INVESTIGATION OF THE THERMAL REGIME IN A CYCLOTRON TARGET

Konjachin N.A., Krasnov N.N., Mironov V.N., Lapin V.N.

Power Physics Institute, Obninsk, USSR

Abstract

The effect of temperature reduction in a cyclotron target by means of forming cooling ribs on its back surface is investigated. It is experimentally found that ribs 1 mm thick and 5 mm long decrease the temperature of the target back surface 3.4 times in comparison with a non-ribbed target. A formula for evaluation of temperature of the ribbed target is presented.

1. Introduction

One of the main problems of radioisotope production on the cyclotron is the creation of target assemblies allowing the irradiation of different materials at a rather high power level. Usually high intensity is inherent in an internal cyclotron beam. However, the cross section of the internal beam is not large and is commonly less than 1 cm². To increase the target irradiated area and to decrease power density, rotating targets and grazing incidence targets are usually used[1,2]. Such methods allow a decrease in power density on the target by factors of 10 to 50. However, the power density obtained in these cases remains rather high if one aims at high production rates. Therefore, it is necessary to take away heat from the target reliably at high power density. One of the possible modes of increasing permissible thermal loads is the formation of ribs on the target back which are in contact with cooling water. This work is aimed at the investigation of the use of ribs on the back surface of the target which is used for radioisotope production on the Power Physics Institute cyclotron[3].

2. Theory

The scheme of the target with cooling ribs is presented in Fig. 1. The coolant flows through the clearances between ribs perpendicular to the plane of the picture. If we assume that heat spreads only along axis x and that the temperature is constant in the plane x = Const., then it is not difficult to obtain a formula for evaluation of the temperature on the back surface of the ribbed target.

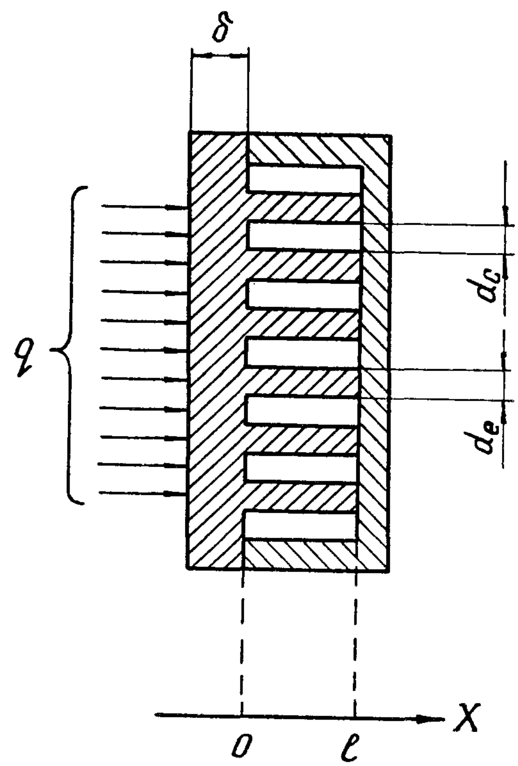

Fig. 1 Scheme of ribbed target.
(q) Direction of thermal flux,
(d_c) Channel width,
(d_e) Rib width,
(ℓ) Rib length,
(δ) Thickness of front plate of target.

In this case, the differential equation of heat spreading in the region x > 0 will be the following:

$$\lambda \frac{d^2t}{dx^2} - q_v = 0 \qquad (1)$$

where λ(kcal/m h deg C) is the thermal conductivity of the medium. At $d_e = d_c = d$, the average thermal conductivity is $\lambda = \lambda_m/2$ where λ_m is the thermal conductivity of rib material. The thermal conductivity of the coolant can be neglected.

Proc. 7th Int. Conf. on Cyclotrons and their Applications (Birkhäuser, Basel, 1975), p. 365-367

The temperature of the heat dissipating surface is t(deg C) and q_v (kcal/m²h) is the density of the heat flux from the surface of the ribs:

$$q_v = \alpha[t(x) - t_c] \qquad (2)$$

where α(kcal/m h °C) is the average value of the heat irradiation coefficient for the rib surface. Also, t(x) is the rib temperature at x, t_c is the coolant temperature and F(m^{-1}) is the heat irradiation surface of ribs in a unit volume (m³), so that at $d_e = d_c = d$, F = 1/d.

Denoting $t(x) - t_c = \theta$, we get equation (1) in the following form:

$$\frac{d^2\theta}{dx^2} - m^2\,\theta = 0 \qquad (3)$$

where $m = \sqrt{\alpha \cdot F/\lambda}$. The solution of equation (3) is:

$$\theta = c_1 e^{mx} + c_2 e^{-mx} \quad . \qquad (4)$$

Coefficients c_1 and c_2 are determined using the following boundary conditions:

$$\left(-\lambda\frac{d\theta}{dx}\right)_{x=0} = q_0 , \quad \left(-\lambda\frac{d\theta}{dx}\right)_{x=0} = 0 \qquad (5)$$

Then equation (4) becomes

$$\theta = \frac{q_0}{m\lambda}\left(\frac{e^{mx}}{e^{2m\ell} - 1} + \frac{e^{-mx}}{1 - e^{-2m\ell}}\right) \qquad (6)$$

From equation (6) we see that at x = 0,

$$\theta = \frac{q}{m\lambda}\left(\frac{e^{2m\ell} + 1}{e^{2m\ell} - 1}\right) \qquad (7)$$

If the ribs are rather long ($\ell >> d$), then $2m\ell >> 1$ and the function in brackets becomes equal to 1. In this case, the relation (7) has a simple form:

$$\theta_0 = q_0\sqrt{\frac{d}{\alpha \cdot \lambda}} \quad . \qquad (8)$$

It is seen from relation (8) that the efficiency of ribs is greater for greater conductivity of rib material and for smaller thickness of ribs and clearances.

Equation (8) gives the temperature of the target back surface. The temperature of the front surface of the target which is bombarded by the beam will be higher by Δt:

$$\Delta t = \frac{q_0\,\delta}{\lambda_m} \qquad (9)$$

where δ is the thickness of the target plate.

3. Experiment

The experiments were carried out with the internal beam on the Power Physics Institute cyclotron, which accelerated deuterons up to 20 MeV. Copper targets with thermo-couples in them were installed in the target assembly which is usually used for irradiation of materials with the internal cyclotron beam. The increase of irradiated area in this target is achieved by means of grazing beam incidence at 9° angle. This target assembly is similar to that described in our paper[3] and differs from it by having somewhat larger size and the possibility of installation of both ribbed and smooth targets. In the case of smooth targets, cooling water flows through clearances 1.5 mm width. In both cases, water flows are approximately 30 l/min. Target shape and thermo-couple location are shown in Fig. 2.

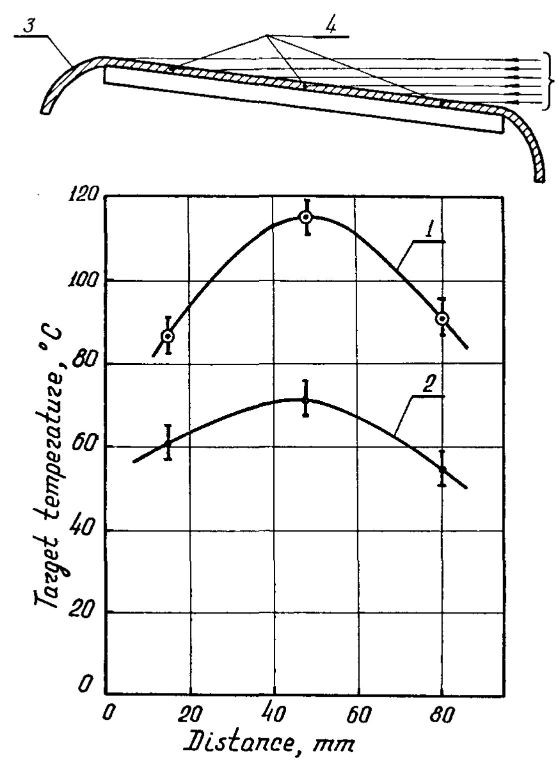

Fig. 2 Temperature distributions along the targets: (1) Smooth target, (2) Ribbed target, (3) Horizontal section of ribbed target, (4) Thermo-couple positions, (5) Beam direction.

Calibration of the thermo-couples was performed by placing the targets in hot water of known temperature.

Regulation of the beam in the vertical direction was performed by additional coils which displace the magnetic plane. The desired radial size of the beam cross-section was achieved by means of displacement of ion-source and by control of the first harmonic of the magnetic field.

The most uniform beam distribution along the target surface, which was easily achieved, had the shape shown in Fig. 2. In this beam distribution, the dependence of the temperature of the front target surface on beam power was obtained. This dependence is shown in Fig. 3. The curves show the temperature measured in the centre of the target, i.e., the maximum temperature.

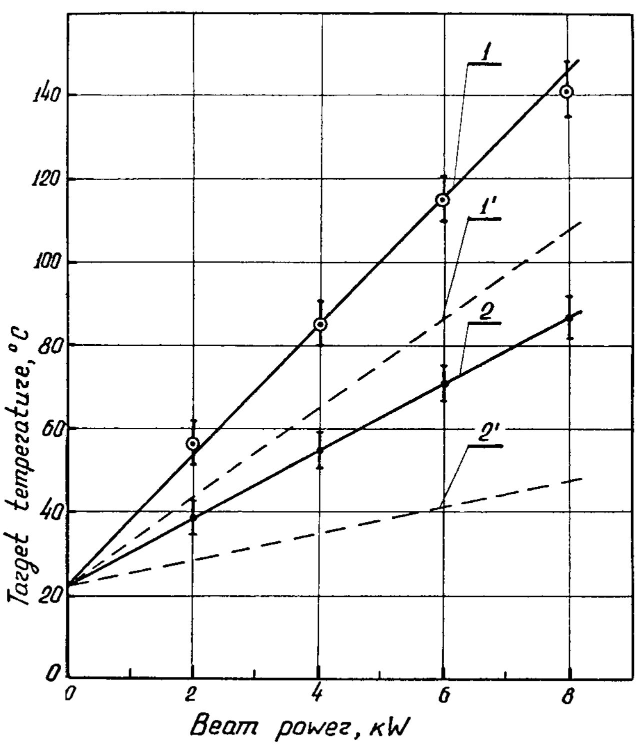

Fig. 3 Target temperature vs incident beam power: (1) and (1') front and back surface of smooth target; (2) and (2') front and back surface of ribbed target.

As the edges of the thermo-couples were placed near the front target surface, the measured temperatures were close to the temperature values of the front surface.

The temperature of the back target surface will be lower by Δt which may be calculated by formula (9).

4. Discussion

The experimental data presented in Fig. 3 show that the use of ribs on the back target surface significantly decreases its temperature. The evaluation of the temperature on the back target surface (i.e., at $x = 0$) was carried out. Having determined the beam density on the target by a radio-autography method, the value of the thermal flow density was determined and the magnitude Δt was calculated by means of formula (9). The values of temperature of the back target surfaces calculated in this way are shown in Fig. 3 by dotted lines. It follows from these data that the heat irradiation coefficient of the ribbed surface in this case is 3.4 times more than for a smooth surface.

As is seen from relation (8), decreasing the thickness of the ribs and clearances should increase the heat irradiation of the rib surface. The thickness of ribs and clearances of 1 mm thick taken in this work is caused by technological possibilities. Targets with ribs and clearances of 0.5 mm width seem to be optimum, since their preparation is not technologically difficult and at the same time it allows a decrease in the temperature of the back target surface by $\sqrt{2}$ times in comparison with the ribs of 1 mm thick.

The direction of ribs is parallel to the long dimension of the target in order to provide reliably identical cooling water flow in every clearance. The direction of ribs perpendicular to the long dimension of target would have provided somewhat better expansion of heat flow, but at the expense of good water flow.

References

1) J. Martin et al., Nucleonics, 13, 3, 28 (1955)
2) D.D. Vonberg et al., Uses of Cyclotrons in Chemistry, Metallurgy and Biology, p. 258, Butterworth, London, 1970
3) N.N. Krasnov et al., Uses of Cyclotrons in Chemistry, Metallurgy and Biology, p. 159, Butterworth, London, 1970