INDUCED RADIOACTIVITY DECREASE METHOD IN HIGH INTENSITY LINACS

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Abstract

To keep induced radioactivity to retain hand-on maintenance is a main task of high intensity linacs design. It was shown that in order to solve the problem, the inside of the accelerator tubes should be covered by a layer with a low radionuclides yield. The energy distributions of the layers thickness were obtained for ion fall at small angle to the layer. It is also shown that the low secondary particles yield from the layer allows the utilisation of hard magnet focusing lenses.

1 INTRODUCTION

The significant and permanent interest to new technologies on destruction of nuclear wastes, plutonium disposition , etc. stimulate the design of 1 GeV energy and 100 mA current accelerators . The major problem in the creation of such accelerator is the ensuring of the radioactivity level for hand-on maintenance of the equipment. In the submitted work a solution of this problem approach is considered, namely the use of graphite for the lost particles absorption. The estimations are made for parameters of the accelerator design offers, put forward in ITEP [1]. The accelerator consists of an injector, RFQ, DTL (7 - 100 MeV) as intermediate part, and main part (up to 1000 MeV), consisting of resonators placed between the focusing quadrupoles.

2 Low radioactivity "graphite" accelerator

The strong restrictions to particle losses arise at the energy of about 10 MeV, if copper is used as the material for the accelerating channel (see Fig. 1, the curve 2 from [2]). The curve 1 on Fig. 1 is obtained by proportional transformed of particle losses in LAMPF [3] on a 100 mÀ current level. As it can be seen to retain hand-on maintenance, sufficiently lower beam losses are required.

The radiation problems can be solved not only by great decrease of the particle losses in comparison with the achieved level, but also by application of materials, having considerably smaller induced radioactivity yield. One of such materials is, for example, graphite, for which advanced technologies of use in radiation technique are available.

If copper is replaced by graphite in any linac parts, where particles absorption takes place, the level of radioactivity will be considerably lowered. The estimate calculations are made for homogeneous distribution losses along accelerator (the main information sources are [4,5,6,]. The analysis shows the following:

The accelerator becomes practically free from

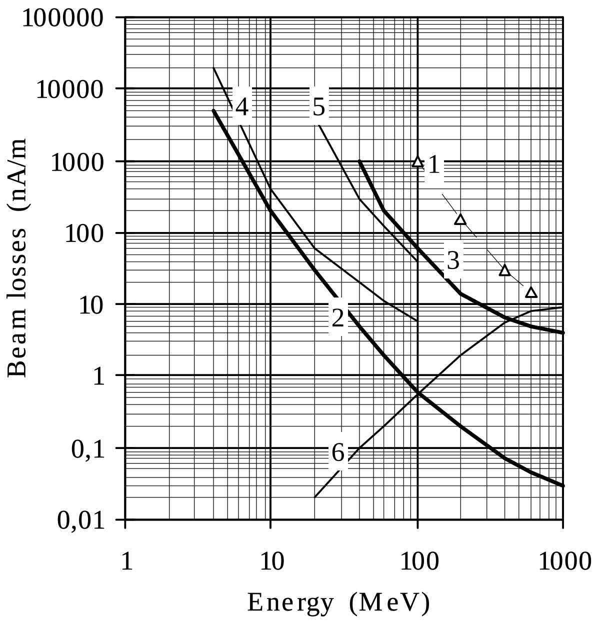

Figure 1. Beam losses characteristics.

1 - beam losses in LAMPF transformed for I = 100 mA;
2 and 3 - allowable beam losses for hand maintenance in the case of copper or graphite use;
4 and 5 - allowable beam losses in permanent magnets in the case of copper or graphite use;
6 - rms depth of lost protons penetration in graphite (left scale in mm).

radioactivity up to energy of 25 MeV. In this range, residual radiation is caused by ^{13}N and ^{11}C radionuclides with half-life of 10 and 20 minutes accordingly and, hence, radiation near the accelerator is quickly reduced to allowable level.

For greater energies, induced radioactivity level is also lower (curve 3). At proton energy above 500 MeV the doze rate 2 hours after accelerator stop becomes by factor of 100 less, than in case of copper used (accurate to within a factor of two).

As it can seen (curve 4 and 5), beam focusing can be provided in DTL by permanent magnets, because neutron yield for carbon is less than 10 % compared to that for copper.

3 LOST PARTICLES TRANSPORT PROPERTIES

The principal possibility of using graphite in designs of the linac's accelerating channel laies in the physical process features of particle losses in the accelerator. As the accelerated beam has small phase volume, the lost particles fall on the inside of beam pipes with slip angle less than 10 mrad and hence, their trajectories pass in a thin surface layer. The depth of the proton penetration is increased due to multiple scattering of protons on atoms of the wall. Nevertheless, the thickness of this layer remains rather small and there are of most amount of the nuclear collisions.

For an estimation of a protons penetration depth into a wall it is possible to use the model of the thin beam transport inside the substance. After the passage of distance z inside the substance the average square of its radius is increased according to the law [7]:

$$\left\langle r_z^2 \right\rangle \cong 0.10 \left\langle \vartheta_s^{\,2}(\gamma_0) \right\rangle z^3 (1+\gamma_0)^2/\gamma_0 \ . \qquad (1\ )$$

Here $\left\langle \vartheta_{\breve{u}}^2(\gamma_0) \right\rangle$ - increase of the mean square of a angular deviation on unit of a path, γ_0 - initial relativistic factor. The path z does not exceed ionisation free path R_0 .

As process of particle losses of as well as their interaction with a wall substance , fit in the statistical laws, so there is the mean square of a slip angle - $\left\langle \alpha_m^2 \right\rangle$. Then a mean-square depth of penetration in a wall after the passage of a path z is defined by the expression

$$\left\langle t_z^2 \right\rangle = \left\langle \alpha_m^2 \right\rangle z^2 + \left\langle r_z^{\,2} \right\rangle, \qquad (2)$$

The particles distribution on penetration depth in a wall is a superposition of distributions for the particles, with a wall path from 0 up to R_0 . Taking into account, that the particles with large path have large probability to have nuclear interactions, we shall define complete rms depth, as follw:

$$\left\langle t^2 \right\rangle = \frac{1}{R_0} \int_0^{R_0} \left\langle t_z^2 \right\rangle e^{-\Sigma_t z} dz \ , \qquad (3)$$

where Σ_t is the total cross section of nuclear interactions. That integral is expressed in terms of gamma-functions. Curve 6 shows the calculated rms depth of protons penetration in carbon wall vs particle energy. It would emphasise the dependence correspond to the uniform beam losses in carbon tube without a magnetic field.

We shall now consider the process of losses on the accelerator structures. The particle has its first collision with a wall where the beam envelope has its maximum - inside a focusing. lens. The slip angle can vary from 0 up to α_m Let us α_m .equal to maximum input angle for symmetric path of a lens [9]:

$$\alpha_m = (2aK/D\sin K)/(1+\cos K). \qquad (4)$$

Here *a*-aperture radius, *K* and *D*-rigidity and length of a α_m = 0.01-0.02 rad for the considered accelerator.

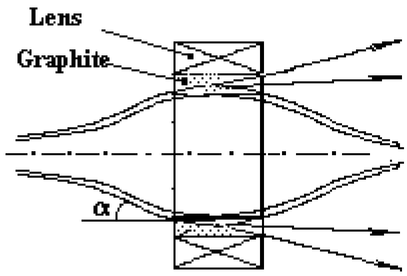

Figure 2. Beam losses in side focusing lens

At a small slip angle its size is connected with the path in the accelerating tube wall by a simple ratio:

$$\alpha = \alpha_m \Delta z / D \ . \qquad (5)$$

Also, the penetration depth for unscattering protons is

$$t_\alpha = \alpha^2 D / 4\alpha_m \ . \qquad (6)$$

Thus the inside lens penetration depth is equal to the quarter of that outside it. So calculated rms depth is the upper estimation that.

The particles undergo multiple reflection prior to their absorption. As culculations show [9], the reflection factor is about 0.9 for 500-1000 MeV protons falling at $\alpha = 1$ mrad to iron surface without a magnetic field. So halo of scattering particles takes place. Its current is greater than the loss current density by factor of N_{ref} /2 transverse oscillation lengths. A number of reflection N_{ref} is dependent on a slip angle of the first scuttering. If the slip angle are small, the increase of the oscillation amplitude A of the particle is $\Delta A \approx A\alpha^2/\alpha_m^2$ and $\Delta\alpha \approx \sqrt{\Delta A}$. It is assumed that the first slip angle equals to the angle of the complete reflection [10] (it is the analogue of a surface channelling angles):

$$\alpha_r \approx 1.5 \cdot 10^{-3} \sqrt{\rho / E} \ , \qquad (7)$$

where ρ - density (g/cm^3), E - energy (MeV).

It is assumed that the scuttered particles distribution is smoothing on beam pipes, if after passing through a lens the particles have a gain of a angular deviation equaled to α_m. The slip angle of the losses delocalization, is

$$\alpha_{del} = \alpha_m^3 / D \left\langle \vartheta^2(\gamma_0) \right\rangle . \qquad (8)$$

For that angle, the path is equal to about 0.1 of the ionisation free path. This angle exceeds α_m at the energy range of 200-400 MeV, as here Δz exceeds D . In this energy, the particles path is comparable with the lens length. For the energy near 300 MeV, the ionisation free path is comparable to the nuclear scattering free path. Hence, at smaller energy there is the fast expansion of losses distribution on the accelerator tubes. At greater energy the losses remain located inside the focusing lenses and any inside lenses part of beam pipe becomes an intense source of secondary particles and scattering protons. The beam of lost particles is strongly anisotropy, therefore at the rather large magnetic aperture of the lens, most particles will leave the lens to be absorbed in the accelerating cavities.

4 DESIGN LINAC TRANSPORT ELEMENTS

The use of graphite has effect with least construction changes in the DTL part of the accelerator. The graphite is placed inside the accelerator (drift) tubes. The absorber thickness is chosen from constructive reasons, but it is not less than 2-3 of rms proton penetration depth. The thickness ranges from 0.1 mm at 5 MeV up to 2 mm at 100 MeV.

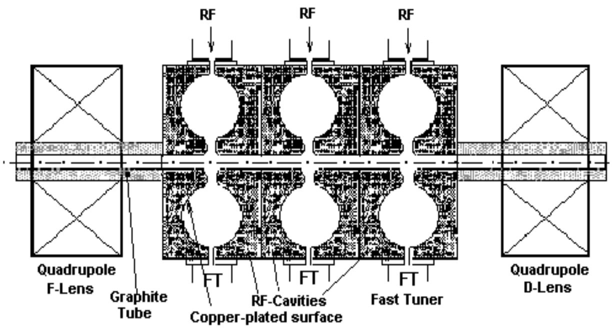

Figure 3. Structure unit of the LINAC main part.

In the main part of the accelerator the inside lenses tubes are manufactured from carbon. The minimum wall thickness gradually grows from 2 up to 20 mm. The single-gap toroidal resonators are manufactured from graphite with copper plated inner surface of all RF junctions . The thickness of the copper layer ranges from 0.01 up to 0.1 mm. Here the quadrupole lattice is FODO with focusing period less than 4 m and field gradient below 20 T/m. As the magnetic aperture diameter is big enough (15-20 m), secondary particles and scattering protons will leave the lens space and enter the accelerating cavities. It is possible the beam aperture inside lenses is made greater the aperture inside cavities. That enable to smooth the distribution of beam losses.

5 CONCLUSION

The use of graphite components improves considerably the radiation situation at the high power linac. However, to have hand-on maintenance relative beam losses should be less than those in LAMPF. The required improvement of the beam dynamics quality can be feasible due to the big progress of the accelerator science and engineering during the latest 20 years.

Further development of the proposed version of the accelerator design requires thorough numerical calculations. The understanding of the picture of the transport of particles being lost, which undergo multiple reflection prior to their absorption, will help the development of methods for smoothing out the distribution of losses.

It is also necessary to solve technical problems of graphite use in deep vacuum and strong electric fields.

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