SUBSTANCE CHOICE OF THE SCRAPER SYSTEM ELEMENTS

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Abstract

In this paper the functioning of scraper system elements at maximum radiation and thermal loads in different regimes of the system's work is considering. Substance choice and design of system elements construction are made with purpose of prevention their thermal,mechanical and radiation destruction. The advantage of using scraper system with scattering target is shown. By simulation of the real scraping process in UNK the maximum heating elements is defined during many circles and at different beam energies. The designed scraper system with W target and Cu scraper can scrape up to 10% of full intensity $6{\times}10^{14}p$ at the energy $E = 70\ GeV$ and up to 1% at $E = 600\ GeV$.

1 INTRODUCTION

One of the main tasks at the design of circling accelerator is engineering reliable and effective scraper system/1/. Apart from optimum configuring of optical structure with purpose of minimization the protons production in accelerator circle and decrease heating and irradiation of system elements and nearby equipment the main meaning for the capacity of work system is the choice of construction substance of target,scraper and collimators that securing long work in condition of large thermal and radiation loads.

The conditions of the thermal load of elements are considered at three possible regimes of system work:
1) stationary regime - slowly scrape the halo beam;
2) to trap particles that are not took in acceleration regime;
3) accident situation - interception the halo beam during the some turns.
At the stationary regime of work the good thermal conductivity λ of the system elements for fast removal heat is important. At the momentary absorption of beam energy by the system for prevention its destruction is needed to choice the substance with big thermal capacity C_p and melting temperature T_{mel} and thermal mechanical stability. The parameters of some considered substance are introduced in table 1.

Table 1

	C_p $\frac{J}{g\times deg}$	ρ $\frac{g}{sm^3}$	λ $\frac{W}{sm\times deg}$	T_{mel} ^oC	L_r mm	$\sim 6L_n$ m
W	0.134	19.34	1.686	3380	3.5	0.6
Cu	0.388	8.93	3.896	1083	14.3	0.9
Al	0.896	2.7	2.093	660	89.	2.4
Fe	0.440	7.88	0.744	1535	17.6	1.0
C	0.670	2.3	0.980	3540	188.	2.4

The basic circuit of a design of a scraper and target U600 is submitted on fig.1. With the purpose of reduction of a thermal heating of a scraper the intercepted protons at first interact with flat scattering target and having changed angular deviation through some turns get on front face of a scraper, having significant impact parameter. For prevention of mechanical destruction of a scraper oving to a non-uniform heating it suppose to make up from blocks, which fasten to frame with gaps $\Delta \sim 2\ mm$ between blocks and frame.

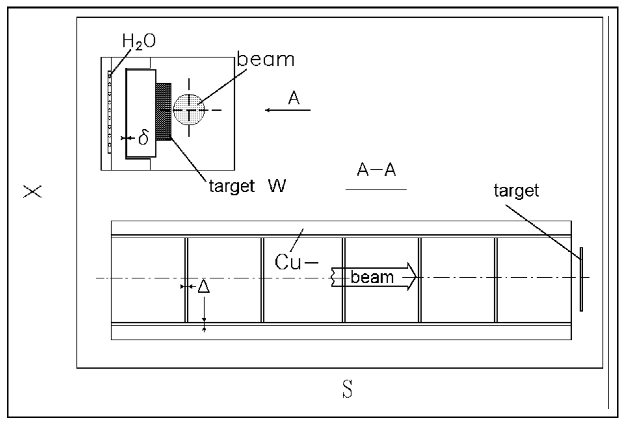

Figure 1: The layout of a scraper.

2 CHOICE OF TARGET SUBSTANCE

At forming the beam by scraper system with scattering target the impact parameter on it is insignificant /2/ and as a result take place the strong heating of its edge that may lead to destruction the substance of target and then self scraper. In case of using the thin target the density of energy deposition in substance is practically constant and weakly depends on the proton energy.

Table 2

	dE/dy $\frac{MeV}{sm}$	α $\frac{1}{deg}$	η $\times 10^6$	η_1	η_2	κ $\frac{sm^2}{s}$	Δt ^0C
W	33.0	4.3	0.84	265	0.21	0.65	800
Cu	18.2	17.0	0.57	206	0.22	1.12	510
Al	6.3	22.9	0.62	253	0.24	0.87	150
Fe	16.5	16.0	0.89	322	0.15	0.22	420
C	5.6	7.9	2.18	974	0.78	0.64	40

The heating of the target can present by process of one-dimensional defusion at presence the heat source:

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial x^2} + p(x,t), \quad where \quad \kappa = \frac{\lambda}{C_p \rho}.$$

In stationary case of scraping process the heat source may be considered as point $p(x,t)|_{x=0} = p_0$, and temperature change will be /3/:

$$T(x,t) = 2p_0\sqrt{\frac{t}{\pi\kappa}}e^{\frac{-x^2}{4\kappa t}} - \frac{p_0 x}{\kappa}(1 - \frac{2}{\sqrt{2\pi}}\int_0^{\frac{x}{2\sqrt{\kappa t}}} e^{-s^2}ds).$$

After closing the process of forming beam with duration t_s the temperature of most heated region of target edge will be: $\quad T = 2p_0 \times \sqrt{\frac{t_s}{\pi\kappa}}$.

If one assumes that the beam distributed for normal law in plane that perpendicular to out plane, then the maximum density of the particles is $Iz_{max} = \frac{I_0}{\sqrt{2\pi}\sigma_z}$, where I_0 - number of scraped particles, and σ_z - r.m.s of the beam in z plane. Since as $p_0 = \frac{I_0 \frac{dE}{dy}}{\sqrt{2\pi}\sigma_z C_p \rho t_s}$, the temperature of the most heated region of target edge $T_{max} = \frac{\sqrt{2} I_0 \frac{dE}{dy}}{\pi\sigma_z\sqrt{C_p\rho\lambda t_s}}$. That is the maximum heating of the target to decrease with increasing the duration of the forming beam. The maximum intensity of the beam that target can stand is

$$I_m = \eta_1 \frac{\pi\sigma_z\sqrt{t_s}}{\sqrt{2}}, \qquad \eta_1 = \frac{T_{cr}\cdot\sqrt{\rho\cdot C_p\cdot\lambda}}{\frac{dE}{dy}},$$

where T_{cr} - temperature of substance destroy. In considering case of slowly heating the T_{cr} practically corresponds to T_{mel}. The coefficient η_1 characterizes the durability property of the target in the stationary regime.

At the accident situation in case of quick beam swelling or orbit displacement the particles during the some turns put to the target. In that case the heating may be considered as momentary and temperature change of the target edge may be defined: $\Delta T = \frac{P_{max}\cdot\frac{dE}{dy}}{\rho\cdot C_p}$, where P_{max} - maximum density of particles during scraping process.

If to approximate the density distribution of the particles on the target in out plane by linear function and to knew the value of impact parameter $\Delta = \sqrt[3]{RV^2}$ /2/, where R - transverse beam size and V - the transverse velocity the beam to the target, one can find the maximum density of protons $P_{max} = I_0/\sqrt{2\pi}\sigma_z\Delta$. Then the maximum intensity of the beam that target can stand in accident situation is

$$I_m = \eta_2\frac{T_{cr}-T_0}{T_{cr}}\sqrt{2\pi}\sigma_z\sqrt[3]{RV^2}, \quad \eta_2 = \frac{T_{cr}\cdot\rho\cdot C_p}{\frac{dE}{dy}}.$$

The coefficient η_2 characterizes the durability property of target in accident regime.

The thickness of the scattering target is chosen with consider of needed scattered angle of the protons for prevention the thermal destroy of the scraper and therefore proportional to radiation length L_r(table 1). With consider the above-mentioned the most suitable substance for making the target is tungsten.

The computer simulation of the beam forming process end energy deposition in system elements was done by codes ”SCRAPER”/4/ and ”MARS12”. Calculated curves of the heating of the edge tungsten target from the beam transverse velocity when to scrape the halo beam with intensity $6 \times 10^{12}p$ are shown in fig.2. From there it can be seen that in stationary work regime (V $\sim 4 \times 10^{-5}$ $mm/turn$, during t$\sim 2\ s$) the heating target not exceeds $120^\circ\ C$. During the rest time of acceleration cycle the thermal energy practically completely removes from the target edge. The shape of the curves explained that with increasing the transverse velocity increases intensity of beam interaction with target and enlarges the impact parameter.

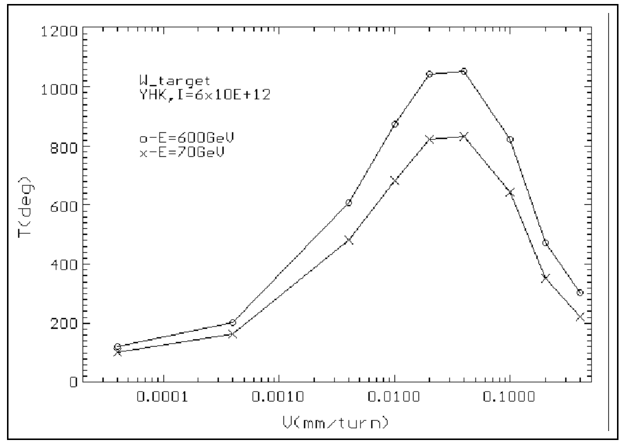

Figure 2: The heating of W target from the transverse velocity of the beam when to scrape 6×10^{12}p.

The most dangerous regime of system work is possible at fast beam swelling in transverse plane or fast equilibrium orbit displacement. Thus the heating of target during some dozens turns of scraping halo beam (V$\sim 2\times10^{-2}$mm/turn) can reach $\simeq 1100^\circ\ C$ (fig.2). In that case for protection of accelerator it is necessary to foresee the turn on the beam abort system.

In the regime to trap protons that not took in acceleration the protons drift to scraper with average speed V $\sim 1.5 \times 10^{-2}$ $mm/turn$ during the time $\sim 30\ mc$ and simulation of process shows that the temperature of the target edge not exceeds $200^\circ\ C$.

3 CHOICE OF SCRAPER SUBSTANCE

The choice of longitudinal scraper size are made with take into account practically full suppression outscattered protons from back face of absorber. The flux of such protons may be estimated $I = I_o \times e^{-l_s/L_n}$. That is when absorber length l_s in six times exceedes the nuclear length L_n(tab.1), then flux of outscattered protons from back face of absorber will be $\sim 0.2\%$ from intercepted protons.

The values of absorber maximum heating Δt at scraping the halo beam with energy $E = 600\ GeV$ and intensity $I = 6 \times 10^{12}p$ for some substance are presented in the table 2. It can be seen that maximum part of the beam to its melting $I > 80\% \times I_0$ to absorb graphite absorber.

But its using is practically impossible because of vacuum aggravation and technologically hard production.

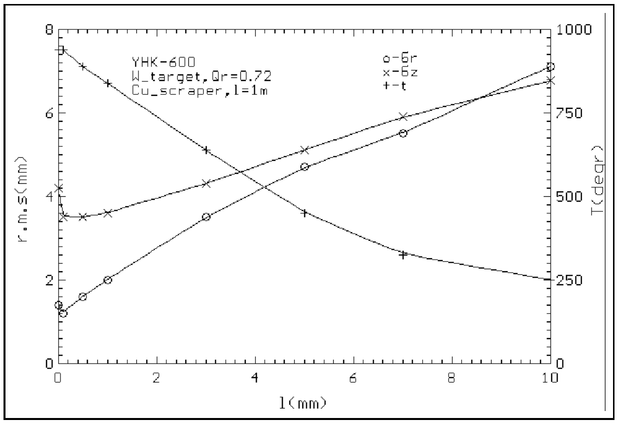

Figure 3: Beam sizes on the absorber and its maximum heating from thickness of the target.

The absorber heating, in view of large impact parameter of protons from them scattering on the target, not depends on regimes of system work, but defined from its energy and intensity. With increased thickness of the target magnifying the beam sizes on the absorber because of increasing the scattered angles of protons and therefore decreasing the maximum scraper heating (fig.3). When intercepted $0.5\% I_0$ the halo beam with the energy $600\,GeV$ by the system without target the maximum momentary heating of copper absorber reaches $1000^\circ\ C$. By using $10\ mm$ tungsten target the heating of most heated region reduces in four times. Such the momentary heating of copper absorber at intercepted 1% of beam with energy 600 GeV (fig.4) and 10% of beam with energy $70\,GeV$ does not exceed $500^\circ\ C$.

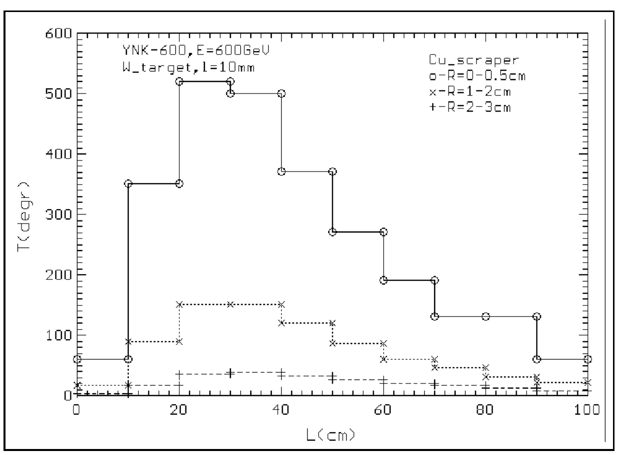

Figure 4: Momentary heating of copper absorber at intercepted 1% of beam with energy 600 GeV.

In case of approximation of the transverse distribution of energy deposition by cosine function, the changing temperature with time is shown by simple expression:

$$T = T_0 e^{-kt} \times cos\frac{\pi x}{2l},$$

where $k = \frac{\kappa\pi^2}{4l^2}$ is the coefficient that characterizes the rate of absorber cooling , l - thickness of absorber. Then the maximum absorber heating will be $T_{max} = T_1(1 + e^{-kt})$, where T_1 is the maximum temperature changing at single intercept of the halo beam. When used cooper blocks with thickness $l_b = 5\ sm$ and the same thickness of the frame(fig.1) like energy absorber the heating enlargement during the many acceleration cycles will be the least from the considers substances: $\Delta T = T_1 e^{-kt} = T_1 e^{-3}$. The additional increase of a heating will occur because of presence thermal resistance between blocks and frame α_1 and between frame and pipes with cooling water α_2:

$$\Delta T = \frac{dQ}{dt} \cdot (\alpha_1 + \alpha_2).$$

Considering above-mentioned facts and technology production, cooper as an absorber substance is chosen. In that case at multiple intercept the halo beam with consideration of machining contacting surfaces not less then 4 precision class and water cooling the temperature of most heated region to enlarge weakly $\Delta t \sim 100^\circ$ C.

The designed scraper system with W target and Cu absorber allows in stationary regime intercepted up to 10% of the beam intensity $6\times10^{14}\ p$ at $E = 70\ GeV$ and up to 1% at $E = 600\ GeV$. In accident case can allow intercept not more then 3% of beam from the possibility of destruction the tungsten scattering target.

4 REFERENCES

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