BEAM OBSERVATION AND MANIPULATION IN THE AGS*

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(Presented by M. PLOTKIN)

INTRODUCTION

The procedure for a general orbit analysis, and setup of the AGS for proper operation, involves the use of a set of observation pickup electrodes and the monitoring of the effect on capture and acceleration of various machine adjustments.

The AGS incorporates a set of 72 pairs of pickup electrodes. The information derived from these electrodes leads to a rapid, accurate orbit determination. A special set of electrodes, one for radial position and one for total beam detection, feeds the RF system but is also separately monitored. By proper observation and analysis of these different signals the machine parameters can by quickly adjusted for minimum betatron oscillations and maximum capture and acceleration efficiency.

In addition, the pickup electrode signals can be used to measure ν values at different energies and radii and for beam intensity determination.

The Brookhaven AGS is constructed of 240 main guide field magnets arranged in twelve superperiods of 20 magnets each. This twelvefold arrangement is carried through into the radiofrequency system which accelerates on the twelfth harmonic of the beam revolution frequency. To facilitate identification the superperiods are designated by the letters A through L and the magnets are numbered from one to twenty. Thus we inject into magnet A1 and the inflector which precedes A1 is in straight section L20.

STRUCTURE OF OBSERVATION ELECTRODES [1]

The primary system of beam observation is based upon a series of electrostatic induction electrodes. These electrodes are mounted in five foot straight sections located in each superperiod following magnet numbers 3, 7, and 15. At each location there is both a vertically sensitive and horizontally sensitive set of electrodes. In the 3 and 7 positions quadrupole and sextupole correcting magnets are also located.

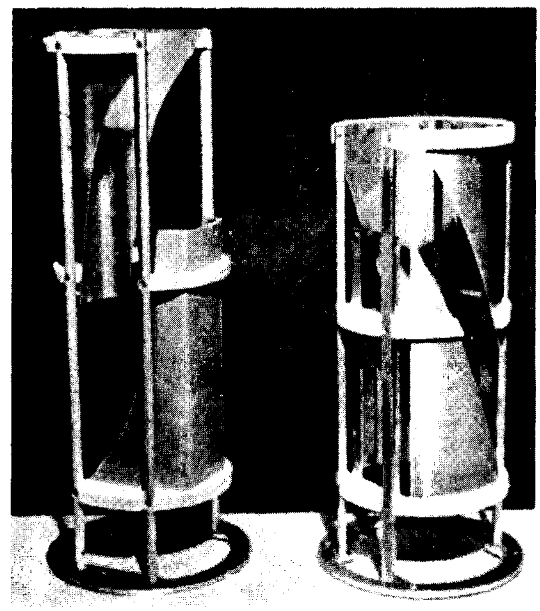

Fig. 1. Vertical and horizontal observation pickup electrodes.

The design of the pickup electrode structure was greatly complicated by the existence of these magnets. To keep the size of the magnets down, the outside diameter of the vacuum pipe was fixed at six inches. The minimum horizontal aperture was fixed at 5-3/4 inches. The electrodes were all located in positions where the beam is focused horizontally allowing the aperture to be less than 5-3/4 inches.

* Work done under auspices of the Atomic Energy Commission.

A cut cylinder was considered, but although this yields excellent positional information, the very high capacitance to the vacuum pipe in the restricted aperture would reduce signal levels considerably. After several steps the final designs were adopted. The shapes are different for vertical and for horizontal pairs because the aperture requirements differ. The results of wire measurements indicate very good linearity for positional information and very little vertical sensitivity in the horizontal electrode and vice versa (Fig. 1).

OBSERVATION ELECTRODE ELECTRONICS

To present a high input impedance to the signals from the electrodes, a vacuum tube cathode follower is used, physically mounted as close as possible to the electrode. This is followed by a wide band transistor amplifier with two highly fed back pairs for gain stabilization. The amplifier characteristics are controlled with respect to gain and bandwidth to about 3% and are periodically checked. This enables us to take radiofrequency differences of the output signals, yielding excellent position information. The output circuit can be remotely switched to give us an RF signal or a detected signal. The detected signal is used for orbit measurements at times later in the acceleration cycle.

The signals are conducted to the control room on specially made cables which contain two shielded coaxial cables within an additional shield.

The shields are grounded in such a fashion that no ground loops are closed and no power line frequencies are introduced. To preserve good RF differences, the two cables from each electrode pair were electrically balanced for length, and matching pieces, as necessary, were added as permanent parts of the system.

The cables terminate in the main control room on an insulated patch panel board. A cathode ray oscilloscope and photography of traces is used to accumulate data. The techniques of these data taking will be described more fully later.

In the initial design stages of the AGS the linear accelerator was expected to inject one milliampere of protons with the intention of a considerable increase in current as the system was improved. Rather than allow for gain switching in the electronics it was decided to change the over-all sensitivity by switching in capacitive loading directly on the electrodes. We can select any of four gain positions from the main control room which represent the unattenuated signal, and gain reductions by factors of five, fifteen and fifty. The range of beam intensities covered with this arrangement is roughly from 10^8 protons/pulse to 10^{12} protons/pulse. In normal operation the attenuation by fifty range is used. However, when the beam is aperatured for various studies, the more sensitive settings are selected. The unattenuated over-all gain of each channel is approximately 1000. With the present intensities of 3 to 5×10^{11} protons/pulse it is possible to use an electrode pair with only the cathode follower and no additional amplification.

MINIMIZING BETATRON OSCILLATIONS [2]

Each time the machine is turned on, or whenever any significant change is made in injection conditions, the vertical and horizontal betatron oscillations at injection are routinely minimized. The ν value in the AGS is about 8-3/4. Thus, 28 bending magnets represent one betatron wavelength. Corresponding electrodes in adjacent superperiods are spaced just about 3/4 of a betatron wavelength apart. For this procedure two sets of electrodes at E7 and F7 were selected to set up the proper injection conditions. Two parameters which most influence the betatron oscillations in each plane were chosen. These are two sets of vertical steering magnets in the injection lineup for vertical adjustments and the inflector voltage and timing for horizontal adjustments.

The amplitude of betatron oscillations at E7 and F7 were observed for a given change in each parameter. A simple numerical formula was determined giving the required changes in vertical steering and inflector settings to minimize betatron oscillations. In practice, the operators read the difference in position between the first and second turns at each electrode at E7 and F7, insert the required changes and thereby reduce the oscillations. For very large initial oscillation amplitudes, repetition of the corrective procedures are sometimes necessary. Fig. 2 shows the first three turns of a spiraling beam with and without the correction. In each case the upper trace is a sum or total amplitude signal and the bottom trace is a difference or position signal. The same procedure can be applied to an accelerated beam, the only change being the appearance of RF structure on the traces.

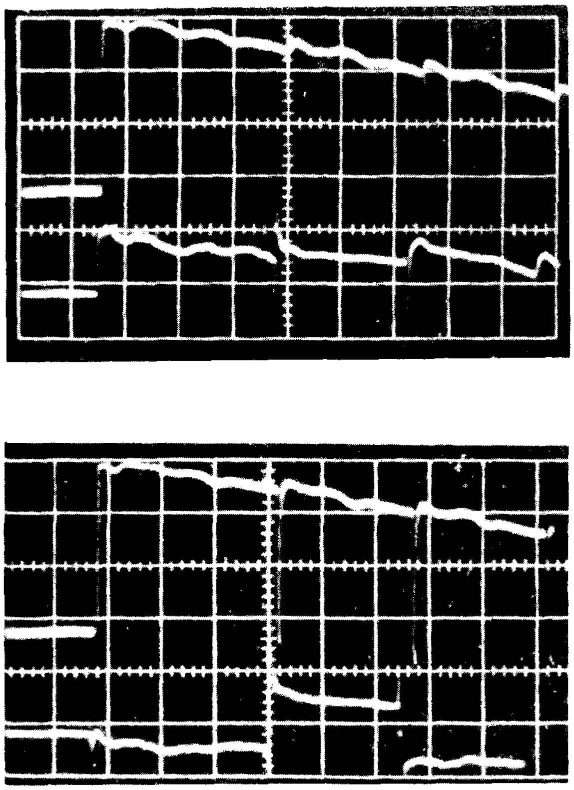

Fig. 2. Lower — uncorrected horizontal betatron oscillations at injection. Upper — corrected injection conditions.

MEASURING EQUILIBRIUM ORBITS

To determine an equilibrium orbit under injection conditions, that is a spiraling non-accelerated beam, the following procedure is used. Initially, the linac injector is reduced in intensity to about three milliamperes. At this current level the momentum spread can be considerably reduced and the emittance is small. The radius for injection is selected to allow the beam to spiral for 800 to 1000 μs. The vertical and horizontal betatron oscillations are minimized by the method described above.

The pair of signals from either the horizontal or vertical electrodes is fed in parallel into the two inputs of a dual beam oscilloscope. One channel is connected as a summing amplifier, the other as a difference amplifier. The two oscilloscope traces contain the amplitude and position information respectively. The start of the oscilloscope sweep is delayed so that the time interval under consideration occurs in the central portion of the screen. The pattern is photographed with a note being made of gain settings. The camera, which records on 100 foot roolls of 35 mm film, can take up to 20 or more sets of orbit pictures without reloading. The film is developed immediately after a run is completed and a projector setup enables us to measure the ratio of difference to sum signals. For any ratio of gain settings a numerical multiplier yields orbit deviations in centimeters. If there are betatron oscillations present, the difference pattern is visually averaged over several pulses. Fig. 3. The basic accuracy and reproducibility is about ½ mm. As a general rule the orbits are rechecked whenever a major shielding move is made or construction work is carried out in the vicinity of the ring.

If the orbits are desired at some time after injection, pictures are taken of the detected signal and the orbit positions can be determined at each pickup electrode location at any time during the cycle.

VERTICAL ORBIT CORRECTIONS [3]

The most recent use of the electrode system for equilibrium orbit analysis was to check on the behavior of the vertical orbit as a function of the currents through a newly installed set of vertical harmonic corrector coils. It has been known for some time that the low field vertical equilibrium orbit contained a strong twelfth harmonic component. This twelfth harmonic is superimposed on the normal ninth harmonic component. The twelfth harmonic arises from the twelve-fold periodicity of the magnet matrix. A set of coils was installed in 96 of the 144 two foot straight sections in eight series connected groups of 12 each. It was computed that 2 A flowing in each group would substantially reduce the twelfth harmonic component. When these coils were installed the vertical orbit was improved as shown in Fig. 4. The next step was to see if an unbalance in current in the eight groups would also reduce the ninth harmonic. As the third plot in Fig. 4 shows, this helped considerably. With large injected currents, when the apertu-

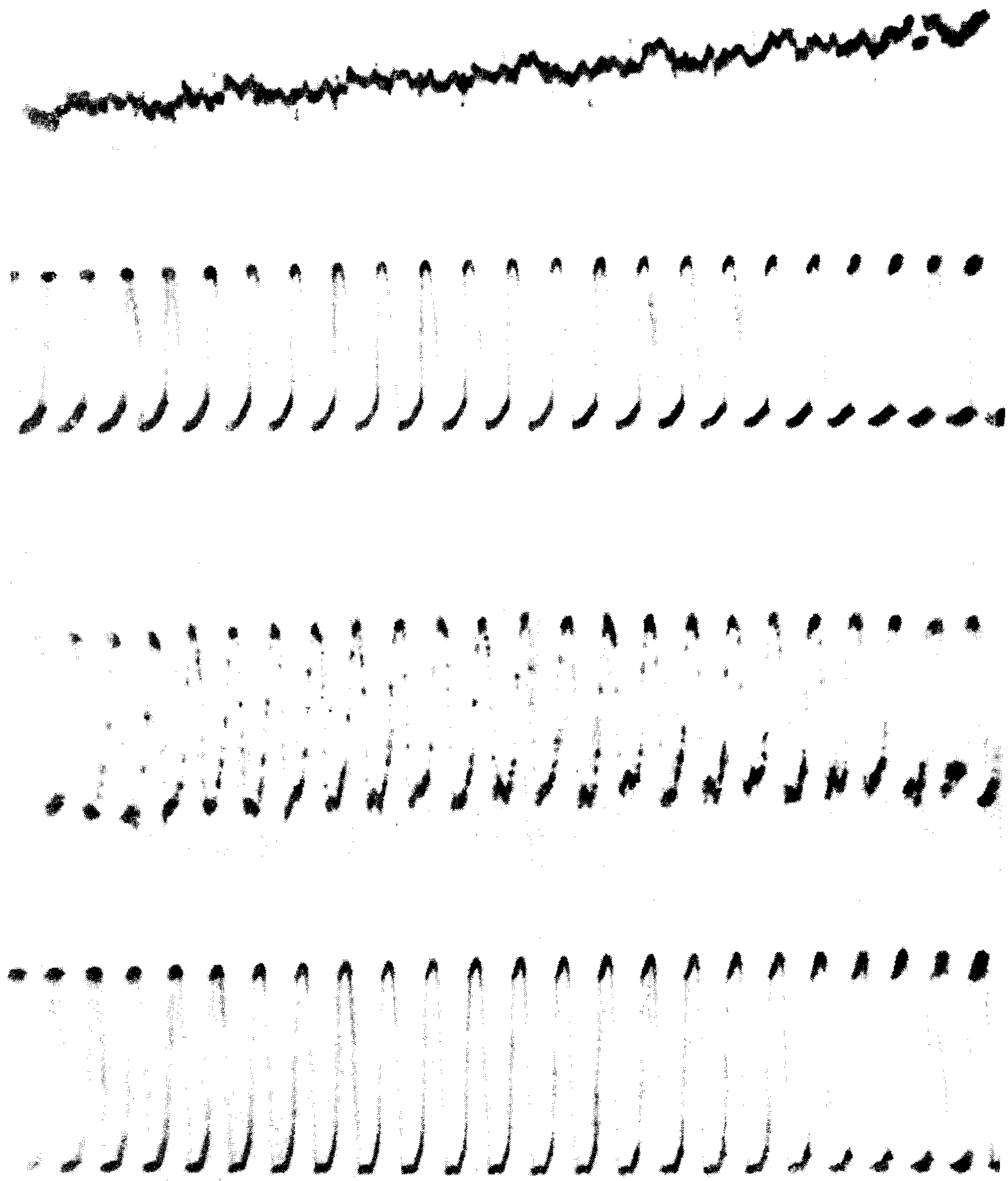

Fig. 3. Sum and difference signals, on two vertical electrode sets, used for orbit measurements.

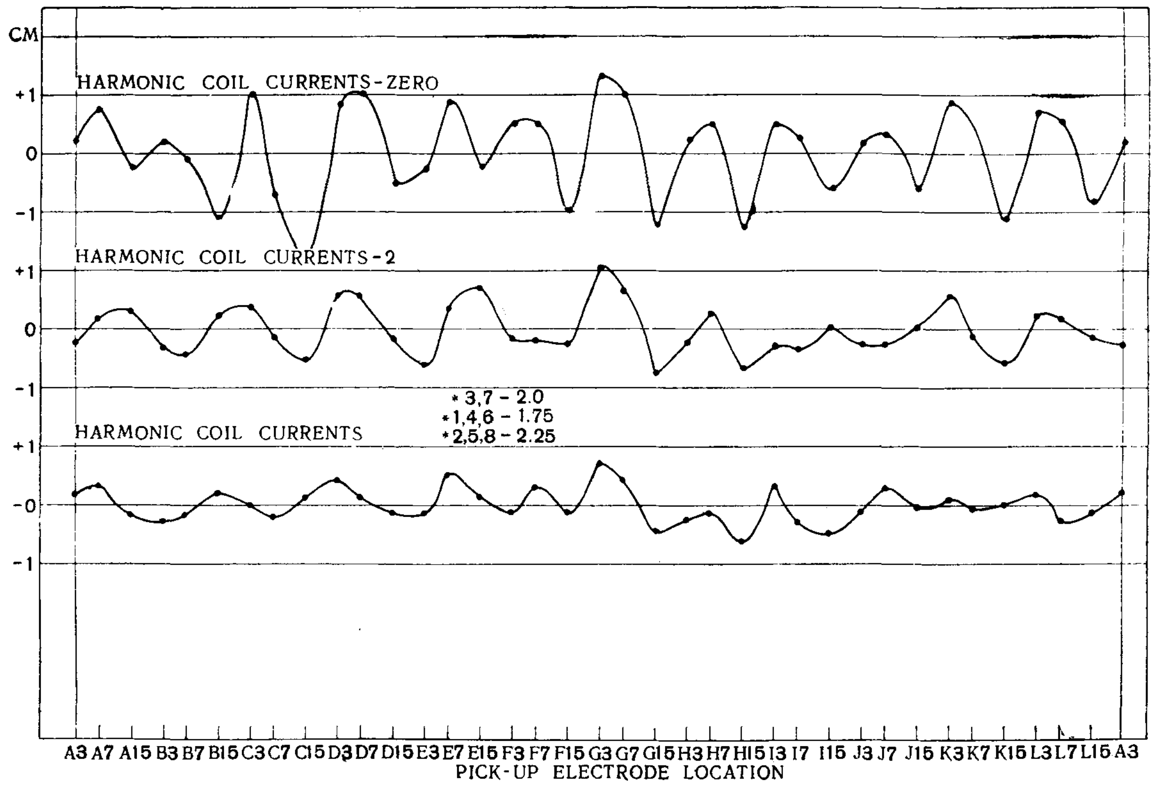

Fig. 4. Vertical equilibrium orbits corrected with harmonic coils.

re is filled, this correction noticeably increased over-all acceleration efficiency. Although the orbit is determined only at the discrete positions shown, a smooth curve has been drawn through the points.

RF SYSTEM ELECTRODES [4]

The special pickup electrodes for feeding the RF system are located in the ten foot straight section at E20. The sum electrode for frequency information is an aluminum cylinder 7 inches in diameter. The electrode signal is fed to a wideband cathode follower and then to a high frequency, low attenuation cable about 450 feet in length going to the control room. The system bandwidth to the main control room is greater than 50 MHz. Although RF information for the ring RF system needs only a few megacycles bandwidth, the wideband information can be used to view actual proton bunch chapes. Since near transition the bunches are only about 15 ns wide, a bandwidth greater than 50 MHz is desirable. The wideband sum signal is continuously displayed on the console and is useful for observing beam losses, beam shakeup and for rough beam sharing information. Fig. 5 shows the wideband signal on a high frequency oscilloscope.

The RF system radial pickup electrode is a diagonally cut cylinder. The signal is fed into the RF phase control for radius determination. For targeting purposes, variable capacitance silicon diodes can be gated in near the end of the cycle to act as a radius offset. The radial error signal inside the phase control loop is also continuously displayed and is used to set up the RF initial phase control, transition phase adjustment and the adjustment of the radius hold control or «integrator» [5].

BEAM INTENSITY MEASUREMENTS [6]

During normal operation the E15 observation pickup electrode, with only the cathode follower in the circuit, is used as a beam intensity indicator. A narrow band aplifier, set at the final RF frequency, extracts the funda-

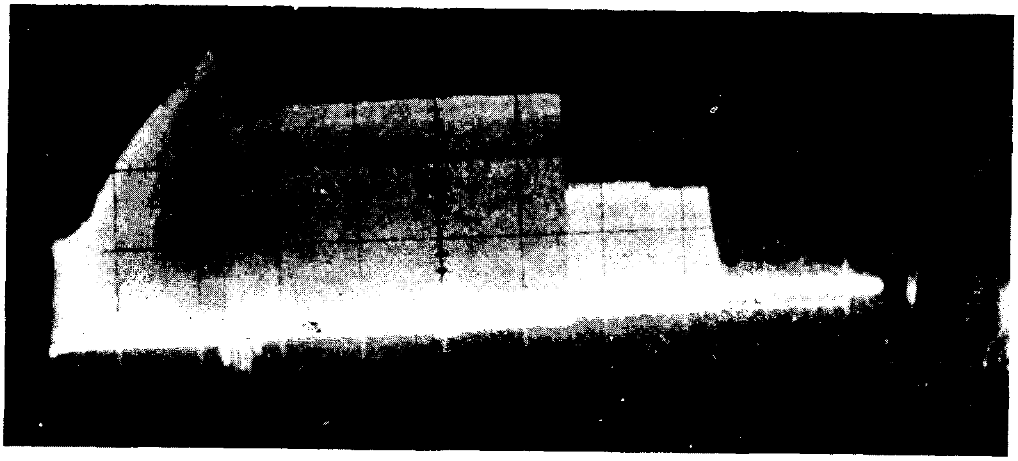

Fig. 5. Wideband pickup electrode signal showing beam sharing.

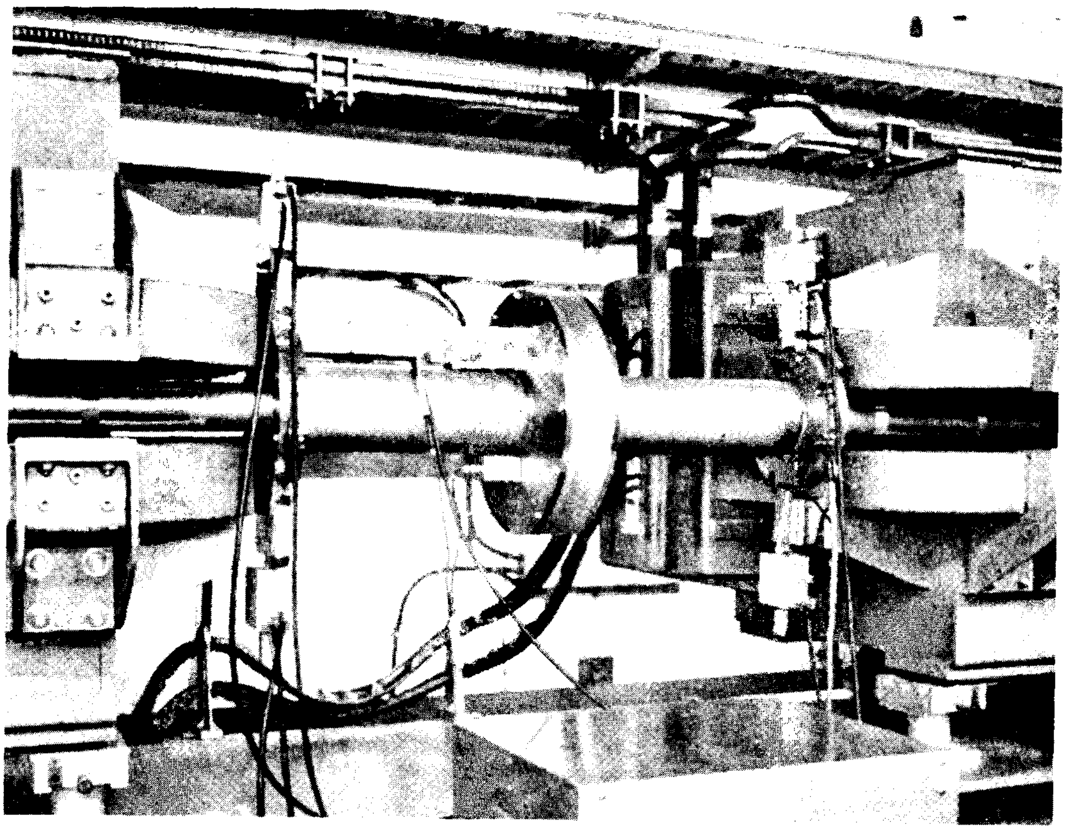

Fig. 6. Mounting of beam current transformer on ring.

mental component of the train of narrow pulses. This fundamental component is directly proportional to beam intensity. The basic calibration of the electrode was made with a wire measurement and takes into account end effects.

A ferrite core current transformer is also permanently installed at E15 and has been independently calibrated with a wire loop and fast rise current pulses. The two intensity measurements generally agree to 5% with the pickup electrode measurement reading higher than the current transformer. Fig. 6 shows the placement of the current transformer between the vertical and horizontal electrodes at the E15 location.

DETERMINATION OF ν [7]

Another determination which can be made using a pickup electrode as a detector is a precise measurement of ν values as a function of time and radius. In the long straight section E10 is a set of kicker coils which can be pulsed to perturb the beam either horizontally or vertically. The signal from a set of electrodes is fed into a high quality communications receiver. The intermediate frequency output of the receiver is then connected to an oscilloscope whose sweep can be initiated at any time during the cycle. The pattern on the oscilloscope shows peaks corresponding to the integral harmonics of the rotation frequency and side peaks representing the mixing of the betatron oscillation frequencies with the rotation frequency. The frequency values can be accurately measured and the differences of the ν value from an integral number can be computed.

By controlling the average beam radius as observed on another set of electrodes and by triggering the kicker coils at various times during the cycle the ν values, both horizontal and vertical, can be found. This setup also yields an accurate measurement of the beam rotational frequency during the cycle.

ACKNOWLEDGEMENT

The work reported here represents the efforts of many of the AGS staff people who are continually finding new methods of applying the AGS beam observation systems to solve existing problems and to expose new ones.

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DISCUSSION

A. A. Kuz'min

1. How is the frequency of the betatron oscillations during the entire acceleration cycle measured and in what manner?

2. In what manner is the intensity measured during a slow outward flow of the beam?

3. What is the minimum intensity which can be measured by the intensity measuring system of the AGPS?

M. Plotkin

1. Reference is given in the paper to be printed in the proceedings and is described in the proceedings. The reference is M. Q. Barton, RSI, **31**, 1290—1291 (1960).

2. At injection the linac can check the intensity along the injection path through a series of 3 or 4 current transformes. The last is near the inflector and can be compared to the calibrated pick up electrode or ring current transformer to check the efficiency of inflection and to measure the actual injected beam current.

3. The minimum beam current was about 10^8 protons/pulse when the machine was first turned on. We now attempt to achieve higher beam currents and have not checked to see how low in intensity we can go and still properly operate the machine.

S. M. Rubchinskiĭ

In the circuit for orbital displacement for signal electrodes, silicon diodes are used. It is interesting to know how the characteristics of these diodes are affected by radiation and how long they operate satisfactorily under these conditions.

M. Plotkin

The silicon diodes used to shift radius in the machine for target purposes are not set to a given bias value but instead for a given experiment the bias values are adjusted for proper targeting. In a given experiment we do not see any changes. Undoubtedly if we were to compare the characteristics of the diodes now to the values as originally installed, there would be a difference, but by setting up each run individually, these charges do not bother us.