EFFICIENCY OF THE UNK SCRAPER SYSTEM

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Abstract

Optimum collimators location and choice of their apertures with the purpose of decreasing the flux of outscattered protons in circle is considered in this paper. The analytical and computer graphic methods are used for solution of this task. Statistical modeling of forming beam process are made for the UNK and sources of lost protons are defined. With the help of the scattered proton traces out from the system and special curves the correct installation of collimators can be defined. The optimum set and efficiency of collimators can be defined by showing collimator jaws on the phase planes in the scraper place. Also the advantages of systems with the scattering target are considered. It is shown, that the losses in the circle are $\sim 0.05\%$ from all scraped protons in the UNK.

1 INTERCEPTING COLLIMATORS

To trap the protons, outscattered from a scraper, collimators installed downstream are used. An optimum location of collimators and displacement them jaws$^{/1-3/}$ can be found from outscattered protons trajectories which are defined by initial coordinates at scraper $x, x',\ \delta = \Delta p/p$ and magnet structure of the accelerator:

$$\begin{aligned} x = &\sqrt{\tfrac{\beta}{\beta_0}}(\cos\Delta\psi + \alpha_0 \sin\Delta\psi)(x_0 - \eta_0\delta + \Delta x) \\ &+ \sqrt{\beta\beta_0}\sin\Delta\psi(x'_0 - \eta'_0\delta + \Delta x') + \eta\delta, \end{aligned} \tag{1}$$

where α, β - Twiss parameters, η ,η'- dispersion and its derivative, $\Delta\psi = \psi - \psi_0$ - a change of a phase betatron oscillations from scraper, $\Delta x'$ - scattering angle. The parameters with index "0" correspond to scraper location.

In the case of dispersion absence in system $\eta_0, \eta = 0$ for particles, which were on a phase ellipse with maximum coordinate x_0, with appreciation $\Delta x \lll x_0$, the movement equation become more simple:

$$x = x_0\sqrt{\beta/\beta_0}\cos\Delta\psi + \Delta x'\sqrt{\beta\beta_0}\sin\Delta\psi. \tag{2}$$

Let us assume that coordinate of scraper edge $x_0 = m\sigma,\ \sigma = m\sqrt{\varepsilon\beta_0}$, where ε is a beam emittance. Distance from a beam axis to collimator jaw is $x_c = \pm n\sigma_c = \pm n\sqrt{\varepsilon\beta}$, where the mark " $+$ " means the jaw installed at the same side as the scraper from beam and " $-$ ", when any. In this case the collimators intercept particles with amplitude more then $k\sigma$:

$$k^2 = m^2 + (\pm n - m\cos\Delta\psi)^2/\sin^2\Delta\psi. \tag{3}$$

The collimator position, when to trap outscattered particles with minimum amplitude, is defined from(3):

$$\Delta\psi = \pm arccos(\frac{m}{n}) + \pi i, \qquad where \quad i = 1, 2, \ldots .$$

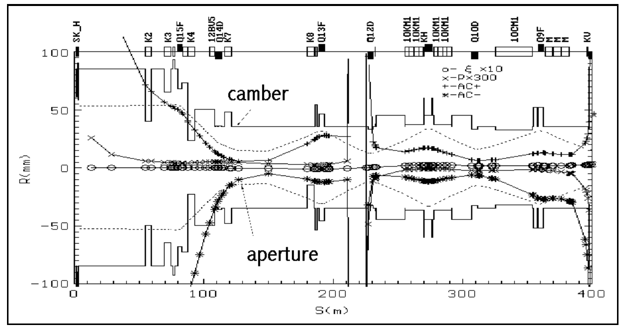

Figure 1: Horizontal plan of SS1,UNK-600

In this case the size of a beam, which not interacting with collimator, coincides with collimator aperture, that is $k = n$. It is desirable to install the collimators as possible closer to the scraper (i=0,1,...), in order not to irradiate the equipment stand between them. The size k is defined by the narrowest place in the accelerator.

The particles escaping from the system may change also a moment. In case of dispersion availability the displacement of outscattered proton may be presented like:

$$x = \tilde{x} + \delta\xi, \tag{4}$$

$$\xi = \eta - \sqrt{\beta/\beta_0}(\cos\Delta\psi + \alpha_0\sin\Delta\psi)\eta_0 - \sqrt{\beta\beta_0}\sin\Delta\psi\eta'_0,$$

where $\tilde{x}$ - coordinate of escaping particle with equilibrium moment. Consequently it is necessary else to consider such way will be scrape particles with changed moment on the main collimators, and then may define the necessity to install the additional collimators.

In order to reduce of outscattered protons from the system it is necessary to take into account, that their density on the edges of collimators jaws was as small as possible. If we know normalized angular density of protons, scattered by the system target and scraper $\rho_0(x')$, and its intensity I_0, then density of protons on the edge of collimator jaw can be defined as

$$\rho = I_0\rho_0(x')\cdot p(s) \quad \text{, where } p(s) = \frac{1}{\sqrt{\beta\beta_0}\sin\Delta\psi}.$$

Having drawn on plan(fig.1) the curves $Ac = k(s)\sigma$, which define a displacement of collimators jaws, intercepting particles with amplitude of betatron oscillations exceeding $n\sigma$, and knowing distribution function of density on the jaw edge, it is rather simply to define an optimum location and aperture of collimators. The collimators jaws are desirable to install in places with least density p(s) and minimum significance $k(s)$. To trap the protons with changed moment it is necessary to know the dependence $\xi(s)$ (fig.1)

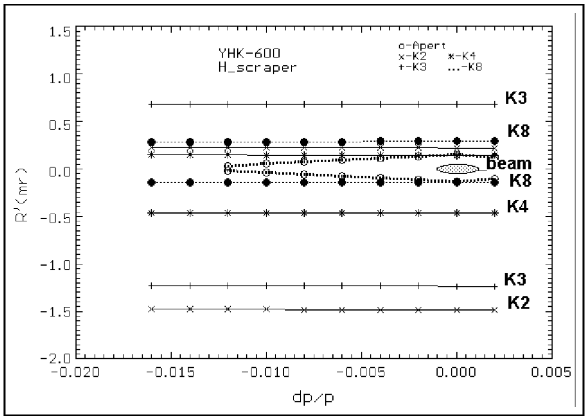

Figure 2: Position of collimator jaws on the phase plane r',p in location of horizontal scraper.

and in places with sufficient size of this function (4) to install additional collimators.

The particles outscattered by a scraper can significantly change deviation in vertical plane and to pass through the hole of horizontal collimators put on the equipment. With the purpose of interception such particles it is necessary to install a minimum two additional collimator jaws in vertical plane. The dispersion in vertical plane in circular accelerator usually is negligible. Therefore at the account of system we shall consider only particles with equilibrium moment:

$$z = z_0(\sqrt{\beta/\beta_0}\cos\Delta\psi + \alpha_0\sin\Delta\psi) + (z'_0 + \Delta z')\sqrt{\beta\beta_0}\sin\Delta\psi. \quad (5)$$

For particles with different initial coordinates z_0 there will be the different optimal position of collimators. Let us consider a particle with zero coordinate $z_0 = 0$, that equals to average size of particles coordinates of the whole beam. Such particle at hit on collimator edge will have an angle $z'_1 = n\sqrt{\varepsilon/\beta_0}/\sin\Delta\psi_z$.

Maximum coordinate z of betatron oscillations which can have a scattered proton escaping from the scraper $z_0 = m\sqrt{\varepsilon\beta_0}$. That is the maximum amplitude of protons (in vertical plane), which can pass in the accelerator circle, will be $A_z = k\sigma$, where $k^2 = m^2 + (\alpha_0 m + n/\sin\Delta\psi_z)^2/\beta$. So as $\alpha_0 \simeq 0$ in scraper location in UNK-600 $k^2 \simeq m^2 + n^2/\sin^2\Delta\psi_z$. Then the optimum position of such collimators will be in case: $\Delta\psi_z = \frac{\pi}{2} + \pi i$, and the maximum amplitude of vertical betatron oscillations of outscattered protons, that will pass in circle will be $A_z = \sqrt{m^2 + n^2}\,\sigma$.

Analogically, as well as in case of radial plane, by drawing curves $Ac(s)$ and $p_z(s)$ on plane, it is possible to define optimum position and aperture of vertical collimators.

In order to visualize the losses process on plan it is possible to draw trajectories of particles leaving from a scattering element with some angles and moments. The places of intersections the consequent trajectories with vacuum chamber or magnet elements define a location of expected losses. For further consideration of system work it is necessary to take into account the collimators as a source of scattered protons.

2 METHOD OF PHASE PLANES

By way of drawing inner edges of collimators jaws on the phase planes in scatterer position(target, scraper, collimator or another equipment) it is possible to define the optimum set and sufficiency of collimators. On the fig.2 the location of jaws and circulating beam on the phase plane x',p is shown. Two-dimensional consideration is possible because the protons leave scraper with the same coordinate x_0. The jaws surfaces are imaged by straight lines, that defined by expression received from (1):

$$x' = x'_0 + \frac{x_c - x_0\sqrt{\beta/\beta_0}sin\Delta\psi}{\sqrt{\beta\beta_0}sin\Delta\psi} - \frac{\delta\xi}{\sqrt{\beta\beta_0}sin\Delta\psi},$$

which must be disposed outside of circulating beam region. If in straight section there are not large magnet dipoles, then the lines will be almost parallel to an axe abscissa, since $\xi(s) \sim 0$. If it is necessary to trap the protons with large moment displacement the collimators should be install in normal periods. Then the lines, representing the jaws surfaces, will have slope that proportional to $\xi(s)$. From the picture one can see the duplicating of the jaws, although for the interception of scattered particles in one transverse plane is enough two, that disposed at any sides from circulating beam. The additional collimators are used for protection of the equipment in straight section from the particles are obtained from nuclear reaction and for interception the scattered particles from the main collimators. On the phase plain it is possible to image the narrowest places in accelerator. In our case these are some places of vacuum cambers of normal periods, that are imaged by dotted line. The protons scattered by the system located on the phase plane outside of accelerator aperture between nearest to the beam collimator jaws(K4,K8), which have small vertical amplitude of betatron oscillations, will be lost in the accelerator circle. Knowing distribution of scattered protons it is possible to find losses on the collimators and the equipment by considering them consecutive along downstream.

In view of the fact that dispersion in vertical plane is close to zero it is enough to consider the phase plane z,z'. The edges of collimator jaws will be imaged by straight lines and circling beam - by ellipse(5).

3 ESTIMATION OF LOSSES

There are two main sources of scattered protons which are lost in circle:

- scraper and scattering target;
- main collimators.

The particles escaping from the scraper with big amplitude of betatron oscillations are intercepted by main collimators in radial and vertical planes. The protons pass in the circle with changed moment and put in places with big bend magnets. With decreasing the aperture of collimators the quantity of such particles decreases, but from the increasing the density of protons on the edge jaws the losses in the

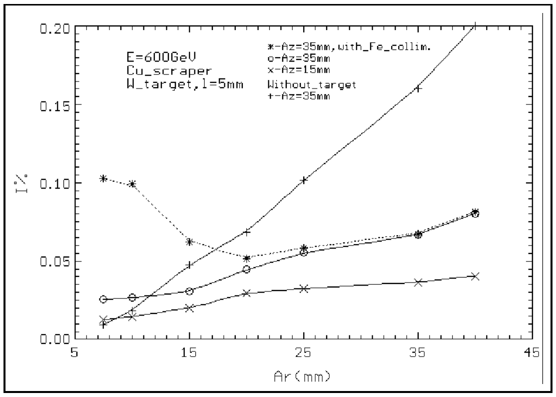

Figure 3: The losses in the circle from main collimators aperture.

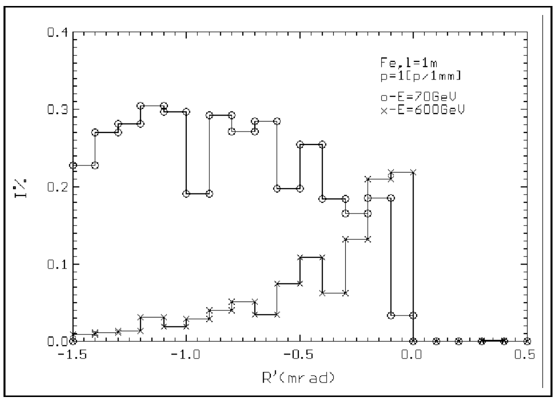

Figure 4: Distributions of the protons scattered by steel collimator for angle.

circle grows. Solid lines show the dependencies with using the collimators of full absorption and dashed line - with using the collimators on the base of iron. In first case with diminution collimator aperture the flux of scattered particles in the circle decreases. In the second case is minimum of losses I ~0.04% when aperture of main collimators are $A_{r,z} = 20 - 25\ mm(\beta = 152\,m)$. By using the system without target such losses will increase twice.

Fig.4 represents calculated distributions of protons scattered by steel collimator on the angle at beam energy 70 and 600 GeV at the density of hitting beam is 1p/mm. From distribution it is visible, that at small energies the flux of scattered protons is more, but fraction of particles that pass in circle is about identical, since even without using of additional collimators particles with scattered angle from $x'_1 \sim 0.1$ to $x'_2 \sim 0.2\ mrad$ will be lost in circle. That is quantity of such particles is possible to estimate $I \simeq 2\Delta x'_c \cdot P_c$, where $\Delta x'_c = x'_2 - x'_1$, and P_c - average angle proton density in this interval.

In order to define the density of scattered protons on the collimator edges it is necessary to know normalized angular density of the protons leaving from the scraper and the target $\rho_0(x')$. Then density can be estimate: $\rho(x) = I_0\rho_0(x')/\sqrt{\beta\beta_0} sin\Delta\psi$, and the size of losses of such particles in circle will be $I = I_0\lambda$, where $\lambda = 2\frac{\Delta x'_c \cdot P_c \rho_0(x')}{\sqrt{\beta\beta_0} sin\Delta\psi}$. For UNK-600 decreasing coefficient will be $\lambda \sim 4 \cdot 10^{-5}$, but with consideration of additional scattered protons on any collimators except main the real coefficient is increased twice. By using the system without target its fraction of losses is doubled. That is the main part of losses in the circle form the protons with change moment. For superconductor accelerators interception of such protons is especially important. In UNK-3000 the additional collimators can decrease a level of losses in circle up to 0.01% from the intercepted halo beam.

4 REFERENCES

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