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### OPERATING EXPERIENCE WITH LAMPF MAIN BEAM LINES INSTRUMENTATION AND CONTROL SYSTEM

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# Summary

Instrumentation and control (I&C) for the Los Alamos Clinton P. Anderson Meson Physics Facility (LAMPF) main beam line is based upon central computer control through remote stations which provide input and output to most devices. Operating experience shows that the ability of the computer to give high-quality graphical presentation of the measurements enhances operator performance and instrument usefulness. Experience also shows that operator efficiency degrades rapidly with increasing instrument response time, that is, with increasing delay between the time a control is changed and the result can be observed. For this reason, instrumentation upgrade includes speeding up data acquisition and display times to under 10 s. Similarly, television-viewed phosphors are being retained where possible since their instantaneous response is very useful. Other upgrading of the instrumentation system is planned to improve data accuracy, reliability, redundancy, and instrument radiation tolerance. Past experience is being applied in adding or relocating devices to simplify tuning procedures.

#### A Systems Outlook

The four authors have had the task of tuning up the experimental area primary beam lines during the past year of LAMPF low intensity running in. This paper will record some observations on our operating experience with the I&C system.

The operator uses the instrumentation system to measure beam characteristics and the control system to make adjustments to the beam transport. To this extent, the operator has a systems-wide viewpoint, which we try to present here.

The system in its present and foreseen state requires a human operator during tune-up. Therefore, in addition to the ever-present requirements of reliability, accuracy, and reproducibility, the I&C system should present data in a <u>man-efficient form</u>, the data and controls should be <u>easily accessible</u>, and the tune-up sequence should be reducible to <u>elementary steps</u>.

Obviously, these system requirements will be more easily met when the 1 {C layout has been integrated with the beam line optics and data system characteristics in the design stage. This lesson is being applied in the beam switchyard redesign during the LAMPF shutdown (January-June 1975) in preparation for high-intensity operation.

With the existing I&C system, tune-up times were initially in excess of 24 h for all beam lines, this time and energy being expended at each biweekly startup. Through improved resettability and stability in the accelerator and beam line controls, systemization of procedures, and increased operator proficiency, the tune-up time dropped to around 4 h, with times under 1 h considered to be a realistic goal.

The scope of the tune-up task may be seen from the diagrams of the beam line I&C system, Fig. 1. Almost every device shown in the diagrams produces information considered by the operator during the tune-up procedure, and perhaps one-third of the magnet currents are adjusted. The operator works through a computer system providing extensive data-reductiongraphics capability, as well as full parameter-changingrecording resetting capabilities.

The characteristics of the existing instruments, the data system, and typical data displays as seen by the operator are described in the next section. The layout of beam controls and the beam-tuning procedure are briefly discussed in the third section. Subsequent sections will discuss problems with three of the primary instruments and the approaches that are planned to upgrade the system.

#### Beam Line Instruments

Two instruments are used to measure beam position and profile in the LAMPF experimental areas: the wire scanner and the "harp." Wire scanners have two wires, horizontal and vertical, mounted on a U-shaped frame and driven across the beam at 45° to the horizontal by a stepping motor (see Fig. 2). Secondary emission currents from the wires are amplified and integrated over one beam pulse. The voltage is read out between step moves by the RICE analog data system<sup>2,3</sup> driven by the main control computer (SEL-840). The harps have 40 to 60 fixed wires per plane which are read between beam pulses by a multiplexer driven by a dedicated small computer (PDP-11). There is provision for integrating up to 64 pulses on the cable capacitance before reading, and digital readouts can also be averaged; both processes enhance the signal-to-noise ratio. A harp, mounted on epoxy-fiberglass boards, is shown in Fig. 3.

The displays from the two systems are similar (Figs. 4 and 5), but the response time differs significantly. Six harp profiles are generated in from 5 to 10 s, even with pulse integration and digital averaging, while six wire-scanner profiles require from 45 to 60 s; if a beam interrupt occurs in this time, a rerun is required. (The long time spent by the wire in the beam often causes a beam interrupt from detection of the beam spilled by the wire.) The slowness of the wire-scanner data is due partly to the use of stepping motors and partly because of the heavy load on the RICE data system. The harp data system with its own multiplexed digitizer has a data input rate to the SEL-840 which is an order of magnitude more rapid.

A feature that was very popular during tune-up was television-displayed phosphors in the lower intensity beams. Since the display is instantaneous and feedback from control operations is immediate, these phosphors enabled very fast initial tuning. Although higher intensity gives problems with phosphor burnout and radiation damage to cameras, the man-efficiency of this display will ensure its incorporation in the beam lines for some time yet.

Beam line component protection against missteered beam is provided by scintillator-detector spill monitors ("AP" in Fig. 1). The system use and usefulness was enhanced by making a graphical display of the spill pattern available at the operator's console, so that





Fig. 2. Wire Scanner Profile Monitor

calibration and anticipation of spill faults were facilitated, and deviation from normal patterns were more easily detected. Readout is through RICE, which for the relatively small amount of data provided adequate data rates.

The beam current monitors are all of the common toroidal transformer type, except in the EP lowintensity (~1 nA) beam line, where an ion chamber and Faraday cup are available. The toroid transformers must have a sufficiently high L/R time constant to minimize droop during the 500  $\mu$ s beam pulse while maintaining adequate signal voltage. The high inductance (typically 0.2-0.4 H) promotes vulnerability to stray inductive and microphonic noise pickup. The original data system provided toroid readout through RICE, which was capable of a slow digitized reproduction of the toroid waveform by sequential, short (10  $\mu$ s) time samples.

### Control and Instrument Layout

The primary tune-up procedure consists in beam steering. The accuracy and efficiency of this procedure depends critically upon the relative locations of controls and instruments, as well as on their sufficiency. The most man-efficient arrangement is to locate a steering control upstream of a profileposition instrument in a 1-to-1 fashion, so that beam steering proceeds sequentially down the line one adjustment at a time. Unfortunately, this arrangement is not always possible, usually because economy of space forbids providing the long drift spaces required to observe a deflection due to a small angular steering change. Thus many steering operations are indirect wherein a steering or bending magnet is set by



Fig. 3. Harp multiwire secondary emission beam profile monitor.



Fig. 4. Wire Scanner Profiles

centering at some location well past the next profile monitor. Under these conditions, beam steering becomes an exercise in solving simultaneous linear equations. Experience shows that the human operator can cope with the two-constraint, two-knob, coupledsteering problem, but that the three-knob problem can be intractable. Sequential one-knob, one-constraint steering is more nearly approached in the revised beam line layouts, with the addition or relocation of steering magnets and wire scanners.

The operation of measuring and tuning to adjust the beam transverse phase-space shape is a more difficult job than beam steering, but ordinarily need not be done as frequently. For this application sufficency and accuracy of information count heavily. The harp and wire scanner quantitative profile data were augmented for a period of time by a television picture of the beam spots on the Area A and Area B targets, but the spot-size information is qualitative and other parameters of the beam variance-covariance matrix are not inferable without at least three accurate profile measurements. A major part of the



## Fig. 5. Harp Profiles

instrumentation upgrade is being devoted to revision of the Area A harp system (which will be discussed later) to ensure that the data necessary for the target spot size computations is available.

### Wire Scanner Problems and Upgrade

The slow response time of the wire scanners, described above, can be easily cured. First, the stepping mode of scanning will be augmented by a continuous scan mode for operation above perhaps 15 Hz beam pulse rate. Second, a multiplexer-digitizer will be dedicated to the wire scanners. These changes produce a data rate which will be handled locally by a small computer (PDP-11) and the CAMAC system under the direction of the central control computer.

Another problem area will arise with the climb to high-intensity operations, from 1974 peak currents of 200  $\mu$ A up to 20 mA planned in 1977. The scanner wires (presently 2 mm tungsten ribbons) must be replaced with a lighter and thinner material to avoid burnout, but the system must still perform adequately on low peak-intensity beams for tune-up and H<sup>-</sup> operations. Therefore, the amplifier sensitivity must be increased to provide usable counts at 1 nA or less wire current. It is believed that only by integrating the full pulse charge can these low signals be kept above noise.

The fast-wire-scanner system will be the primary beam profile instrument in all lines except Area A and the EP beam. The harps presently installed in the other lines (A, X, B) will be removed since the fastwire scanners are competitive in profile speed and intercept much less beam--in fact, none, except when scanning.

### Harp Problems and Upgrade

In the high-intensity experimental areas (Area A) where beam power is rapidly consumed by serial targeting and the beam emittance is quite large after the first target, free use is made of nonretractable harps for tuning and monitoring. Beam steering is straightforward with a harp at the entrance of each target cell, a harp as close to the target as possible, and with corresponding upstream steering magnets. A third harp per target cell allows at least in principle a measurement of the beam emittance within the target cell. A major effort is being devoted to the harp construction and data system to ensure that the data is of sufficient quality for this task, which demands high precision, say a few percent, on the measurement of profile width. Among the improvements planned are: a) shielding of the harp cards from the beam halo, which induces spurious signals, b) low-impedance, ground-loop-free, short cable run input signal paths, c) reliance on feedback amplifiers rather than cable capacity for pulse-to-pulse current integration, d) radiation-hardening of the harp card and insulated leads, e) addition of clearing field grids adjacent to the secondary-emission grids, and f) addition of another harp per target cell.

Some data were taken on radiation effects already experienced at 10  $\mu$ A average beam currents. The most striking observation was a temporary drop in harp card material resistivity by ~3 decades, effectively shorting out the high impedance readout circuitry. Changeover to radiation resistant materials and to low-impedance circuitry is expected to cure this problem.

Even in the large-emittance beams of Area A, transmitted in 30 cm beam pipes between target cells, the amount of material in the harp wires causes a significant growth in beam phase space and consequent beam spill. For this reason, and also because of wire burnout, smaller and fewer wires must be used on each harp. A criterion of about 3 wires per rms spot size, for the smallest expected beam under normal conditions, will be adopted. The readout system, as with the wire scanners, will therefore be taxed with a greater dynamic range requirement and lower minimum wire currents, down to the picoampere range. Integration over many 120 Hz beam pulses is the expected normal mode of operation in order to obtain usable signal levels.

### Beam Current Monitor Problems and Upgrade

The current monitors (CM's) are often useful for the first beam steering, vital for optimization, measurement, and monitoring of transmission, and useful to the experimenters, for whom outputs are made available. The initial readout system, based upon sampling the waveform, was slow and tended to accentuate high-frequency noise and waveform fluctuations. These problems were cured by the addition of a charge integrator system, read out through a PDP-11/CAMAC terminal, after accumulating a selectable number of beam pulses. The operator's display can now be made to give about 1-s updating with readout in microamperes. A continuous calibrate pulse (through the toroid calibrate winding) permits frequent and automatic recalibration. The toroid system with proper calibration and data processing is seen as sufficiently stable and accurate to permit inclusion in an automatic rapid transmission monitor spill protection system.

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