ratio K_R from Eq. (2) becomes:

$$K_R = \frac{(DR)(C)}{i_{ws}}\left(\frac{1}{DF} - 1\right) + \frac{(i_a - i_c - i_d)}{i_{ws}} \qquad (13)$$

For a properly functioning beam-spill monitor, the cable leakage and dark currents are negligible and the bleed-off current is adjusted to a very low level, nominally 2 nano-ampere, so that within reasonable precision, K_R is given by the first term of Eq. (13):

$$K_R = \frac{(DR)(C)}{i_{ws}}\left(\frac{1}{DF} - 1\right) \qquad (14)$$

Eq. (14) is the most important computation made in the program. To compute it accurately, an equilibrium condition must be established as shown in Fig. 4b, which requires that the charge supplied to capacitor C in time interval τ is equal to the charge decay in interval $T-\tau$. The program provides a digital servo controller which drives a selected wire scanner into the beam until the beam-spill monitor output voltage (integrator voltage) reaches a selected level below the fast protect value at which time the necessary equilibrium condition is established. This chain of events is shown in Fig. 5. The code assures the equilibrium condition in the quasi-second-order servo by

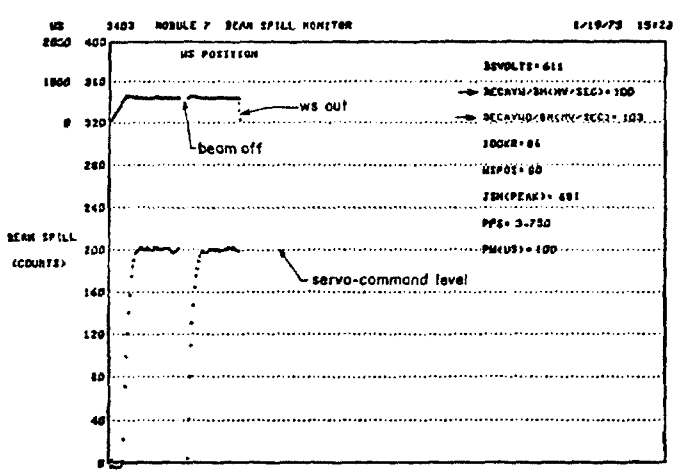

Fig. 5. Digital Servo Operation-Stable Beam Condition.

rate damping to prevent excessive overshoot and keeps the current intercepted by the wire scanner constant. The resulting beam-spill, as seen by the adjacent beam-spill monitor, is typically commanded to be half the fast-protect level, the level at which the beam is automatically shut down to prevent excess activation. Equilibrium is typically reached in about a minute for pulse rate of 3.75 pps. If the beam is well steered and there is little background radiation in the vicinity of the wire scanner, the servo response is effective and precise as shown in Fig. 5. If beam-loss is not confined to the wire scanner or if the beam is fluctuating, equilibrium cannot be established precisely as shown in Fig. 6.

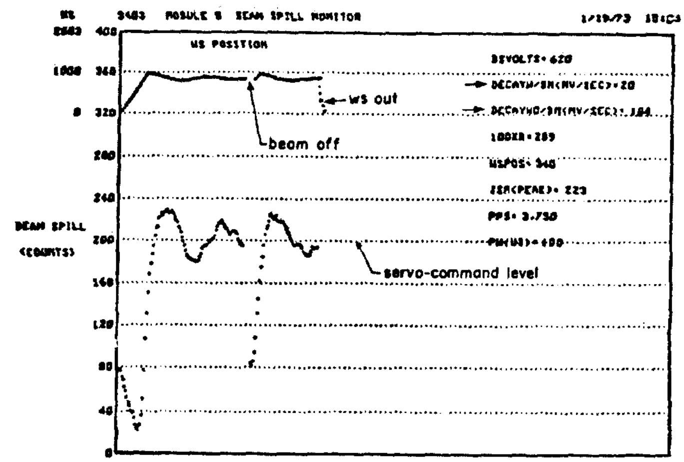

Fig. 6. Digital Servo Operation-Unstable Beam Condition.

To obtain the best possible computation of beam-spill monitor sensitivity as given by K_R, the decay rate DR is computed in two ways. In the first the wire scanner is driven quickly out of the beam, and the rate of decay of the integrator voltage is measured. In the second, the beam is shut off long enough to allow the integrator to decay without the effects of background beam-spill produced radiation. Any difference in the decay rates so measured is an indication of either local losses not due to the wire scanner or of excess cable leakage. Evidence of this is shown by the fact that the two calculated decay rates shown in Fig. 6 differ radically. The decay rate is therefore a means of monitoring long-term changes in phototube dark current, buildup of residual machine activity, cable losses due to radiation damage, and it provides a check on the condition of the electronics. Thus, by measuring decay rate, the updated sensitivity of the beam-spill monitors can be checked as well as the long term stability of the system.

Using this system code, all the monitors along the accelerator have been set to the desired K_R ratio and the resulting consistency in fast-protect shut-down of the beam has facilitated general operation of LAMPF.

References

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