ESTIMATION OF THE ELECTRON EMISSION FROM THE RCS COLLIMATOR

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Abstract

The RCS of J-PARC accelerator complex has been commissioned since September 2007. By a study of one year, we were able to demonstrate more than 200kW beam operation. In such high intensity operation, the electron cloud effect may have an important role for the accelerator limitation. We estimated the electron emission from the collimator surface of RCS by a simulation.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) project is a joint project of Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK). The accelerator complex consists of a 181MeV (at the first stage) or 400MeV (at the second stage) linac, a 3GeV Rapid-Cycling Synchrotron (RCS), and a 50GeV synchrotron Main Ring (MR) [1]. The RCS ring accelerates a proton beam up to 3GeV and supplies it to the MR and the neutron production target. The beam commissioning of RCS have been started since 2007[2]. At the latest study, the J-PARC RCS ring accelerated $1.8*10^{13}$ protons per pulse at a repetition rate of 25Hz. This value corresponds to more than 200kW beam power operation. In this demonstration, 5.6% beam losses were occurred during the acceleration period and almost all losses were absorbed in the collimators.

In the previous estimation, the secondary electron yield (SEY) per one proton was assumed to be 100. By using this assumption, we calculated the influence of the secondary electron cloud due to the beam loss during 200kW beam operation[3]. A tune shift due to the electron cloud is expressed as follows[4].

$$\Delta\nu_{x(y)} = \frac{r_p N_e < \beta_{x(y)} >}{2\pi\sigma_{x(y)}\left(\sigma_x + \sigma_y\right)} \qquad (1)$$

Here r_p is the classical radius of a proton, σ is the beam size, $<\beta>$ is the averaged β function, N_e is the number of electron in the electron cloud and $\Delta\nu$ is a tune shift due to the electron cloud. As a result, the estimated tune shifts were 0.46 for the horizontal betatron oscillation and 0.52 for the vertical betatron oscillation [3]. They were considerably larger than the measured tune. If $\Delta\nu$ were such a large value, we would not be able to accelerate a 200 kW beam because of the massive loss due to the tune shifts. We think that the reason of the overestimation is the assumption of the SEY per one proton. Therefore, we estimated the number of the secondary electron due to the beam loss during 200kW beam operation.

BEAM LOSS IN RCS

We measured with current transformers (CT) and beam loss monitors (BLM) during 200kW operation. We estimated the number of lost protons in the RCS by these results. The CT measurement result shows that the loss during the acceleration period was 5.6%. The loss occurred during 2 ms after injection start and after that there was no additional significant loss. This fact meant that the lost beam energy was almost injection energy (181MeV). Further, the BLM signals also indicated that almost all lost particles were absorbed in the collimators. We have one primary and five secondary collimators in RCS. The transverse primary collimator consists of horizontal and vertical scatterers, and is installed in the entrance to the collimator region. The five secondary collimators are installed in the downstream of the transverse primary collimator[5].

From the BLM signals and distribution of the residual dose around the RCS tunnel, we can consider that almost all losses are concentrated on these collimators.

SEY DEPENDENCE ON THE ANGLE AND THE STOPPING POWER

The SEY per incident proton is expressed as follows[6].

$$\gamma = \Lambda_M \left(\frac{dE}{dx}\right)_e \frac{1}{\cos\theta} \qquad (2)$$

Here γ is the SEY from the surface, Λ_M is a constant for a material, $(dE/dx)_e$ is the electronic stopping power, θ is the angle of incidence with respect to a line perpendicular to the surface. The RCS collimators were covered with TiN coating in order to reduce the SEY due to the electrons. The incident angle dependence of the SEY from TiN coated surface was measured by Hanson[7]. Since the incident proton energy of measured data was 28MeV, the ratio of $(dE/dx)_e$ at 28MeV to $(dE/dx)_e$ at the lost beam energy (181MeV) was multiplied by the SEY data in order to normalize the measured data to the RCS injection energy. In this case, the ratio is about 0.25. The normalized SEY curve is shown in figure 1. When θ is small, γ is very small and γ increases rapidly with an increase of θ.

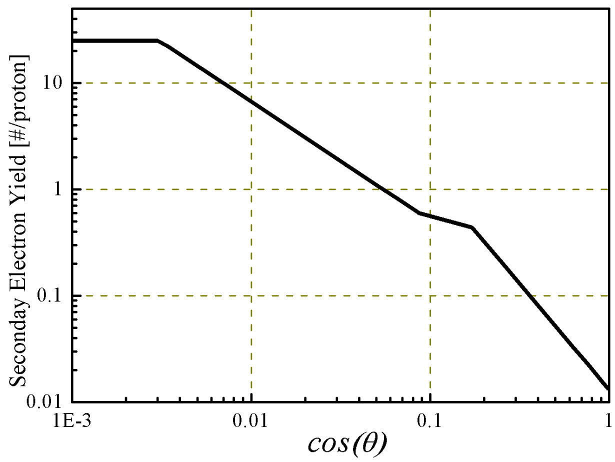

Figure 1: Normalized SEY curve.

RESULTS AND DISCUSSION

Electron Emission from the Primary Collimator

The following three patterns can be assumed as ways to hit the primary collimator with an incident proton(See figure 2).

a) A proton incidents on the front surface of the primary collimator, and escapes from the side.
b) A proton incidents on the side surface of the primary collimator, and escapes from the rear.
c) A proton incidents on the front surface of the primary collimator, and escapes from the rear.

Here, since the incident or exit angle θ of the case c) is small ($cos\theta \approx 1$ at incidence and exit), the SEY of case c) is much smaller than the SEY of case a) and b) because of the SEY dependence on the incident (or exit) angle. Next, we compared the SEY of case a) and case b). In these case, the secondary electron emission from the front or rear surface is much smaller than the secondary electron emission from the side because of the same reason of the case c). Thus we compared the ratio of the backward yield γ_B and the forward yield γ_F. γ_B means the backward electron yield on the occasion of a proton incidence on the front surface and γ_F means the forward electron yield on the occasion of a proton exit from the rear surface. γ_F and γ_B can be written by the partition factor β_s;

$$\gamma_B = \gamma\beta_s \quad (3)$$

$$\gamma_F = \gamma(1-\beta_s) \quad (4)$$

Previous measurement data[8] show that β_s is 0.3-0.5. Therefore, γ_F would be 1-3 times larger than γ_B. This is due to the fast δ-electrons which were scattered over the forward direction.

As a result, it is thought that the case a) would cause the largest emission.

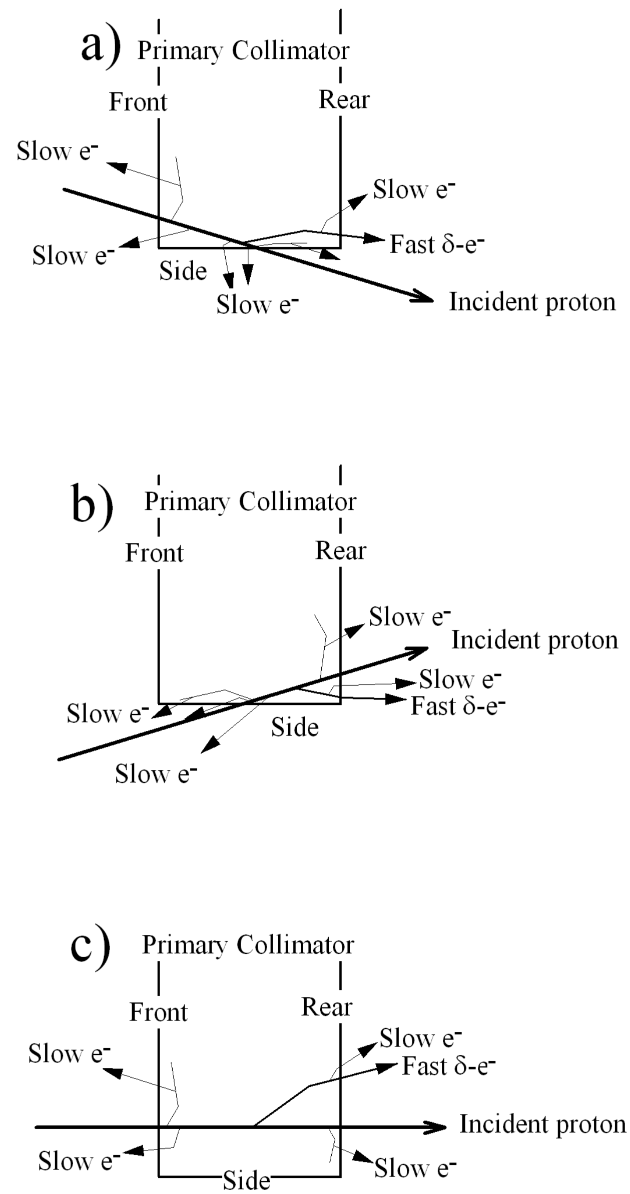

Figure 2: Patterns as ways to hit the primary collimator with an incident proton.

On the other hand, it is thought that the incident (halo) protons which hit on the primary collimator are diffused around the beam emittance, therefore the angle of incident proton would be almost same as the angle on the edge of emittance at the primary collimator(See figure 3). In the RCS, the twiss parameter α_x at the primary collimator is positive and α_y is negative. This means that the direction of the horizontal lost particle (which hit on the horizontal primary collimator) is inward. The angle of the horizontal lost particle with respect to a beam center axis is 7 mrad. at the primary collimator.

Then, as the worst case, we assumed that all losses are the horizontal lost particles of the case a) and the partition factor β_s is 0.3, the SEY per one proton is estimated as 21.24.

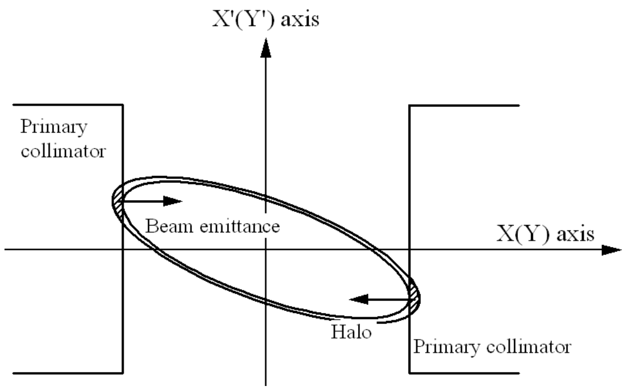

Figure 3: The angle of the lost (halo) particle.

Electron Emission From the Secondary Collimator

A particle scattered by the primary collimator enters into the secondary collimator or a vacuum duct with various angle. Therefore, the scattering angle by the primary collimator and a track after scattering were calculated by the STRUCT code[9]. The amount of the SEY was evaluated from the incident angle of lost point that had obtained by the tracking result.

Calculation result indicates that the SEY per one proton is 0.947. This is much smaller than the SEY of the primary collimator. In this case, θ becomes much smaller because the secondary collimator is suddenly protuberant and almost scattered particles incident the front surface of the secondary collimator(See figure 4). As a result, the SEY from the surface becomes smaller.

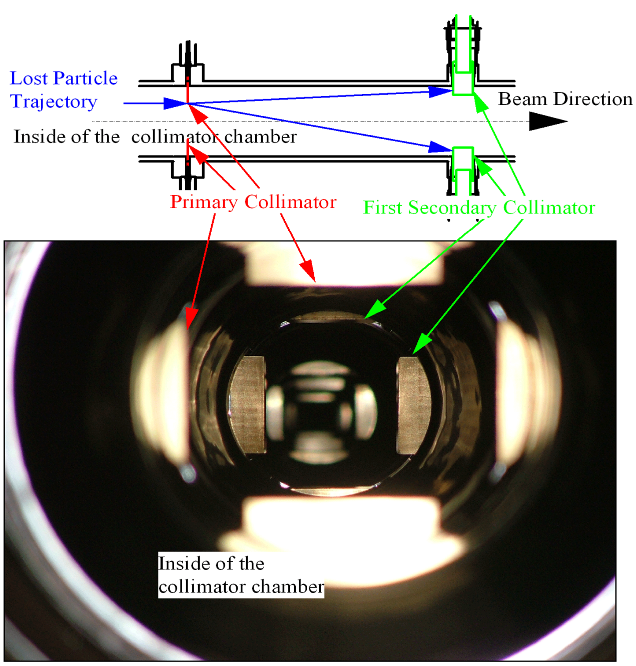

Figure 4: Inside of the collimator chamber.

CONCLUSION

We estimated the SEY due to the beam loss during 200kW beam operation. If we assumed worst case, the SEY per one proton is estimated at about 22, and almost electrons were produced at the primary collimator. The number of electron becomes 1/5 compared with previous assumption (the SEY per one proton is 100) and tune shift due to electrons becomes 1.0-1.1. It still seems an overestimate.

Although it was also overestimation, it can be thought that the primary collimator becomes the main source of the secondary electrons in RCS. Therefore, for the further beam power upgrade, it is very important to take measures of the secondary electron to the primary collimator.

REFERENCES

[1] Y. Yamazaki *et al*, Accelerator Technical Design Repor for High-Intensity Proton Accelerator Facility Project, J-PARC, KEK-Report 2002-13; JAERI-Tech 2003-044.

[2] H. Hotch *et al*, “Status of J-PARC commissioning”, Proc. 42nd ICFA Advanced beam dynamics workshop HB2008 (2008).

[3] K. Yamamoto *et al*, “Estimation of Secondary Electron Effect in the J-PARC Rapid Cycling Synchrotron after First Study”, Proc. 4th Vacuum and Surface Sciences Conference of Asia and Australia (VASSCAA-4) (2008).

[4] K. Ohmi, F. Zimmermann and E. Perevedentsev, Phys. Rev. E **65**, 016502(2001).

[5] K. Yamamoto, Phys. Rev. ST-AB **11**, 123501 (2008).

[6] P. Thieberger,* A. L. Hanson, D. B. Steski, V. Zajic, S. Y. Zhang, and H. Ludewig, Phys. Rev. A. **61**, 042901(2000).

[7] A. L. Hanson et al., J. Vac. Sci. Tech. A **19**(5), 2116 (2001).

[8] H. Rothard, J. Schou, and K. O. Groeneveld, Phys. Rev. A **45**,1701(1992)

[9] A. I. Drozhdin. “STRUCT Program User’s Reference Manual”, http://www-ap.fnal.gov/users/drozhdin/