PERFORMANCE OF THE PLA

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Availability

The PLA has been operating 24 hours per day since January, 1962 on a schedule of 10 days for operation and 4 days for maintenance and for the setting up of experiments. In late summer of each year there has been a shutdown of one to two months for major modifications, repairs and installations. The percentage of this scheduled operating time which has been lost by machine faults has decreased from 30% in 1962 to 12.5% in 1964 (January to June). During the 12 months, July, 1963 to June, 1964, the total number of hours available to the experimenters was 4638 hours and the total number of hours scheduled for operation was 5424; an availability of 85.5%. Figure 1 shows the monthly availability figures since the start of regular operation in April, 1960.

Faults

Analysis of the fault log of the machine shows that the lost time was due to rf amplifiers (grounded grid triodes) (15%), modulators (20%), accelerating structure (15%), polarized source (10%), coaxial lines (7%) and miscellaneous small items.

The grounded grid triodes, which are continuously pumped valves manufactured by AERE Harwell and tested and serviced by the PLA group, operate for a total of about 30,000 valve-hours per year.

The faults which cause loss of time are water leaks (in the grid), damage to some silvered mica condensers in the cathode assembly, broken rf windows, anode-to-grid sparking, and broken cathodes. Grid water leaks are normally caused by the accumulation of deposits in the fine bore stainless steel tubes of the grid. Control of the water conductivity to less than 10 μ mho and filtering by scintered stainless steel filters has not eliminated the trouble. The mica condenser forms part of the cathode/grid resonant circuit, and carries about 90 amp rf. Spark erosion of the silver reduces the capacity, puts the cavity off tune and reduces the gain of the valve. Mica life is about 6000 hours. Six to ten valve changes per year are due to the above faults.

Modulator faults are often minor faults now and have become less frequent since the main switch valves were changed from ignitrons to deuterium thyratrons (CV 3336). The basic circuit of the modulators is

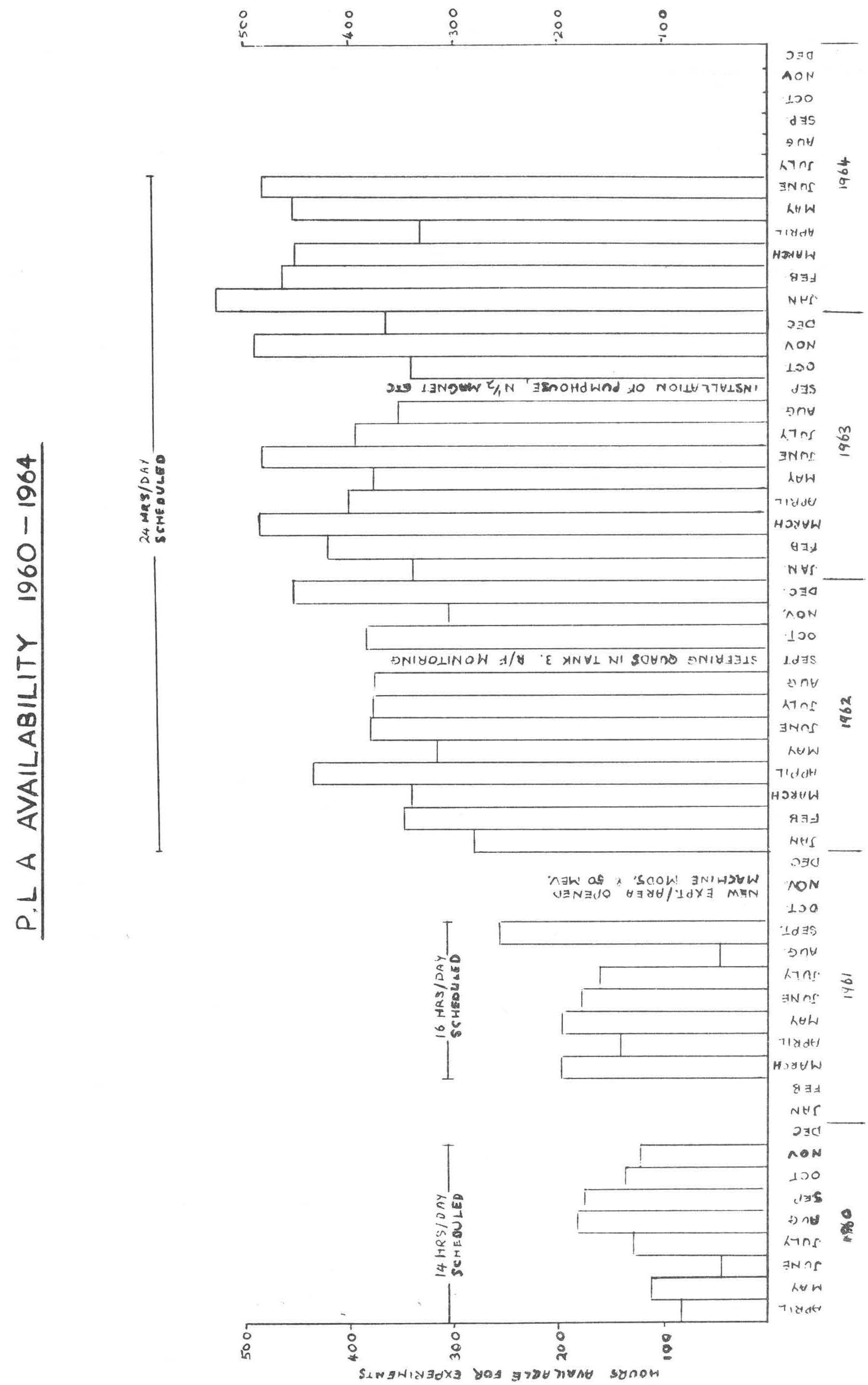
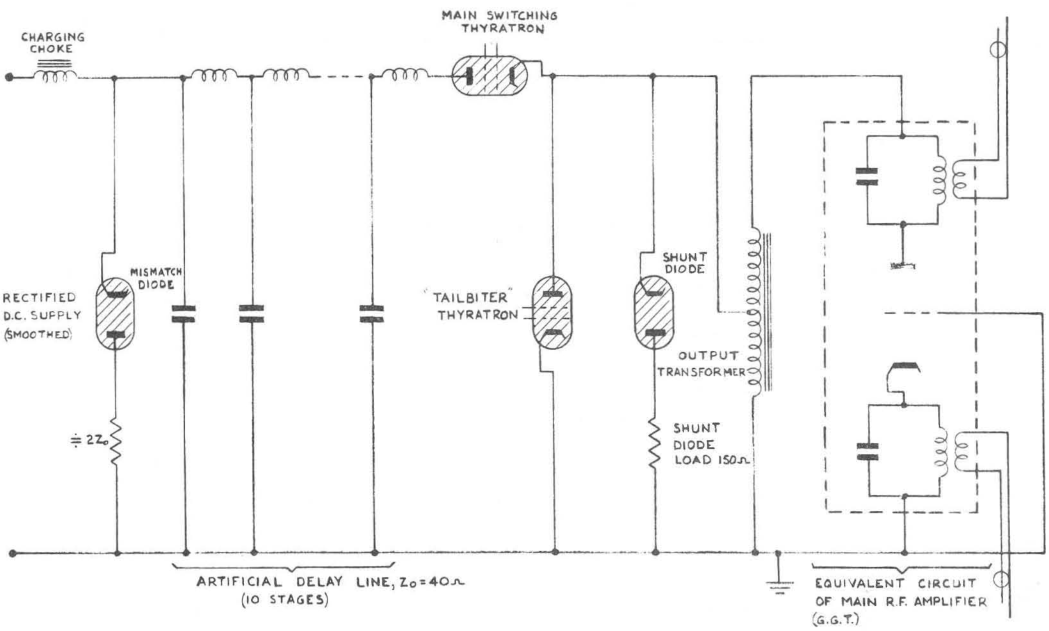

P.L.A AVAILABILITY 1960 – 1964
24 HRS/DAY SCHEDULED
16 HRS/DAY SCHEDULED
14 HRS/DAY SCHEDULED
INSTALLATION OF PUMPHOUSE, N/2 MAGNET ETC
STEERING QUADS IN TANK 3. R/F MONITORING
NEW EXPT/AREA OPENED
MACHINE MODS, & 50 MEV.
HOURS AVAILABLE FOR EXPERIMENTS
100
200
300
400
500
1960
1961
1962
1963
1964

FIG. 1



BASIC CIRCUIT OF PLA MODULATOR
FIG. 2

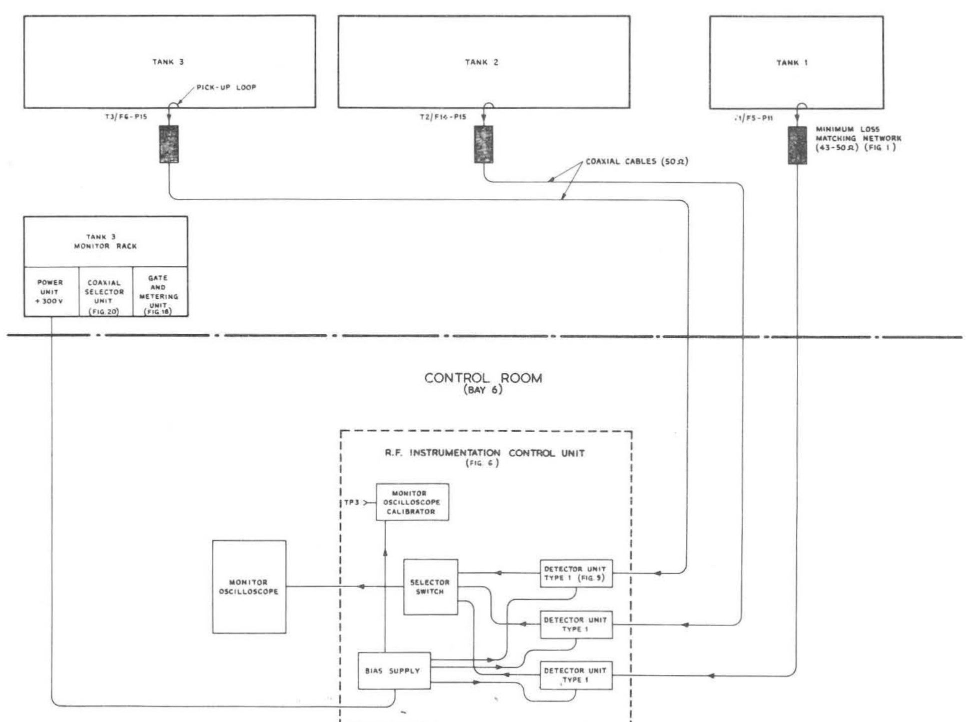


FIG. 3 BLOCK SCHEMATIC DIAGRAM OF ACCURATE R.F. LEVEL MONITOR

shown in Fig. 2. Protection against high impedance mismatch conditions of the modulator load is provided by the "tail-biter" thyratron which is triggered near the end of each modulator pulse. A negative voltage swing on the delay line results and the mismatch diode (a deuterium triggered diode) fires. Subsequently the main switch tube and tail biter are extinquished by the reflected wave. Low impedance mismatches are absorbed by the mismatch diode. The CV 3336 thyratrons have run well, one for over 10,000 hours without a fault. Some have had partial heater failures and some have had gas pressure trouble. These faults have caused very little lost time and are mostly due to preproduction difficulties with the valve and are being cured.

Lost time on the accelerating structure has been due to some water leaks in the drift tube and liner cooling circuits. These have all been "repaired" by pumping a weak solution of resin varnish through the faulty circuit.

Coaxial line faults are nearly always due to fractures in soft soldered joints or to accidental damage to joints during assembly. Peak powers of over 1 Mw (2% duty cycle) cannot be reliably carried by 50 ohm coaxial lines of 3" OD. The use of 4-1/2" and 6" lines and copper plating of all surfaces has improved the reliability very significantly. For further descriptions of the faults, see NIRL R/55 and R/60.

RF Monitoring

The basic requirement here is to obtain for each tank a measure of the rf accelerating field, the phase and the "tilt." Rf amplitudes are measured by loops in the cavity walls which transmit an rf signal to the control room to a matched and biased diode detector (Fig. 3). The bias voltage ($\sim$ 7 V) to give a 0.2 V residual pulse is read off the dial of a helipot. The accuracy of the measurement is $\pm$ 0.1% and the long term stability is about 0.2%. A measurement of the tilt of a cavity is obtained from several loops along the cavity; the calibration of each loop must be obtained by comparison with a perturbation measurement of the tilt. This comparison has only been completed for tank 1, where a perturbation measurement was performed recently. This showed that, for the same position of the tilt tuners, the tilt had changed greatly over the past four years. The tilt can now be checked from time to time to look for long term changes in the cavity. The tanks are individually servo tuned to maintain the cavity phase in a constant relation to the phase of the input power. The intertank phase is controlled manually and is monitored by a phase bridge with thermocouple detectors and a meter indication (Fig. 4). This system can detect small phase changes ($\sim 0.1^{\circ}$), but it is sensitive to changes in the shape of the rf pulses in the tanks,

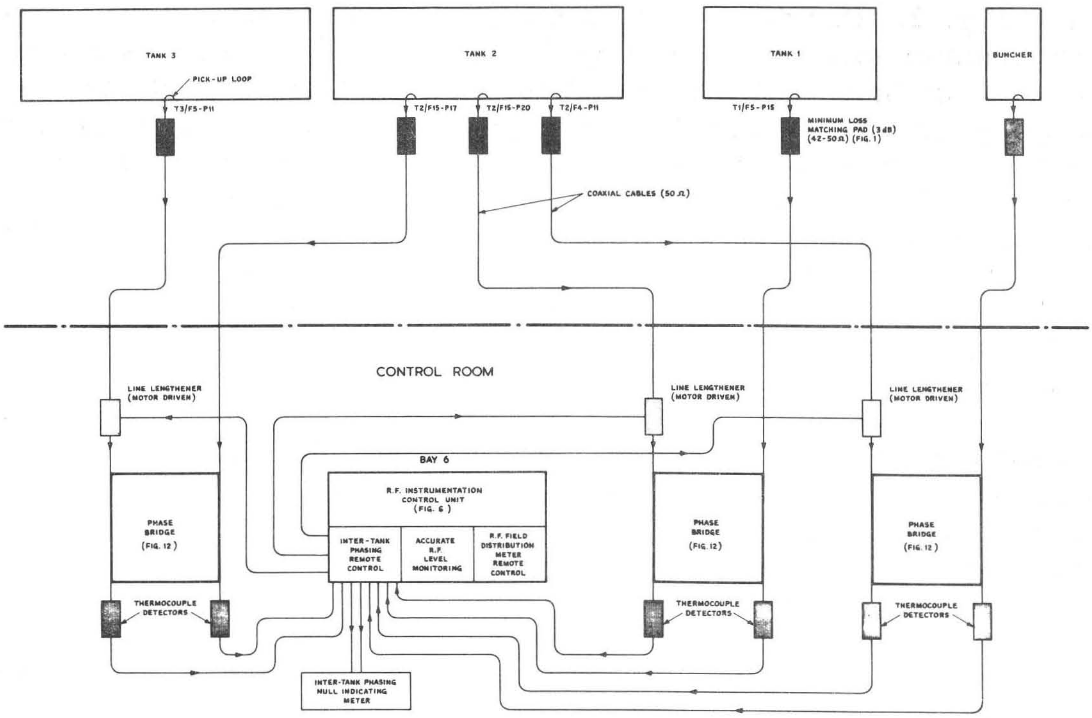
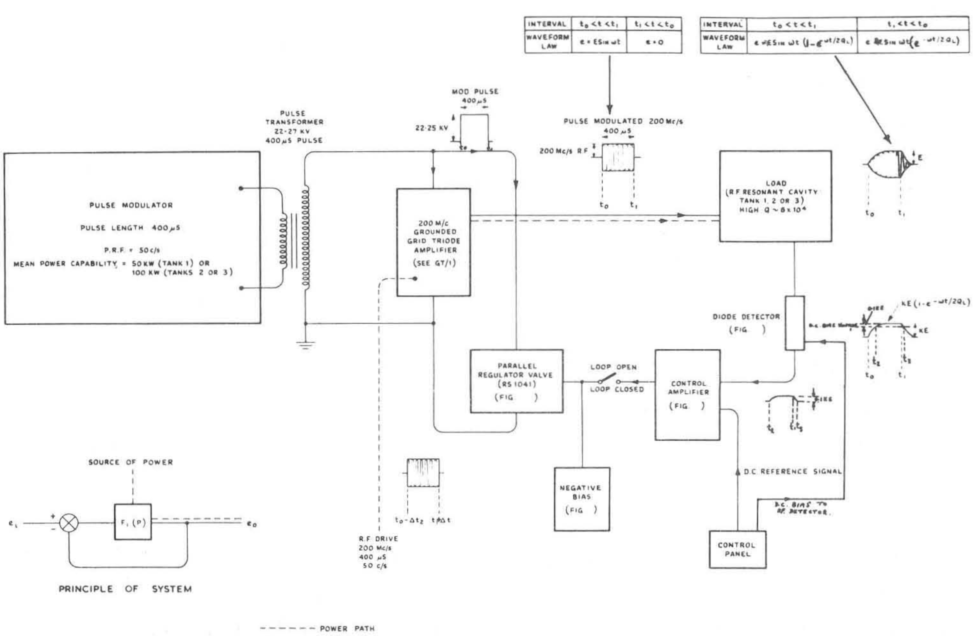


FIG. 4 BLOCK SCHEMATIC DIAGRAM OF INTER-TANK PHASE MONITORING SYSTEM



SIMPLIFIED BLOCK SCHEMATIC DIAGRAM OF CAVITY R.F. FIELD STABILISER

FIG. 5

in particular to the build-up rate, which can be affected by changes of amplifier valves or their associated coaxial line components. It is hoped that by using diode detectors that better long term stability can be achieved.

RF Stabilization

It is important for many experimenters on the PLA that the output beam energy of the machine should remain constant over long periods and that it should be constant throughout each beam pulse. Slow acting stabilization of the rf could satisfy the first requirement, but the second is more demanding. The rf field stabilizer shown in the block diagram, Fig. 5, produces a nearly flat-topped rf pulse; variation along the pulse is about 0.1% and $\pm$ 5% changes in field can be corrected by a factor of 50. Variation of the modulator mains or H. T. voltages produces a variation in the length of the flat top of the stabilized pulse. This is particularly noticeable, when the Nimrod magnet is being pulsed at full power, but it is not embarrassing operationally.

Beam Energy Monitor

Beam energy measurements by the time of flight method, by momentum and by range measurement have all been used to observe the dependence of beam energy on machine parameters. The range measurement method has the advantage of requiring relatively simple appartus and in the arrangement used it imposes only one restriction on the beam, that it should have a peak current of 10^{-6} to 10^{-9} A. The beam energy monitor is located about 6 feet from the end of tank 3 and can be moved in an out of the beam by remote control.

Figure 6 shows the principal parts of the device. Ion chambers A and B form a differential ion chamber with a common collector which is connected to a vibrating reed electrometer. The thin degrader is equivalent in thickness to two standard deviations of the nearly Gaussian range distribution. The relative thicknesses of A and B is such that the larger number of protons passing through A is compensated by the greater ionization loss per proton in B, to produce equal currents in A and B when the mean range of the protons is coincident with the center of the thin degrader. The thick degrader is removed for measurements at 30 MeV. The variable wedge degrader is motor driven and arranged to give a digital read-out of its position. The ion current as a function of the wedge position (results for a prototype with a dial reading only) is shown in Fig. 7. The zero cross-over point can be repeatedly found to be better than the equivalent of $\pm$ 10 keV for 30 and 50 MeV beams; its position is insensitive to changes in the ion chamber voltages under the recommended operating conditions.

This energy monitor needs to be calibrated at one energy near 50 MeV and one near 30 MeV. The incremental energy calibration can be obtained from range energy tables and the mechanical movement of the wedge degrader; it has also been checked against time of flight energy measurements. The monitor measures the mean energy of the beam and it is insensitive to the energy spectrum provided it is not too wide (less than 1 MeV). The most important advantages of this instrument is that it is always available for measuring the beam energy, whatever experiment is scheduled and its calibration remains unchanged since it depends only on one measurement of degrader thickness.

Beam Loss in Tanks 2 and 3

When the PLA was first operated, there was practically 100% transmission of beam current from the end of tank 1 (10 MeV) to the output of tank 3 (50 MeV). Recent measurements showed that the transmission had deteriorated to about 60%. Part of this loss was found to be due to a fault in the quadrupole current wiring in tank 2 which had increased the current in one of the quadrupoles by 40%. When this fault was cleared, the transmission increased to about 75%. Further measurements of quadrupole currents showed that there was a rms deviation from a $1/\beta$ quadrupole gradient law of 7%, which would produce an rms increase in beam spot size of 3 mm radius. This fault alone would not account for the beam loss, but it is also known that the mechanical alignment of the quadrupoles is not perfect and this will cause a radial oscillation of the beam, which now appears to be sufficient to cause the beam to be intercepted by the drift tubes. After a run at $1\,\mu$A mean beam current for a few hours, radioactivity of the drift tubes can be detected by a γ-ray monitor outside the vacuum envelope. Two peaks, at approximately a half-wave radial oscillation interval, are found, one of 2 mr/hr near the output end of tank 2 and one of 10 mr/hr in tank 3.

The majority of the neutron radiation, measured outside the shielding walls of the machine, is due to this beam loss, since the irradiated material here is copper, while all beam degraders, collimators and beam stoppers in the experimental areas are carbon. Experiments on the relative neutron yields from various materials are planned, which will give useful data for the control of radiation from machines of around 50 MeV.

SHAYLOR: I was interested to see that you are using a simple shunt type modulator to regulate rf amplitudes. Are you happy that just regulating the drive in the way you are doing keeps the whole of one tank flat to 0.1%? Don't you think that you may be regulating the rf level at the point where the detector is, but not elsewhere in the tank?

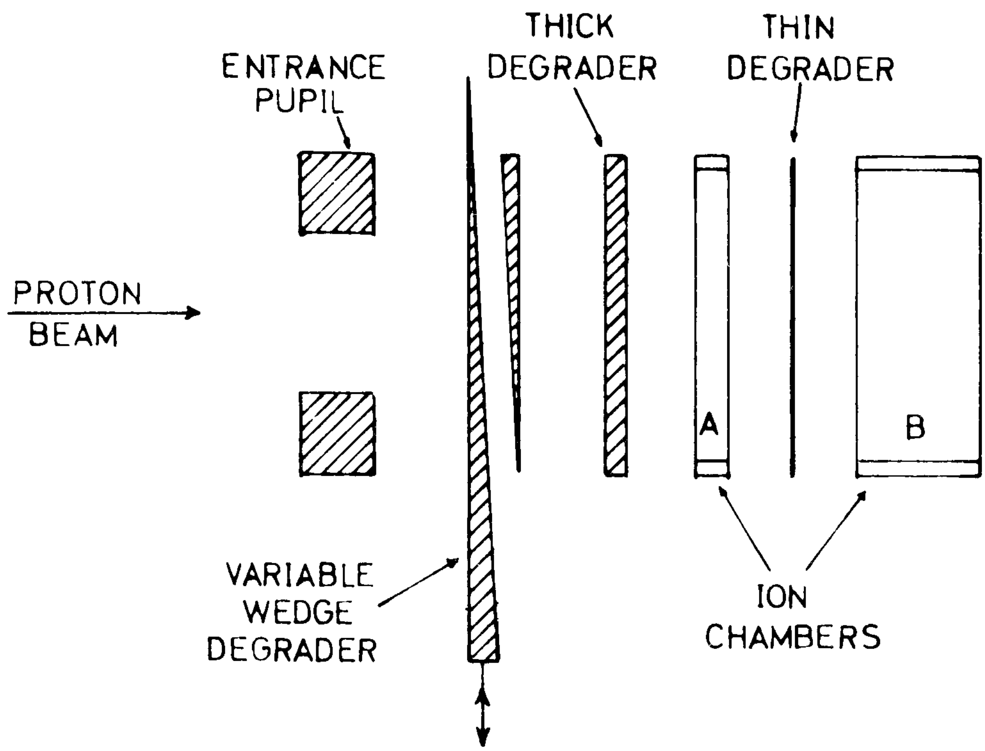


Fig. 6 Layout of Beam Energy Monitor.

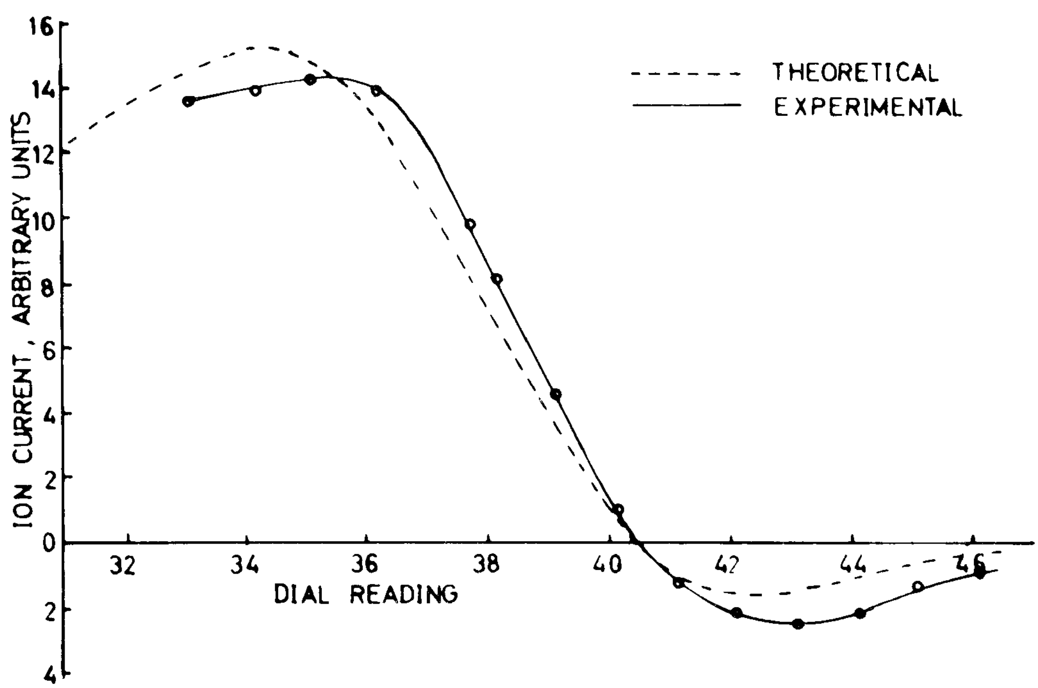


Fig. 7. Response Curve of Beam Energy Monitor.

DICKSON: I haven't seen any trouble like this, no. I have not looked at this very carefully, but we have got some evidence on this because the pickup for the stabilizer is at one part of the tank (I think in the middle), and the pickup for some other monitoring is in another part of the tank. They both flatten together.

SLUYTERS: We have done also at CERN these radiation measurements along the tank, but we have not found these bumps. Everything was very equal all along the tanks.

PRIEST: You have a nice servo mechanism there which keeps the pulse flat. I would like to know more about what it tells you. I think you are talking about the last part of the pulse after the beam is injected into the machine. And this corresponds with what Taylor was talking about. Have you got a measure of the extra amount of power that you have to put in when the beam is turned on?

DICKSON: Very little in our case. We are only running with at the most a peak current of around 200 μA. Beam loading doesn't worry us.

TENG: Do you have any experience similar to CERN that you can reduce the energy spread by detuning the phase of the second tank.

DICKSON: Can we leave that till Carne gives his paper? We have not measured the absolute phase between tanks.

HUBBARD: Can you not affect beam loss as you have indicated by adjusting the quadrupole magnet strengths?

DICKSON: I hope we can. We have not tried this yet. The adjustment is not so easy since the adjusting resistors are in boxes right underneath the tanks and there are a whole lot of things built in front of them all the way along. It is a slow and tedious business, but it probably has been done by now, since there was a shutdown last week. I hope that it has been fixed.

PERRY: Do you contribute any significance to the second peak?

DICKSON: No.

FEATHERSTONE: I was interested in your experience on blocking the water passageway within one of your vacuum tubes. This is an experience we share in our resnatrons. In our case, it turned out to be largely copper compounds which apparently had been removed from other parts of the system, and we are now undertaking a program of deoxygenating and filtering and hope to prevent recurrences of this sort. We have also been trying to go to a higher purity of water. Are these the measures that seem appropriate in view of your experience? First of all, was it copper that plugged up the passages in your case?

DICKSON: There is some copper in the water circuits. We used not to have very much but in the last three months it has been building up. We don't know why but we had this blockage of the grid tubes before that. One of the main components is silica in this blockage. I think there are all sorts of other components.

QUESTION: What was the conductivity of the water.

DICKSON: 10 micromhos.