PB01

LONGITUDINAL EMITTANCE MEASUREMENT FOR 433 MHZ PROTON LINAC

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Abstract

We are developing a new device to measure the longitudinal emittance of the proton beam accelerated by the Alvarez linac. For the longitudinal emittance measurement, the simultaneous measurement of the phase and energy is required. The protons scattered by a gold target placed on the beam line are deflected by an RF electric field and detected by a position sensitive detector (PSD). We can reconstruct the phase and energy of the protons on the target by the position and energy information from the PSD.

1. Introduction

The information of the longitudinal emittance may be useful for the understanding of the operation condition of the linear accelerator. But it has not yet been measured for the high frequency proton linac. There are two difficulties in this measurement. At first, the simultaneous measurement of the phase and kinetic energy of the beam requires very careful treatment. Secondly, the phase measurement requires a high time resolution.

The longitudinal emittance measurements for the H^- beam using the laser neutralization technique were studied at Los Alamos laboratory [1,2]. They neutralize the H^- beam by the short pulsed laser for the time slice of the beam, and separate them by the dipole magnet. Then the energy distributions of the neutralized beam are measured. But this technique cannot be used for the proton linac.

The measurements of the phase distribution for the proton beam were studied by some laboratories [3,4]. They developed such devices as detect the secondary electrons emitted from the biased thin wire target and deflected by an RF electric field. Only a part of the beam in the short time region sliced by this RF shutter are detected with the Faraday cup. The time distribution of the secondary electrons obtained from this monitor is well considered to have the same longitudinal structure as that of the original beam. This device has a good phase resolution, but cannot measure the kinetic energy of the proton beam.

We have been developing the new longitudinal emittance monitor which detects the phase and energy of the proton simultaneously since autumn in 1994 [5]. A focusing system using permanent magnets has been studied in order to decrease the RF voltage of the deflector and increase the phase resolution. The mechanical design of this new measurement system and the fabricated devices are described.

2. Measurement System

The longitudinal emittance monitor mainly consists of five parts: Au target, RF deflector, permanent-magnetic quadrupole-lenses (PMQ), position sensitive detector (PSD), and the circuit system. The schematic view of the monitor is shown in Fig. 1.

The 7MeV proton beam from the Alvarez linac is scattered by the narrow Au strip target. Some protons scattered to the 90 degree go through the thin slit and the PMQs. The PMQ1 and PMQ2 focus the protons to the PSD. Then the particles are deflected horizontally by the RF deflector whose RF frequency is the same as that of the Alvarez linac. The deflection angle mainly depends on the RF phase when the protons go through the RF gap. The PMQ3 enhances the deflection angle. Then the position and the energy of the protons are measured by the PSD. The yield of this measurement is estimated to be about 23 counts/s at the peak beam current of 1 mA with the pulse width and the repetition of 60 μs and 180 Hz, respectively. The signals from the PSD are amplified and A/D converted in the circuit system. The raw data are accumulated in the personal computer. The longitudinal emittance can be reconstructed by this position and energy distribution data.

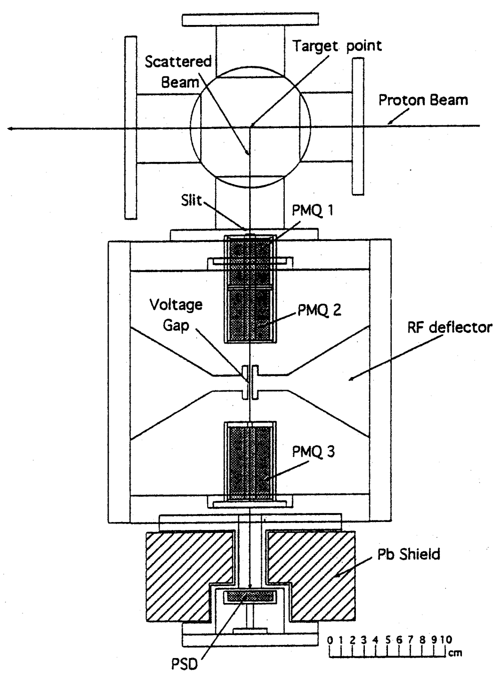

Fig. 1 Schematic view of the longitudinal emittance monitor.

3. Simulation of the system

Simulations of this measurement have been performed to determine the parameters of the system. The optimization factors are the RF voltage, the deflection angle and the position resolution on the PSD. The calculated positions on the PSD as a function of the original position in the bunch applying the decided device parameters are shown in Fig. 2.

The initial longitudinal distribution of the proton beam is assumed to be uniform in a rectangular phase space. The phase spread is ± 90 degree and the energy spread is ± 100 keV. The position X on the PSD depends on the longitudinal position Z0 and the kinetic energy. Because the deflection voltage is sinusoidal, the X is not proportional to the Z0. The spread range on the PSD is about 12.6 mm.

The position data which shows the initial phase value have errors, because of the energy spread and the finite size of the target and slit. This spread limits the phase measurement resolution. We estimated the error less than 4.5 degree assuming the energy resolution of the PSD as 40 keV.

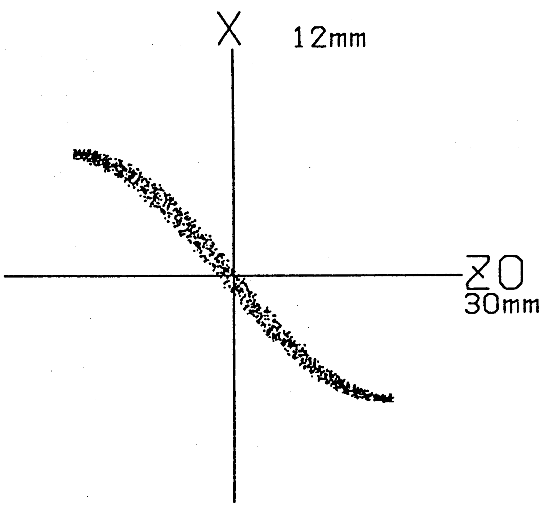

Fig. 2
The simulated positions of the protons on the PSD for the rectangular longitudinal phase space distribution. Z0 means the longitudinal position at the target and X is the position on the PSD.

4. Target

The target is located at the 20 cm downstream from the Alvarez linac. The narrow Au strip target is evaporated on the thin carbon foil whose thickness is 20 $\mu g/cm^2$. The deposited area is 0.7 mm × 3.0 mm and the Au thickness is 0.1 μm. The target should be set on the straight line passing centers of the PMQs. The alignment error should be less than 0.1 mm to obtain enough measurement accuracy. The angle between the accelerated beam direction and the normal line to the target plane is 20 degree. In this way, the area of the Au viewed from the PSD are reduced to nearly 0.2 mm × 3.0 mm, and the scattering cross section becomes large. The mean energy loss in the target is 9.8 keV that is not small enough but compromised value with the yield.

The proton beam is scattered by the Au on the target and is also scattered by the carbon film. The protons scattered by the contamination material in the target can be separated by the kinetic energy of the scattered protons, because the kinetic energy of the proton scattered by Au is 6.93 MeV, and one by carbon is 5.91 MeV.

5. Cavity

The RF cavity produces the electric field which deflects the proton scattered by the target. The deflection cavity is shown in the photo 1, and the specifications of the cavity are shown in Table 1. The inner conductor is tapered in order to increase the shunt impedance. The resonant frequency is tuned by a ϕ34 mm plug tuner with 30 mm moving range. The folders of the PMQs are fixed before and after the voltage gap. The unloaded Q and the shunt impedance are evaluated as 12680 and 4.69 MΩ, respectively by the 3-D field calculation with the MAFIA code. The measured resonant frequency of the fabricated cavity was 420 MHz which is lower than design value. Then the electrode gap was enlarged from 4.0 mm to 4.65 mm for tuning. The Q value was measured to be 7010 after the resonant frequency was tuned to 433.0 MHz. The design value of the electric field is 116 keV/cm. The high electric field is desirable for the better resolution of the phase measurement. But the high electric field needs a high power source. We estimate the necessary power as 1.1 kW by the measured Q value and the calculated Z/Q. We tried the high power test and more than 1.1 kW peak power could be supplied.

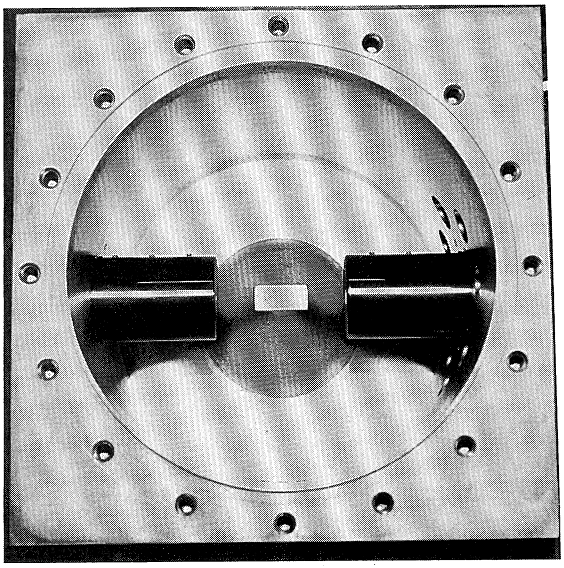

Photo 1 RF cavity for deflecting the protons. The rectangular one seen in the center is an 30 × 14 mm^2 electrode for deflection gap.

Table 1
Specifications of the RF cavity.

frequency [MHz]	433.0
unloaded Q	7010
electrode gap [mm]	4.65
electrode length [mm]	30.0
electrode height [mm]	14.0
outer conductor diameter [mm]	200
inner conductor maximum diameter [mm]	100
inner conductor minimum diameter [mm]	14
outer conductor height [mm]	210
inner conductor height [mm]	106
outer conductor material	Aluminum with Cu-plated
inner conductor material	Copper
shorting plate material	Copper
design gap voltage [keV]	54.0
necessary peak power [W]	1100

6. PMQ

The permanent magnetic quadruples (PMQ) are set to the holders in the RF cavity. The PMQ is assembled from the eight trapezoidal magnet pieces made of Nd-Fe-B (NEOMAX-41H). The PMQs installed in the holder is shown in photo 2. The specifications of the PMQs are given in Table 2. The PMQ1 and PMQ3 defocus the protons, and the PMQ2 focus them horizontally. The PMQ3 enhances the deflection angle. The 0.1 mm $\times$ 3.0 mm slit is located on the front cover of the PMQ1. The slit is made of the four pieces of 0.2 mm tantalum plates.

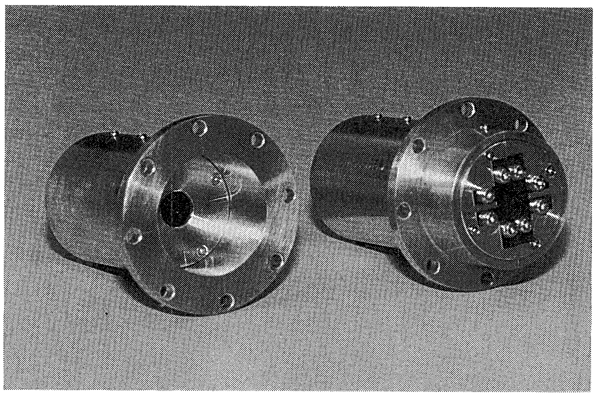

Photo 2 The PMQ folders. Right one has PMQ1 and PMQ2, and left one has PMQ3. The folders are made of copper-plated stainless . The tantalum slit is attached on the PMQ1.

Table 2
Specifications of the PMQs.

PMQ - No.	1	2	3
Bore diameter [mm]	10	10	12
Numbers of the Segments	8	<--	<--
Height of the segment [mm]	9.18	9.18	8.18
Lower base of the segment [mm]	11.75	<--	<--
Upper base of the segment [mm]	4.14	4.14	4.94
Field gradient [kG/cm]	-19.5	+19.4	-14.8
Length [mm]	43.0	43.0	45.0
Material	Nd-Fe-B	<--	<--

7. PSD and circuit system

The PSD (IPP 1508-500) is a Si charged particle detector with PN junction, whose front surface is P-type semiconductor and back side is N-type semiconductor. There are two contacts on the surface side edges, and the resistance between them is about 10 kΩ. The bias voltage is + 80 V to the backside N-type semiconductor. The one connector on the P-type side is grounded, and another connector is the output of the signal proportional to the position and the energy. The connector for the N-type side is the output of the signal proportional to the energy. Therefore the position is given by the ratio of the two signals. The area of the PSD is 8$\times$15 mm^2, and the position resolution is 0.15 mm. This detector is set at the 75 mm from the exit of the PMQ3. For decreasing the X-ray from the Alvarez linac, we set the Pb shield around the detector. Two magnets are also used for sweeping out the electron cloud coming from the deflection cavity.

The circuit diagram for the signals from the PSD is shown in Fig. 3. The two signals from the PSD are amplified and A/D converted to 13 bits. The timing of the event in the 60 µs of the RF macro pulse is also measured. We can know the time dependence of the longitudinal emittance in the RF macro pulse. The outputs of the three A/D converters go to personal computer and the raw data are memorized. The data taking program is KODAQ [6] which is a flexible data acquisition system based on NEC PC-9801 distributed by Institute for Nuclear Study (INS), Univ. of Tokyo. The histograms of the three ADC-outputs and two-dimensional scattered plots for the ADC-outputs of the position and energy signals can be seen on the graphic display by using this program.

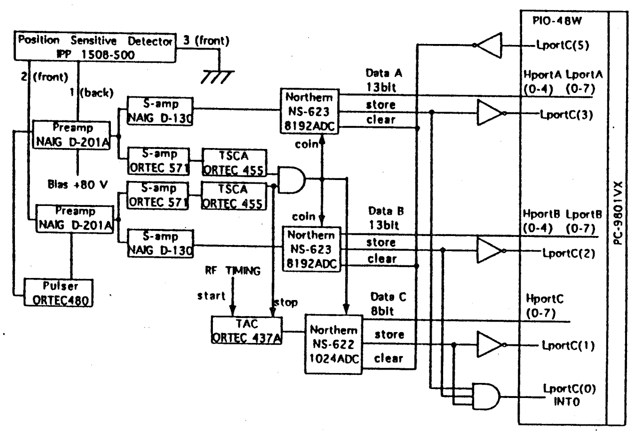

Fig. 3 The circuit diagram for the data taking system.

8. Acknowledgments

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