Measurement of the Beam Size and Emittance for the CRC Cyclotron

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1. Introduction

The purpose of the present study was to confirm beam property for regional Cyclotron Research Center (CRC) installed at Chosun University Hospital. The regional CRC has been developed to produce radioisotope for positron emission tomography (PET). The original radioisotope production cyclotron had a large beam size, which need to be reduced by collimator. In order to construct the proton-induced X-ray emission and proton-induced gamma-ray emission (PIXE-PIGE) beam line, ion beam will be transported to PIXE-PIGE chamber that we have identified the beam size decreased by collimator and beam emittance.

There are several methods to measure the emittace, such as the slit and collector method, the pepper-pot method, and the quad scan method. These methods use a slit and monitor to measure the beam profiles, which depend on the field gradient of the quadrupole magnet. In this study, we did not use magnet and monitor. The emittance calculation based on simulated data by previously proven program is approached to consider various methods. Beam emittance was calculated in two methods. The two methods were classical method and ion beam position with divergence method. We found that the beam sizes of x, y-direction are reduced very well.

2. Experiment Set Up

The experimental beam line consisted of a collimator, a beam line of 300 mm length and a beam dumy is shown in Fig. 1. The collimator length was 120 mm and carbon plates of 2 mm width are attached at both ends of collimator. There was a hole of 2 mm diameter in the center of carbon plate. A carbon plate with measurement film, a width of 5 mm, is mounted at the front of the beam dumy.

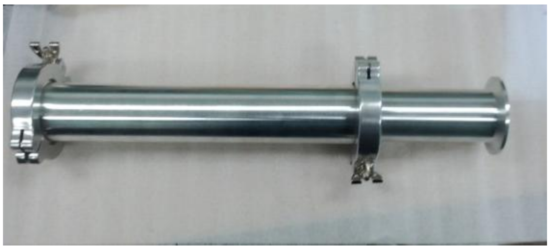

Fig.1. Experimental beam line

Beam extract time will be within 5 seconds. If extract time is longer, measurement film will be damaged and image will not obtained exactly. The experimental beam line total length was 301.5 mm from the carbon plate to measurement film for calculation of beam emittance.

3. Measurement beam size and emittance

3.1 Classical method (1)

Position and divergence of particles are presented (x, y), (x', y'), respectively. The divergence x' was gained by using following equation.

$$\tan x' = \frac{X-x}{L}, x' = \tan^{-1}(\frac{X-x}{L}) \quad (1)$$

where L, length from center of carbon film to measurement film, was 301.5 mm and x, radius of carbon plate, was 1 mm.

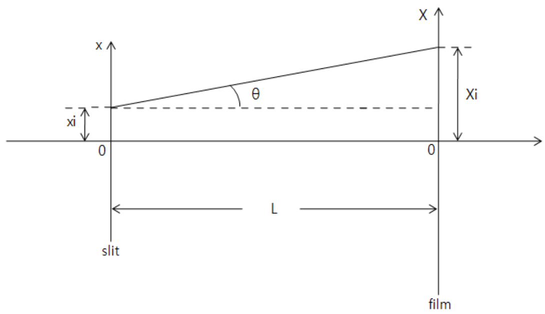

Fig. 2. Concept of the classical method

The theoretical result was confirmed with this method based on previously published specification. The result is shown in Table. 1. These results of emittance were closely accorded with beam size were 5.3 mm and 3.149mm in the horizontal and vertical direction, respectively. The range of beam size was 3.75-12.7 mm and 2.25-11.2 mm in the horizontal and vertical direction.

Table. 1. Pepper pot method

X(mm)	X'(mrad)	emittance	Angle
5.29	5.456053068	28.86252073	0.312605712
5.291	5.457711443	28.87675124	0.312700727
5.292	5.459369818	28.89098507	0.312795742
5.293	5.461028192	28.90522222	0.312890757
5.294	5.462686567	28.91946269	0.312985772
5.295	5.464344942	28.93370647	0.313080787

Y(mm)	Y'(mrad)	emittance	angle
3.15	1.907131012	6.007462687	0.109270425
3.149	1.905472637	6.000333333	0.109175408
3.148	1.903814262	5.993207297	0.10908039
3.147	1.902155887	5.986084577	0.108985373
3.146	1.900497512	5.978965174	0.108890355
3.145	1.898839138	5.971849088	0.108795338

3.2 Ion beam position with divergence method (2)

A beam of particle can be characterized in detail by its density in the six-dimensional phase space, (x, px, y, py, z, pz) . The six-dimensional phase space is divided into three two-dimensional subspaces, (x, px) , (y, py) and (z, pz) , where z is average direction or axis of beam. The emittance is defined as the area occupied by beam in two-dimensional phase spaces. If the area occupied by the beam in phase space is Ax , then the emittance is defined as $\varepsilon = Area / \pi$. The emittance term is the product of measured ellipse axes. The unit of emittance is π mm mrad . The maximum size of particle beam is $\pi\varepsilon$. We have discerned the emittance in drift space. The result by using the method (2) was calculated by dividing figures which appear in Dose Image Viewer (DIV) according to beam intensity. The intensity for DIV is shown as percentage of contrast. The intensity is defined as boundary of intensity percentage. The result is shown as Table. 2.

Table. 2. Beam position with divergence method

	X(mm)	X'(mrad)	emittance	Angle
Intensity 90	3.8	7.631578947	29	0.437257356
Intensity 80	5.6	5.178571429	29	0.296710348
Intensity 40	7.3	3.97260274	29	0.227613418
Intensity 20	12.6	2.301587302	29	0.131871266

	Y(mm)	Y'(mrad)	emittance	Angle
Intensity 90	2.3	2.608695652	6	0.149467282
Intensity 80	5.4	1.111111111	6	0.06366199
Intensity 40	7.1	0.845070423	6	0.048418979
Intensity 20	11.5	0.52173913	6	0.029893456

The range of the divergence in this method was 2.2834-7.7333 mrad and 0.5194-2.6666 mrad in x direction and y direction. Correspondence between result value and general specifications has to be confirmed by finding effective intensity with area because result value of range had large error.

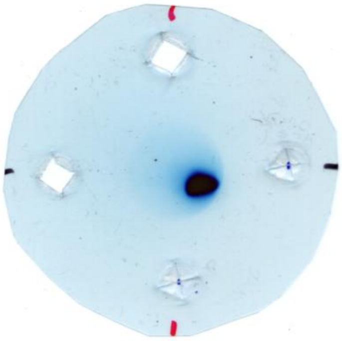

Fig. 3. Experimental film

4. Conclusions

In conclusion, results were compared as x and y-axis of angle and divergence in method (1) and method (2) is shown that two value accorded with 5.3 mm and 3.149 mm in x and y-directions respectively. When we found this part by using DIV, which was inner part of boundary over the intensity 80 is shown in Fig. 3.

In fact, the extracted film was discolored by black, it was corresponded with the inner part of the black boundary over the intensity 80. This area of emittance was equally 29, 6 π mm mrad in x-direction and y-direction.

The collimator can be useful equipment for reducing beam size. The carbon plate, center diameter smaller than 2 mm, can be effectively reduced beam size.

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