PLANNAR MICROCHANNEL TARGET

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Abstract

The approximate analytic solution of a microchannel target for a uniform beam is given in one-dimentional model. It is modified for an axi-symmetric Gaussian beam. The analytic results are coincident with the numerical solution. A slit target used to measure beam energy spectrum for a beam with energy of 3.54MeV, average beam power of 36kW is developed.

INTRODUCTION

A beamstop (or target) is one of the key components required to develop powerful accelerators, such as the Spallation Neutron Sources, Boron Neutron Cancer Therapy (BNCT), or Neutron Generator etc. The beam power in these accelerators is in the hundreds kilowatts range, and the surface power density is in the order of several kilowatts per square centimeter. In order to reduce the power density on the target surface to an acceptable level, an inclined axi-symmetric target is often used. In some cases, a planar target must be used, such as in BNCT accelerator, or in our work where a slit target is used for measuring beam energy spectrum. In these cases a microchannel target may be used to enhance the heat transfer area [1].

SOLUTION FOR PLANAR MICROCHANNEL TARGET FOR A UNIFORM BEAM

A microchannel target is fundamentally a finned structure with coolant passages of rectangular cross section, as shown in Fig.1.

In order to get an approximate analytical solution, the problem is solved in the region ABCD in one-dimensional model. The power density (heat flux) flowing into the region of AD is modified as follows:

$$P = P_o\left(1+\frac{a}{4b}\right) \tag{1}$$

The temperature on the target surface T_o (℃) may be deduced as follows:

$$T_o = T_w + P_o\left(1+\frac{a}{4b}\right)\left(\frac{d}{\lambda}+\frac{1}{m\lambda th(ml)}\right) \tag{2}$$

where $m=\pm\sqrt{\frac{2\alpha}{\lambda b}}$, α is the convective film coefficient (W/cm^2/℃), λ is the metal thermal conductivity coefficient (W/cm/℃).

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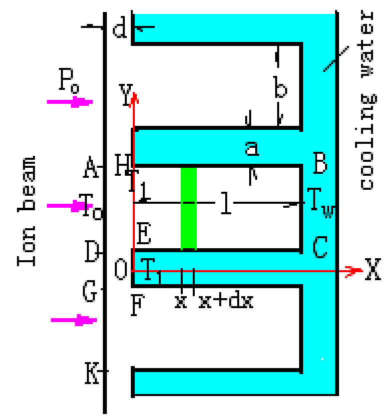

Figure 1: A diagram of microchannel target.

Compared with the general cooling target without the microchannel，the maximum acceptable power density of microchannel target is enhanced by a factor of η:

$$\eta = \frac{P_o}{P_o'} \cong \frac{m\lambda th(ml)}{\alpha(1+a/4b)} \tag{3}$$

For example, when $\alpha=$2W/cm2/℃, $a=$0.5mm, $b=$2mm, $l=$6mm, $\lambda=1.9$W/cm/℃, the enhanced factors for different gaps are shown in the following table.

Table 1. The enhanced factor for different gaps

b(mm)	1	2	4	6	8
η	3.8	2.8	1.9	1.4	1.1

The maximum acceptable power density of microchannel target may be deduced:

$$P_o \approx \frac{\Delta t_1 m\lambda th(ml)}{(1+a/4b)} \tag{4}$$

The maximum Δt_1 is the temperature difference between water boiling point and the cooling water temperature: $\Delta t_{1\max} = t_{1\max} - t_w \approx t_{boil} - t_w$. For example, under the above parameters and assuming Δt_1 =90℃, the maximum acceptable power density is about 500W/cm2. It should be pointed that $P_o \propto \sqrt{\alpha}$.

COMPARISON BETWEEN THE ANALYTICAL AND NUMERICAL CALCULATION

Under the above parameters and assuming the injection uniform beam power density P_o=473W/cm^2, for different gap between both channel, b , the comparison between the analytical calculation and the numerical analog is shown in the following table, where T_{1nu} are calculated by the ANSYS program in two dimension [2].

Table 2. Comparison between the numerical analog and analytical calculation

b (cm)	0.1	0.15	0.2	0.3	0.4	0.6
T_{1nu} (℃)	120	128	137	158	170	199
T_{1cal} (℃)	110	121	132	153	173	214

MODIFICATION FOR A BEAM WITH A GAUSSIAN DENSITY DISTRIBUTION

In most cases the beam density distribution is a Gaussian as follows:

$$P = P_o \exp\left[-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2\right] \qquad (5)$$

In these cases the transversal thermal conduction (in Y-Z plane) should be considered.

Supposed that the transversal conduction is far less than the longitudinal (in X-direction) conduction, after some simplified assumption we may deduce that the maximum temperature at the axis may be estimated by the following equation roughly:

$$T_{o\max} \approx T_w + P_o\beta \Big/ \left\{1 + \frac{\beta\lambda d}{\sigma^2}\right\} \qquad (6)$$

$$\beta = \left(1 + \frac{a}{4b}\right)\left(\frac{d}{\lambda} + \frac{1}{m\lambda th(ml)}\right)$$

Under the above parameters, for different d =0.1cm or 0.3cm, the maximum surface temperature T_{onum} and T_{ocal} for different σ are calculated by the three dimensional ANSYS program and by Eq. (6), respectively. Their comparisons are shown in the following table.

Table 3. The maximum temperature (℃) for different Gaussian width

d (cm)	σ (cm)	3.3	2.8	2.3	1.8	1.3	0.8
0.1	T_{onum}	130	130	129	127	123	114
	T_{ocal}	131	131	131	130	129	124
0.3	T_{onum}	177	176	173	169	151	141
	T_{ocal}	182	180	178	175	166	144

Therefore the above modified equation may be used for the first technical design (error< ± 10%) for a Gaussian beam of $\sigma > \sqrt{10\beta\lambda d}$.

DEVELOPMENT OF A SLIT TARGET WITH MICROCHANNEL

A beam energy spectrum with proton energy of 3.54MeV, pulsed current of 50mA, duty factor of 6% should be measured [3]. The maximum average power (P_o) is 10.6kW with a Gaussian width σ = 1.4cm. So the maximum power density at the beam axis P_o=0.86kW/cm^2.

A magnetic analyzer with the width of sample slit of 0.7mm is used. Two "V"-formed inclined planar water-cooling microchannel targets are used. To solve the problem of the residual radiation produced by 3.54MeV proton beam, an aluminum surface is used. This slit target has been well operated.

The other "V"-formed planar microchannel target is designed and manufactured for a beam with the maximum power density at the beam axis P_o ≈3.5kW/cm^2, as shown in the following figure. The inclined angle at the axis is 8° . In order to reduce the target length, the inclined angle becomes 60° at the end. The target surface is made by 3mm copper with a coated layer of aluminum.

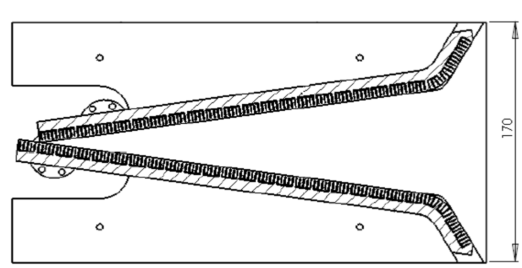

Figure 2: A "V"-formed powerful planar micro-channel beam target.

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