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Theoretical calculation of the control parameters for Beam Selection Magnet of the 30MeV Cyclotron

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Abstract: Beam Selection Magnet (BSM) is a dipole magnet located at the end of the beamline in cyclotron 30MeV system. It performs steering proton beam from beamline to individual targets for radioisotopes production. Therefore, it plays an important role in focusing the beam onto the targets. The aim of this work is to determine its control parameters in theory based on the designed technology and theory of accelerator physics. The obtained calculation results were compared with baseline parameters that have been configured to control this system in producing of ^{18}F and ^{11}C radioisotopes. This work could be used as a basis for new parameters selection to control BSM if new targets are installed.

Keywords: *Beam Selection Magnet, Beamline, Produce ^{18}F, 30MeV Cyclotron, Accelerator physics*

I. INTRODUCTION

The IBA 30 MeV Cyclotron System in 108 Hospital has been using very effectively and providing most of ^{18}F-FDG radiopharmaceutical for 4 nuclear medicine centers having PET/CT scanner in Hanoi city.

Fig.1. The Beam Selection Magnet located at the end of the beamline

Beam Selection Magnet (BSM) is a dipole magnet located at the end of the beamline in cyclotron 30 MeV system. Its rear arranged 5 targets to produce different radioisotopes. Its magnet field will steer proton beam from beamline to individual targets, so it plays an important role in the process of focusing the beam onto the targets and producing radioisotope. During irradiation, proton beam often deflects out of the target because of thermal effect, changing the beam position at the end of the beamline and current drift of power supply, so we have to adjust the parameters of BSM regularly. The aim of this work is to determine its control parameters in theory based on the designed technology, technical parameters and theory of accelerator physics.

The subject is the Beam Selection Magnet located at the end of the beamline in cyclotron 30MeV system. This magnet steers proton beam from beamline to individual targets during irradiation. Its total turns of coils, pole gap and pole width are 504 turns, 50mm and 395mm respectively [1].

The aim of this work is that based on the understanding of design technology and

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technical parameters of the BSM, using accelerator physics and beam transportation methods to develop a general formula for determining its control parameters. Theoretical obtained values were compared with the control parameters which have been installed when producing ^{18}F and ^{11}C radioisotopes.

II. BASIS OF CALCULATION METHOD

A. Targets arrangement on BSM

A charged particle with charge q and velocity *v* in the electromagnetic fields (*B*, *E*) is exerted by the Lorentz's force *F*. Since the magnetic force is perpendicular to both *v* and *B*, the charged particle will move on a circular. Because BSM is a kind of dipole magnet so its magnetic flux density is perpendicular to *v* then bending radius is [2]: $r = \dfrac{mv}{qB}$

or:

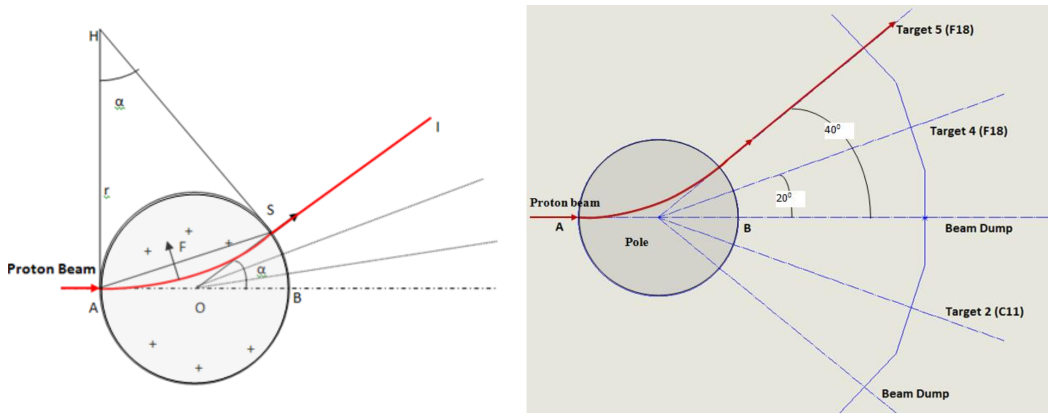
$$B = \frac{p}{rq} = \frac{1}{rqc}\sqrt{E^2 - E_0^2} = \frac{1}{rqc}\sqrt{E_k^2 + 2E_0E_k}$$

(Tesla) (1)

Where:
c - the speed of light (~2.9979.10^8 m/s)
E_k - the kinetic energy of proton beam
E_0 - the rest energy of proton (=938 MeV)

It is assumed that the proton beam extracted from cyclotron has a single fixed energy and locates in the middle of the beamline. We have the trajectory of the beam through circular pole follow the red line (Figure2-a) and we have the bending radius:

$$r = \frac{AO}{\tan(\frac{\alpha}{2})} = \frac{AB}{2.\tan(\frac{\alpha}{2})} \qquad (2)$$



(a) (b)

Fig. 2. Proton beam trajectory through circular pole (a) and Position of targets on BSM (b)

With this trajectory, the targets have to arrange on the lines that across the center of the magnet pole. For the BSM system, it is designed with five targets with the deviation angles -40^0; -20^0; 0^0; 20^0; 40^0 (Fig. 2-b) respectively.

B. Effective magnetic length of BSM

BSM is designed as a type of dipole H-magnet (Figure3) with pole gap *h* so the effective magnetic length is: [3]

$$l_{efb} = \frac{1}{B(0)}\int_0^\infty B(s)ds \sim l_{iron} + h \qquad =>$$

$$l_{efb} \sim d + h \qquad (3)$$

and the magnitude of magnetic field in the gap is: $B_{gap} = \dfrac{\mu NI}{h}$ (4)

Where:
B(s) - magnetic field of magnet
B(0) - magnet field in the gap, B(0)=B_{gap}
d - the pole's diameter (*m*)

h - the high of pole gap (*m*)

μ - the permeability of the environment, for vacuum we have $\mu = 4\pi.10^{-7}$ (Tm/A)

N - the total turns of coils

I - the electric current supply to coils (A)

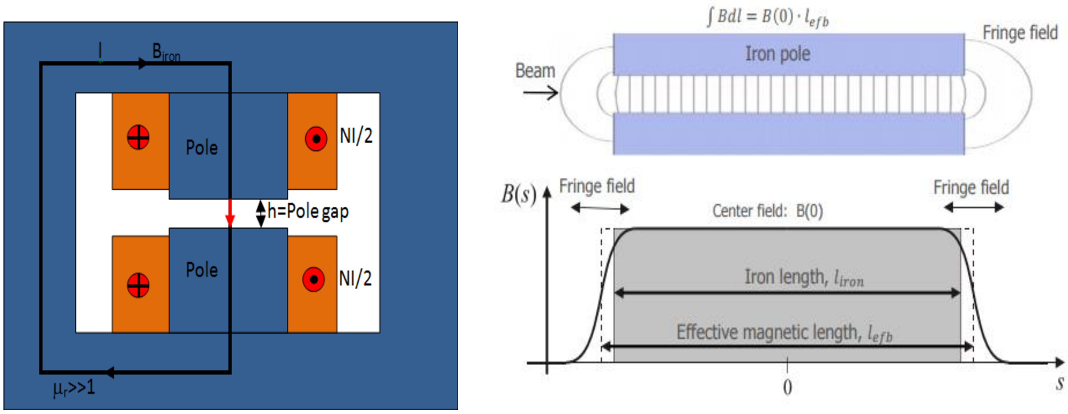


Fig. 3. Dipole H-magnet and it effective magnetic length

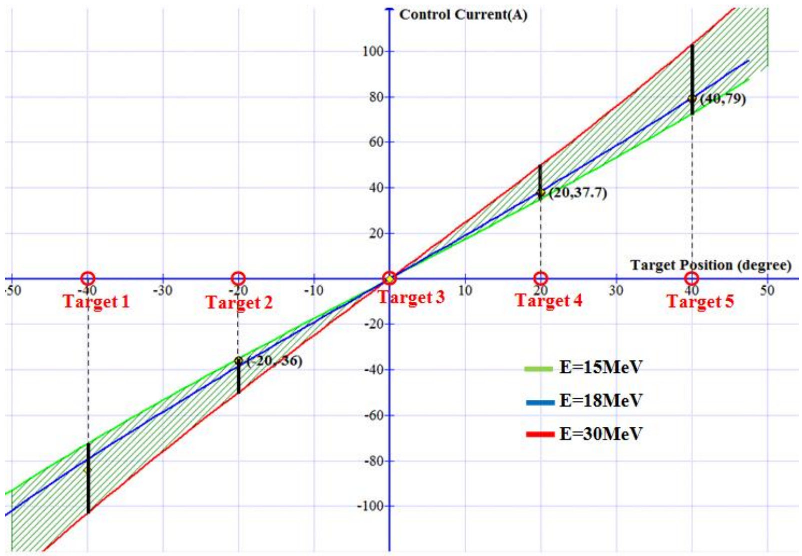


Fig. 4. The current ranges apply to BSM for each target positions

C. The theoretical control parameters for BSM during irradiation

Base on the equation above, with $1\ [\text{MeV/c}]=10^{6}[\text{eV}]/(3\text{x}10^{8}\ [\text{m/s}])=\frac{1}{300}.e[\text{kg.m/s}]$ and the effective magnetic length AB= l_{efb}= (d+h) and B= B_{gap} so one can determine the magnitude of magnetic field in the gap of the BSM and the current need to supply to coils as follows:

$$B=\frac{2.\tan(\frac{\alpha}{2})}{300.(d+h)}\sqrt{E_k^2+2E_0E_k}\ \text{(Tesla)} \qquad (5)$$

$$I=\frac{hB}{\mu_0 N}=\frac{h}{\mu_0 N}.\frac{2\tan(\frac{\alpha}{2})}{300(d+h)}\sqrt{E_k^2+2E_0E_k} \qquad (6)$$

From this general formula one can determine the theoretical currents known as control parameters for BSM for specific target and proton beam energy in the process of irradiation.

Because the proton beam energy extracted from Cyclotron 30MeV is from 15 MeV to 30MeV so it can be built the selection area of the control current for BSM and for specific targets as shown in Fig. 4 (solid black line).

III. RESULTS AND DISCUSSION

To evaluate the effectiveness of the formula and the graph above, we carried out comparing the obtained values in theory with the values that have installed to control BSM focusing the proton beam on the specific targets in the process production of radioisotopes. It could be seen that the obtained values in the theory approximate with the setting current to control BSM [Table I]. Because the beam positions might not locate precisely at the center beamline and the coils also have thermal effect, so when we operate the cyclotron system to produce radioisotopes, we have to adjust the current of BSM regularly. But the adjusted range is negligible compared to the value that have installed already.

Table I. Comparison of the theoretical currents and setting values to control BSM when we produce ^{18}F and ^{11}C radioisotopes

Target	Theory	Installed
Target 5 ($\alpha=40^0$) produce ^{18}F at 18MeV	79.0A	79A
Target 4 ($\alpha=20^0$) produce ^{18}F at 18MeV	38.2A	37.7A
Target 3 ($\alpha=0^0$) -Unused		
Target 2 ($\alpha=-20^0$) produce ^{11}C at 16MeV	-36A	-36A
Target 1 ($\alpha=40^0$) -Unused		

Based on the formula (6) and the graph in Fig. 4, operation engineers get solution to select control parameters for BSM to steer proton beam from the beamline shooting to the target positions. Thus it makes operating the cyclotron system more convenient and effective. The theoretical values are the basis to set the initial values to control BSM when using other target positions and beam energies to produce new radioisotopes in the future.

IV. CONCLUSIONS

Based on designed technology of Beam Selection Magnet and accelerator physics theory, the author has developed the general formula to determine theoretical current to control BSM driving proton beam from beamline onto the target positions during the production of radioisotopes. The results help operators to easily select parameters to control BSM and enhance their operation capacity for cyclotron system. The results also are the basis for selection of control parameters of BSM when using new targets and beam energies for producing other radioisotopes.

REFERENCES

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