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INTENSITY AND POSITION MEASURING SYSTEMS IN THE BOOSTER OF THE ZERO GRADIENT SYNCHROTRON*

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Summary

Soon the new booster for the Zero Gradient Synchrotron (ZGS) will be commissioned at Argonne. Three of its diagnostic systems will be described here: 1) the beam position system, 2) the toroid intensity measuring system and 3) the capacitive intensity measuring system.

Introduction

The booster is an alternating gradient synchrotron with a circumference of 43 m. Its vacuum chamber is approximately 10 cm x 5 cm. Protons will be accelerated from 50 to 500 MeV in 30 ms and then injected into the ZGS. The machine will operate at a 30 Hz rate.

Knowledge of the intensity and position of the proton beam is essential for a successful start up of the machine. The center of charge of the beam will be measured at six different locations around the booster ring. The locations are equally spaced around the synchrotron. The intensity will be measured by two completely independent systems, one sensing current, the other sensing charge.

Because of the anticipated high radiation levels from the booster, all of the solid state electronics will be located outside the radiation shield. Cathode followers will be used to transmit the electrode output voltages to the processing electronics. Although requiring more hardware, this arrangement should make troubleshooting somewhat easier.

Beam Position System

Position electrodes will be located in each of the six short straight sections of the booster. Fig. 1 is a drawing of the electrode and Fig. 2 is a drawing of the inner electrode surfaces. Sixty mil ceramic spacers are used to separate the inner electrode surfaces from the surrounding stainless steel box. 1/4 in x 40 mil brass straps are used to transmit the induced signal from the triangular plates to the covar socket used to penetrate the vacuum chamber. The remainder of the electrode is made of stainless steel. The capacitance from each plate to the surrounding box is 44 ± 1 pF. The LC resonant frequency of each plate as measured at the output connector is 54 MHz.

Protons passing through the electrode will induce a RF voltage on each of the triangular plates. The amplitude of the voltage on any one plate will depend on the position of the proton beam. Cathode followers will drive these signals to electronics located above the booster enclosure. Here the RF signals will be integrated to give four analog voltages (~70 μs response time). The position signals will be produced according to the following formulas:

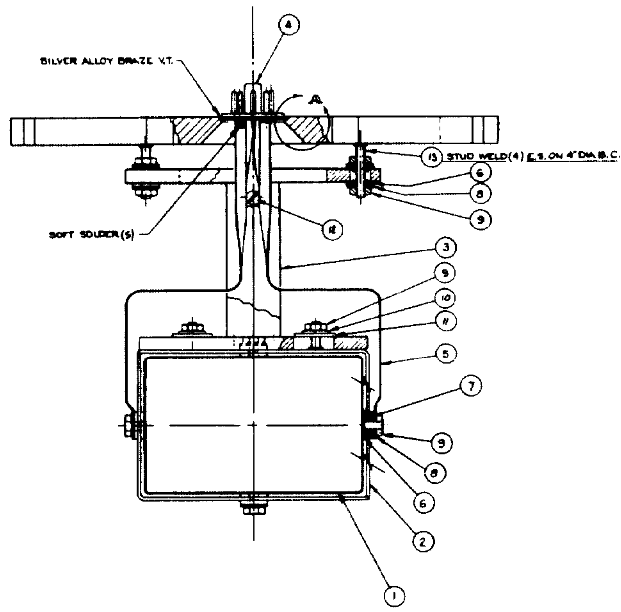

Fig. 1.
① Inner Electrode Surface
② Supporting Box
④ Octal Output Connector

$$\text{Vertical position} = C_v \frac{(V_a + V_b) - (V_c + V_d)}{V_a + V_b + V_c + V_d} \qquad (1)$$

$$\text{Horizontal position} = C_h \frac{(V_a + V_d) - (V_b + V_c)}{V_a + V_b + V_c + V_d} \qquad (2)$$

where

V_a is the analog voltage derived from plate A

V_b is the analog voltage derived from plate B

V_c is the analog voltage derived from plate C

V_d is the analog voltage derived from plate D

C_v and C_h are scale factors.

The twelve position signals will be transmitted to the main control room where they can be displayed on an oscilloscope. In addition, any position signal can be sampled at an operator selected time during the acceleration cycle. The amplitude of the signal will be scaled and displayed digitally in centimeters.

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A ten sample average of the position can also be displayed. When the computer interfacing and software expands, we will be able to sample all of the positions simultaneously and plot the proton orbit on a large CRT.

The beam position system will enable us to observe the position of the proton beam throughout the acceleration cycle. This will allow us to detect and eliminate losses due to beam position and to determine various machine parameters.

Associated with one position electrode is an electronic package designed to give bunch frequency position information. High speed differential amplifiers are used to generate two signals defined by the following formulas:

$$\nu_v = C_1 (\nu_a + \nu_b) - (\nu_c + \nu_d) \qquad (3)$$

$$\nu_h = C_2 (\nu_a + \nu_d) - (\nu_b + \nu_c) \qquad (4)$$

where

ν_a, ν_b, ν_c and ν_d are the instantaneous voltages on plates A, B, C and D. (Fig. 2)

C_1 and C_2 are scale factors.

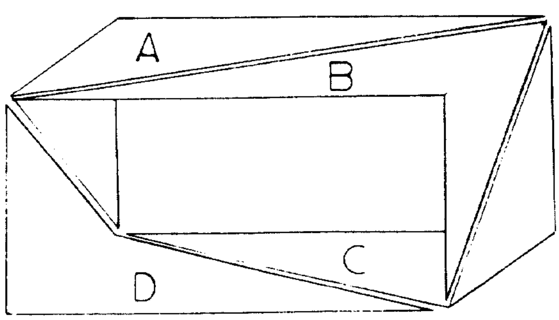

Fig. 2.
Inner Electrode Surfaces

The two output signals are functions of beam position and beam intensity. They will be used to observe high frequency position changes, betatron oscillations and magnetic field conditions at injection. A very similar system is currently in use at the ZGS.[1,2]

Toroid Intensity Measuring System

A 10.75 in ID Pearson toroidal transformer will surround the booster vacuum chamber in one of its straight sections. Protons passing through the toroid will cause a voltage to appear on the output. This signal will be amplified and integrated to provide an analog voltage proportional to the proton beam intensity and velocity. This voltage will be divided by a voltage proportional to the frequency of the accelerating cavity, in order to compensate for the velocity increase during acceleration. The resulting signal will be proportional to beam intensity.

The toroid has a transfer function of 50 MV/A into a 50 Ω load and a 20 μs response time. Its output is connected through 50 ft of 50 Ω cable to a 37 dB amplifier located on the roof of the booster enclosure. A voltage proportional to the average differential output voltage of the amplifier is generated by the electronics. This signal is then normalized to the RF cavity frequency as noted above. The resulting output signal has a 100 μs response time and an amplitude of from 0 to 10 V. This analog signal will be available in the main control room for oscilloscope display. A digital readout of the intensity will also be derived from this signal. The sample time for the digital display will be chosen by the operator. The readout can be updated every booster cycle or a ten sample average of the intensity can be shown. Although the toroid can have a dc voltage component on its output for a short period of time, only the time varying portion of the signal will be amplified. Therefore, only the protons under the control of the RF cavity will have a significant effect on the measured intensity level.

The RF output from the 37 dB amplifier will also be transmitted to the main control room. This signal will be used to observe the bunch shape during acceleration and to determine the phase of the RF cavity relative to the beam bunch.

Capacitive Intensity Measuring System

A second intensity measuring system will use the charge induced on a capacitive electrode as the source of information. Protons passing through the electrode shown in Fig. 3 will induce a voltage on the inner surface relative to the surrounding metal. By choosing

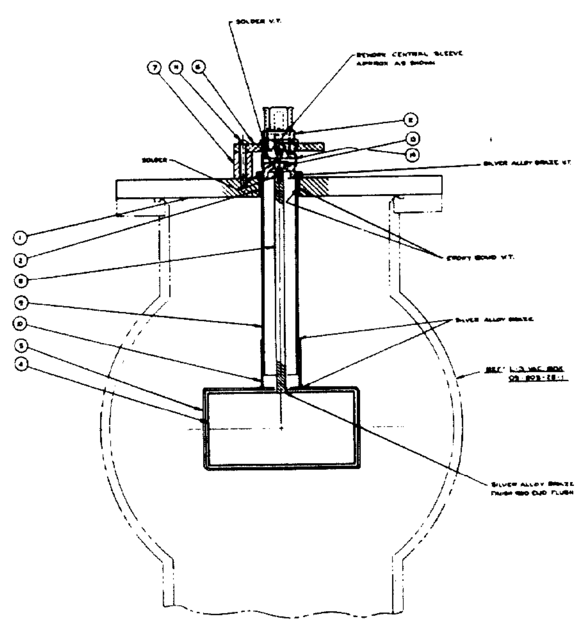

Fig. 3.
Capacitive Electrode

an appropriate load resistor, the output voltage will accurately represent the azimuthal proton concentration as a function of time. The electrode should not be able to charge appreciably in the time it takes a bunch to pass through it, but should be able to fully discharge faster than the desired response time of the system. The capacitance of our inner electrode surface to the surrounding box is 200 pF and the load resistor is 10 kΩ. The LC resonant frequency of the electrode as measured at the output connector is 44 MHz.

A cathode follower is connected directly to the output of the electrode. It drives the RF signals through 50 ft of cable to the electronics located on the roof of the booster enclosure. There an analog signal proportional to the average differential output voltage of the electrode will be produced. This will be the intensity signal. Its amplitude will be sampled at three times during each booster cycle. The scaled voltages will be displayed on digital readouts in units of intensity. The sample times can be changed by the operator. The analog signal will also be available for observation. The amplitude of the intensity signal is 0 to 10 V and the response time is 100 μs. The system is linear for intensities between 10^{11} and 5×10^{12} protons per pulse.

Since the electrode is capacitive, only time varying proton concentrations will cause an output voltage. Thus, the proton bunching due to the RF cavity will cause an RF signal on the output. Protons not captured by the RF system or those that become debunched during acceleration will not have a substantial effect on the output voltage.

Expected Signal Levels

With 10^{12} protons in the booster, the peak to peak output voltage from the capacitive electrode should be approximately 2 V. The average signal from the position electrode plates should also be 2 V. This is because the ratio of surface area to capacitance of the plates is equal to that of the capacitive electrode. With the RF cavity at 2.2 MHz and 10^{12} protons in the machine, the peak to peak toroid output should be 60 mV. At 5 MHz, this voltage will rise to 140 mV.

References

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2. C. W. Potts and F. R. Brumwell, "The Zero Gradient Synchrotron Closed Orbit Position Monitoring System," IEEE Transactions on Nuclear Science (June, 1971), Vol. NS-18, No. 3, p. 918.