RESIDUAL GAS IONIZATION BEAM PROFILE MONITOR ON 40MeV H^- BEAM TRANSPORT LINE

Xu Weipeng (徐伟鹏)
(*Institute of Nuclear Research, the Chinese Academy of Sciences, Shanghai 201800, China*)
and E. Takasaki
(*National Laboratory for High Energy Physics (KEK), Japan*)

ABSTRACT

The monitor is composed of a pair of electrodes, a single stage of microchannel plate, a phosphor screen, a CCD camera and a PC computer. To obtain a good uniform collecting field, forming electrodes system is used instead of that with a resistive divider. The readout system is performed by the phosphor screen and the CCD camera because the spatial resolution is not limited by the mechanical structure like the anode strip type and such video display system is very useful for beam studies and operation of the 40 MeV linac. Besides, the design and test results are described in detail.

Keywords On-line measurement systems, Beam monitors, Hydrogen 1 minus beams

1 INTRODUCTION

In order to investigate the utility of the non-destructive profile measurements on the 40 MeV H^-beam transport line[1], we have designed and constructed the non-destructive beam profile monitor (NDPM), which uses ions/electrons created by the beam traversing the residual gas in the vacuum pipes. This monitor is composed of a pair of electrodes with a mesh, a single stage of a microchannel plate (MCP), a phosphor screen with a thin aluminium layer, a CCD camera and a PC computer. This report presents the design and test results of this monitor and discusses its utility.

2 FIELD SHAPING ELECTRODES

The Schematic of NDPM is shown in Fig.1 When the ionization process method is used to design NDPM, the following principles must be kept for getting an accurate beam profile: the ion or electron density created by ionization process should be in proportion to the accelerated beam density; the collecting electric field should be strong enough so that the trajectory of ions or electrons is not disturbed by the electro-magnetic field produced during ionization process.

According above requests, a variety of electrodes could be employed to collect the ions or electrons generated by the prime beam. For our case, as the good quality of resistors with less outgas could not be got at that time, so the field shaping electrodes were designed to eliminate the resistive divider, which is normally used to grade the voltage and provide a flat electric field region. A 100 mm clear aperture of the electrodes

Manuscript received date: 1994-12-20

is required by some persons' demand who work at the 40 MeV beam transport line. For getting more uniformity area the electrodes should be like bowls with 25 mm deep i.e. one quarter of the distance between two electrodes[2]; and the length of electrode is 200 mm and the width 100 mm along the direction of the prime beam with a 50 mm gap between tips of bowls as seen in Fig.1. Titanium was painted onto surface of the electrodes. It plays an important role to avoid cold emission phenomena from the electrode because the high voltage should be supplied on the collecting electrodes.

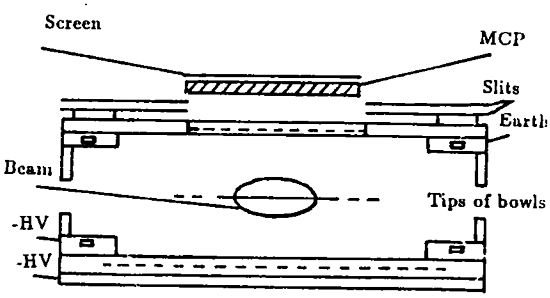


Fig.1 Fundamental plan of NDPM

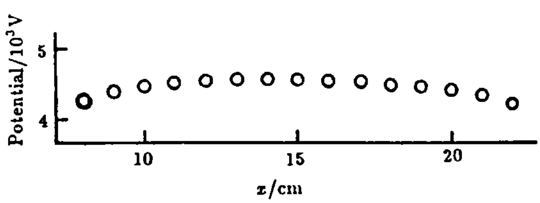


Fig.2 Potential values cross the direction of the prime beam

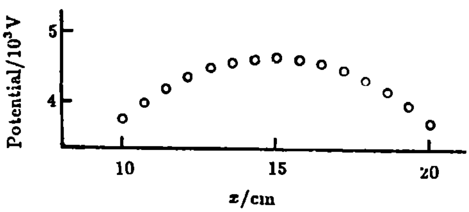


Fig.3 Potential values along the direction of the prime beam

Fig.2 shows a plot of the potential values calculated by a POISSON program. From this figure it seems that it is flat enough for collecting ions or electrons and will not produce some distortion of the beam profile image. But along the direction of the prime beam the distribution of the equipotential lines is not so uniformity, one can see from Fig.3, it will produce a calibration error.

In order to consider above second principle and simplify the following assumptions were made. First, assuming that the charge distribution in one bunch is a Gaussian type with a normalized constant which corresponds the beam intensity to be 5 mA; then assuming that the transversal and longitudinal charge distributions in the beam are uniform. Under these over-assumptions, the error of transversal beam size due to the effects of the electromagnetic fields produced by the prime beam would be about 0.1 mm, when the voltage supplied to the collected electrodes is 10kV.

The length of the collecting electric plates in the direction of the accelerated beam is 100 mm and the clear gap distance is also 100 mm. When the voltage supplied to the plates is 10 kV, the deflecting angle of the prime H^--beam is about 0.065 mrad and the position error is several μm. These values are not large and can be negligible, when the perturbation on the prime beam is considered.

At 3.5 mm above the HV electrode a metal screen (90% transparency) is covered for preventing against second electrons emitted from the HV electrode when ions or electrons produced during ionization process strike against it; and the "to earth electrode" is also completed to enclose with a some metal screen that prevents electrostatic coupling of false signals from the prime beam.

3 SPATIAL AND TIME RESOLUTIONS

As is well known, there are two types of detection electrodes for the NDPM: one is strip electrode and the other is beam viewer.

Spatial resolution of the strip electrode is determined by ratio of the strip electrode to beam size and the analog or digital data processing. So the strip electrode width is determined by the beam size and accuracy required.

Our optical system consists of a single VCL-S06XEA lens for first test and VCL-S12XEA lens for second one with a focal length of 6 mm and 12 mm, respectively. By using the latter lens good spatial resolution is obtained over the entire area monitored by the television camera. A picture resolution of 320×240 lines is used when the video signal is converted to the CPU area. Spatial resolution is about 0.8 mm/point. For the second test horizontal spatial resolution is 0.34 mm/point, vertical one is 0.36 mm/point, respectively. If the CCD camera, CPU and the others will be improved, the spatial resolution will be less than 100μm/point.

In the detection electrode with strip anode, time resolution must be limited by the bandwidth of the associated electronics circuit. However, the time resolution using beam viewer is limited by the television camera sweeping rate. In our case decay time of fluorescent screen P-20 is maximumly 2000 μs and the computer has 30 frames/s. For our case the time resolution is not so important, since a frequency of H^- beam from the output of the 40 MeV Linac is 20 Hz.

Between both types of the detective methods, the beam viewer system is more suitible for our case because of the good spatial resolution.

The collection (transit) time to accelerate electrons to detector, neglecting coulomb forces and initial energies, is about 3.8~2.0 ns under 4~15 kV collecting field strength. So the transit time can be neglected when considering time resolution.

4 TEST RESULTS AND DISCUSSION

4.1 Collection of ions

When the KEK-PS accelerator ran routinely, the test was taken by our monitor. Measuring condition is as follows: intensity of H^- beam is 5 mA; pulse width 60 μs; voltage on the MCP-out +700 V for B, +750 V for C; voltage on the collecting electrode (V_p) +10 kV; voltage on the fluorescent screen (V_s) 3.5 kV.

The result was that the whole-width of the primary H^- beam is approximately 6 mm measured at the 50% brightness. This results coincided with the results measured by other beam profile monitor located upstream at the distance of 20 cm. In the centre of the beam image there are 90% brightness then toward outside the brightness of 50%

and 10%, respectively. The corresponding beam profile measured by collection of positive ions is shown in Fig.4.

4.2 Collection of electrons

By changing the sign of the collecting field, electrons generated by ionization process are accelerated to the MCP. Measuring condition is as follows: voltage on the MCP-out is +475 V for B, +500 V for C; V_p −7.7 kV; V_s 3.1 kV.

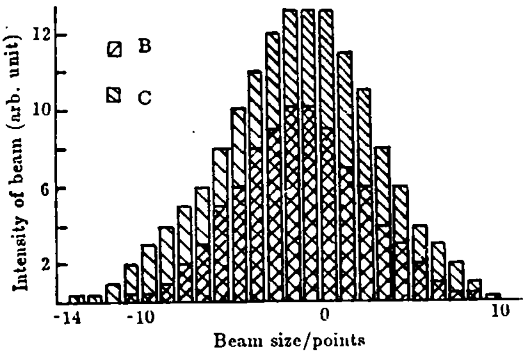


Fig.4 Beam profile measured by collection of positive ions

The measured whole-width of the primary H^- beam is about two times as large as the results measured for collection of ions, *i.e.* about 12 mm measured at the case of 50% brightness. We guess that it is a part reason of an increase in the measured profile width that electrons get the transverse energy much larger than positive ions to get one during ionization process. This scatter error is produced by the transverse energy. Occasionally, some electrons are produced by striping the primary H^- beam. All these undesired electrons enter the central ionization region between two collecting electrodes and at last get into the MCP. Therefore, an additional signal is increased.

To sum up, although a larger signal is obtained with collected electrons, as the poor spatial resolution of collecting electrons may be due to secondary electrons and transverse momentum component of the electrons, collecting ions for the image signal would be prefered only for now.

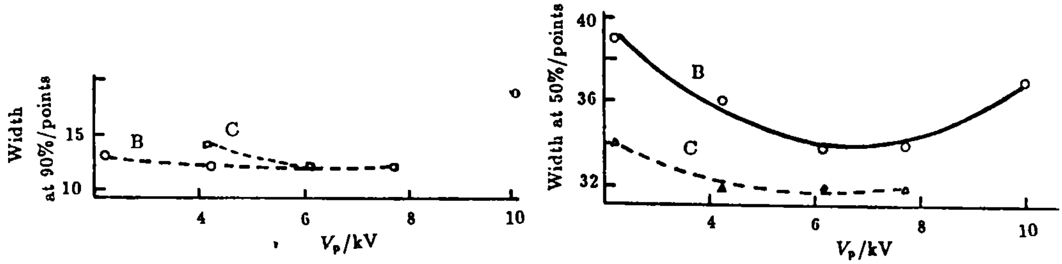
4.3 Experiments about the characters of NDPM

Experiment illustrates that the brightness adds almost monotonously with the voltage on MCP from 400 to 550 V. The higher V_p and V_s are, the brighter the signal is, of cause, within the reasonable range.

Other relations between the widths of the beam profiles at 90% and 50% of the brightness; and V_p are shown in Figs.5,6. From Fig.5 one can understand that the width of the beam profile at 90% of the brightness is the same size in a wide range of the voltage on the collecting electrode and with some different conditions about the voltage on MCP and the phosphor screen. But one point at 10 kV on the collecting electrode the beam width became too big. It may be caused by a saturation effect of the detecting system.

As for the width of the beam profile at 50% of the brightness is shown in Fig.6, they are almost the same size between the voltages of 4 kV and 8 kV on the collecting electrode within a permissible erroneous tolerance of the detecting system. When the collecting field is small, the measured beam width will become large than the real beam width. The increment comes from the collecting field.

But one experiment of them should be emphasized. When V_{screen}=3.91 kV, $V_{MCP-out}$ = 500 V, V_{MCP-in} = 0 V, V_{slit} = 0 V, V_p = −7.72 kV; and V_{screen} = 3.91 kV, $V_{MCP-out}$ = 0 V, V_{MCP-in} = -500 V, V_{slit}=0 V, V_p=-7.72 kV; we have measured maximum brightnesses in both cases. At last, the maximum brightness for first case is 144, and for second case 160, respectively. It means that the output charge of MCP with the gain of the phosphor P-20 has small difference only.



Figs.5,6 Widths of the beam profiles at 90% and 50% of the brightnesses vs V_p one by one

V_{MCP}=500V, V_s-V_{MCP}=3.41kV for B; V_{MCP}=463V, V_s-V_{MCP}=3.45kV for C

This experiment does not agree to some explanation as some references[3,4] said that the MCP output charge produced from electrons was observed to be 7 or 8 times larger than the charge produced from positive ions (this is true indeed). But they explained this phenomenon that some of the secondary and tertiary electrons which they have been produced from primary electrons striking the MCP surface between microchannels, reenter into the MCP as additional signal. This is main reason for the increment of 7 or 8 times of the MCP output charge. We did not find that such explanation can be persuaded. But we do not doubt the correctness of 7 or 8 times larger on this event.

4.4 Liberated electrons with more energy

As known, the ejected electrons produced by collision between the gas molecules and protons have an energy distribution which extends into the tens and hundreds of electron volts. But it was found that over 90% of the electrons had an energy of less than 10 eV. The most probable energy was a few eV. It was verified through an experiment[5].

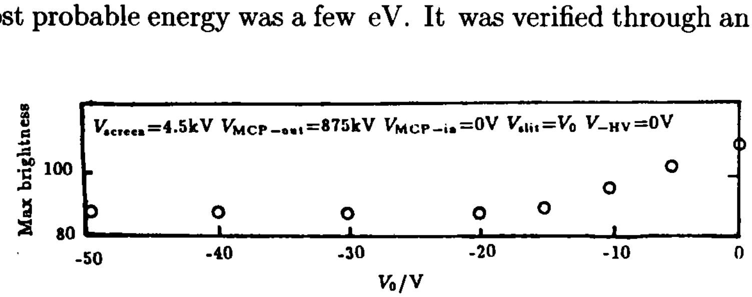


Fig.7 Electrons with enough high energy

In our test much more electrons created by H^- beam have enough high energy distribution, where the effect of the voltage produced by the charge of electrons on the electrode is also included. It is shown in the Fig.7.

4.5 Shift of the image-center of the beam profile

The special phenomenon is that the image-center of the beam profile measured by NDPM moves in the distance of 17 mm from the center of the detecting system, when the voltage was not supplied on the electrodes. This may be explained by the charge distribution on the electrode. The small electric force lines may be produced unsymmetrically by such charge distribution and then electrons move along the nonuniform electric lines. So the image-center of the beam profile has been shifted. But when the electric voltage was supplied on the collecting electrodes such effect was not acted on and was not measured.

5 SUMMARY

A beam profile monitor based on the principle of ionization in the residual gas has been designed, constructed in the 40 MeV H^- beam transport line. The beam profiles by the detection of the positive ions and of the electrons have been measured. The width of the primary H^- beam collected by positive ions coincided with one measured by other beam profile monitor. But the width measured by electrons for some H^- beam is more large. And some different phenomena and results for the negative hydrogen beam with 40 MeV have been found. All these are very interested and more time is needed to understand and investigate.

General speaking, nondestructive beam monitor is an useful diagnostic tool for studies and operations of accelerator. On principle, the NDPM provides continuous on-line measurements of the beam parameters which were previously difficult or time consuming to determine on the 40 MeV transport line. In conjunction with a computer, our monitor can be expanded its function.

ACKNOWLEDGEMENT

We would like to thank Prof. M. Kihara and Prof. I. Yamane for their continuous encouragement and the best of case; and greatly appreciated the fruitful discussions with Dr. T. Kawakubo and Dr. T. Adachi and also indebted to Drs. T. Takenaka, K. Nanmo, T. Kubota for helps in the experiments.

REFERENCES

1 Igarashi Z. Proceedings of the 18th linear accelerator meeting in Japan, July 1993, 123
2 Leal-Quiros E, Prelas M A. Rev Sci Instr, 1989; 60(3):350
3 Krider J. Nucl Instr and Meth, 1989; 278A:660
4 Schippers J M, Kiewiet H H, Zijlsta. Nucl Instr and Meth, 1991; 310A:540
5 Deluca William H . IEEE Transaction on Nuclear Science, 1969; NS-16:813