The Design of the Beam Spreader for Spreading 100-MeV Proton Beam at the PEFP Beam Lines.

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1. Introduction

The Proton Engineering Frontier Project (PEFP) has planned to construct 100-MeV proton linear accelerator and provide 20-MeV or 100-MeV proton beams to users who want to utilize proton beam for their research and development. [1] To meet user's demand, the PEFP will construct a ten beamlines, which each of them have own characteristic purpose

For proton beam utilization, a user demand survey and the operation experiences from 20-MeV proton beam irradiation test facility during several years, tell us most of users demand the broad and uniform beam field transversely. But unfortunately, the initial proton beam delivered by most of proton accelerators is generally quite narrow and non-uniform

To generate a large and uniform beam fields, we investigated the double-scattering method will be applied to the BL 102 and BL 104 beam lines of the PEFP user facility. To achieve our purpose, especially we have applied double-scattering method presented by Takada to the design of double scatterer. [2,3]

2. Methods and Results

2.1 Multiple-scattering of proton beam

When the proton beam pass through the matter, a proton beam experiences a deflection as it passes in the neighborhood of a nucleus. This deflection of proton beam can be estimated by Highland formula.

$$\theta \approx \frac{13.6MeV}{p\beta}\sqrt{\frac{x}{X_0}}[1+0.038\ln(x/X_0)]$$

Thus, When a proton beam pass through the matter, a proton beam was scattered and spread out by multiple-scattering with the matter.

2.2 Principle of Double-scattering

Figure 1 shows that typical arrangement of the double-scattering method. The proton beam which pass through the first scatterer experience a multiple scattering with matter and generate Gaussian beam profile. Then, protons that pass through the inner second scatterer, which is made of heavy material, will be more scattered and spread out, while protons through the outer second scatterer, which is made of light material, will be less spread out. Therefore, the flat beam field can be obtained by double scattering method at the plane of interest.

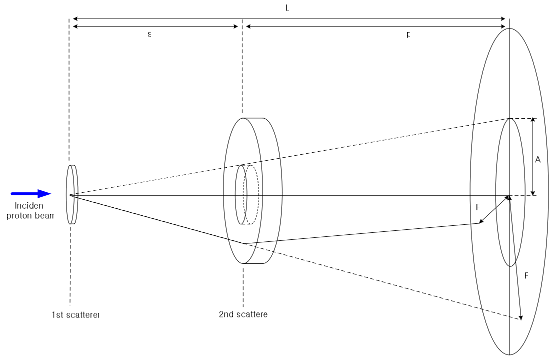


Fig. 1. An typical arrangement of the first and second scatterer for the double scattering method

The beam field distribution which generated by a multiple scattering with the double scatterer can be expressed by

$$F(r)dr = \int \Phi_1(r_1)\Phi_2(r-r_1)dr_1 dr$$

Through the variable transformation, above equation is rewrote the formula in the integral form of the modified Bessel function.

$$F(u) = \frac{4}{1+v^2}\exp[-\frac{u^2}{v^2}]\int_0^{g} dw\cdot w\cdot\exp[-w^2]\times I_0(\frac{2u}{v}\sqrt{\frac{1}{1+v^2}}w) + \frac{4}{1+v'^2}\exp[-\frac{u^2}{v'^2}]$$
$$\times\int_{g'}^{\infty} dw' w\exp[w'^2]I_0(\frac{2u}{v'}\sqrt{\frac{1}{1+v'^2}}w')$$

Where $u = r/R_1$, $v = R_{2,inner}/R_1$, $v' = R_{2,outer}/R_1$, $w = (\sqrt{v^2+1}/v)(r_1/R_1)$, $w' = (\sqrt{v'^2+1}/v')(r_1/R_1)$, $I_0(x)$ the modified Bessel function of zero-th order and g_A and g_A' are expressed as follows.

$$g_A = \frac{\sqrt{1+v^2}}{v}\frac{A}{R_1} \ \textit{and}\ g_A' = \frac{\sqrt{1+v'^2}}{v'}\frac{A}{R_1}.$$

From above relationship, Takada suggest the following optimum solution to determine the design parameters easily. [3]

$v = 1.06$, $A / R_1 = 0.9$, and $R_{2,outer} / R_{2,inner} = 0.413$

2.3 Design parameters of the beam spreader

The design parameters of double scatterers which have to be determined are follows as, the position and arrangement of the first and second scatterers(L,s,p), the thickness of the first and second scatterers, the variety of scattering materials, the geometrical dimension of the inner and outer second scatterers. There are many parameters to design the double scatterers for 100-MeV proton beamlines. But if we determine some parameters, such as the length of the flat beam field, the distance between the scatterer and iso-center and the thickness of scatterers, the remained parameters of the double scatterer will be automatically fixed by Takada's optimum solution.

2.4 Determination of the optimum parameters

To obtain the uniform beam field of 20 cm, the parameters of double scattering method can be determined like this: R_1 = 10 cm, $R_{2,inner}$ = 10.6 cm, $R_{2,outer}$ = 4.13 cm, A = 9. If the distance of scatterers is determined as L = 300 cm and p= 260 cm, the thickness of the scatterers, t_1, $t_{2,inner}$, $t_{2,outer}$ are determined as 0.49 mm, 0.83 mm and 1.37 mm respectively. At that time, the energy loss of proton beam is estimated by 90.2-MeV through the SRIM calculation. [4] These results are described as Table 1.

These results are considered somewhat reasonable because the most of therapeutic proton beam using double scattering method have 10% of energy loss. Therefore, we determined the optimum design parameters of doubles-scattering method for obtaining the uniform beam field as table 2.

Table 1. The variation of the scatterer's thickness and the proton beam energy as function of distance L (When R_1 = 20 cm, p / L = 0.2)

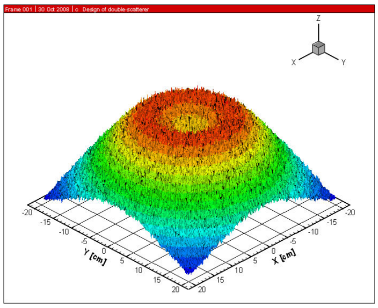
L [cm]	t_1 [cm]	p [cm]	$t_{2,inner}$	$t_{2,outer}$	Beam Energy [MeV]
100	0.377	80	0.636	1.037	0
150	0.177	120	0.299	0.491	59.9
200	0.104	160	0.175	0.288	78.3
250	0.069	200	0.115	0.191	86.1
300	0.049	240	0.083	0.137	90.2
350	0.037	280	0.062	0.103	92.7
400	0.029	320	0.049	0.08	94.3

Table 2. The derived optimum parameter of double-scattering for the 20 cm uniform beam field at the 100 MeV PEFP beam lines

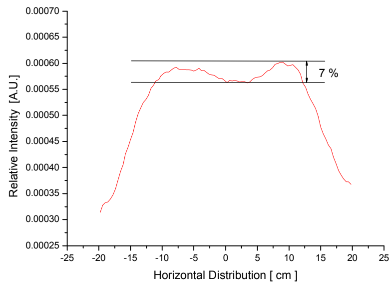
Material of 1st scatterer	Tungsten
Material of 2nd scatterer	Aluminum
Thickness of 1st scatterer (t1)	0.49 mm
Thickness of inner 2nd scatterer ($t_{2,inner}$)	0.83 mm
Thickness of outer 2nd scatterer ($t_{2,outer}$)	1.37 mm
The distance between 1st scatterer and the iso-center plane (L)	300 cm
The distance between 2nd scatterer and the iso-center plane (p)	240 cm
The radius of inner second scatterer (a)	18.5 mm

2.3 Verification of the uniform beam field

The derived the design parameters of double-scatterers have been verified by using Monte Carlo particle simulation method (MCNPX 2.5.0). The initial proton beam has 100-MeV, FWHM of 1 cm and zero emittance. (Fig.2)



(a) 2-dimensional flux distribution of proton beam



(b) Horizontal flux distribution of proton beam

Fig. 2. Total beam distribution of proton beam contributed by the double scatterers

3. Conclusions

Until now, we have investigated the optimum condition of double-scatterers for the 100-MeV PEFP beam line. At the 100-MeV PEFP beam line, a 20cm flat beam field can be produced considering the limited size of the target room due to the relative large energy loss of proton beam.

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