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Macro-particle simulation study on transverse halo collimator for J-PARC linac

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Abstract

To realize the transverse emittance required for the ring injection, a transverse halo collimation system of the charge-exchange type has been developed for J-PARC (Japan Proton Accelerator Research Complex) linac. In this type of collimation system, negative hydrogen ions constituting a tail portion are charge-exchanged to protons with thin foil collimators. Then, the generated protons are separated by a bending magnet to be delivered to a dedicated beam dump. Because a two-species beam is transported along the collimation system, a special care is to be taken to avoid the uncontrolled beam loss along the beam transport. To this end, it is of practical importance to develop an accurate numerical model that has the capability of both particle tracking with space-charge effects and modeling of scattering at the charge-exchange foil. In this paper, a numerical model is developed for the collimation system using a three-dimensional particle-in-cell code, IMPACT, and a Monte-Carlo simulation tool kit, GEANT. Uncontrolled beam loss along the collimation system has been evaluated with this model, and the optimum foil thickness has been determined for the collimation system.

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Keywords: Halo collimator; Foil thickness; Beam loss

1. Introduction

In a high-intensity hadron accelerator, extremely small fractional beam loss is required, because the beam loss of only a small fraction can cause severe residual radiation. The excess residual radiation may seriously undermine the maintenancibility of the accelerator component and consequently the total machine performance. Then, it is of essential importance to mitigate the uncontrolled beam loss to retain reasonable maintenancibility for the latest high-intensity hadron accelerators such as J-PARC (Japan Proton Accelerator Research Complex) [1,2] and SNS (Spallation Neutron Source) [3]. In the beam loss management, it is a common strategy to localize the beam loss to a restricted area with the lowest possible beam energy. One of the presumable causes for the uncontrolled beam loss is considered to be halo formation, where a sparsely populated beam halo is formed around a dense beam core [4,5]. Then, we often have a halo collimation system to realize the above-mentioned beam loss localization. In a high-intensity accelerator facility, successive collimation in a ring is usually used combined with one-path collimation in a beam transport before the ring injection. We focus on the one-path collimation in this paper, which is profitable in reducing the uncontrolled beam losses in the succeeding ring. The one-path collimation is advantageous especially when the beam loss at the ring injection, as is often the case, is a primary factor of limiting the attainable beam power for the whole accelerator complex.

In a high-intensity proton linac, negative hydrogen ions, instead of protons, are often accelerated to enable charge-exchange injection into the succeeding ring. In those cases, charge-exchange removal is a possible choice for halo

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collimation in the beam transport line before injection. In this scheme, a tail particle is charge-exchanged to a proton by a thin foil collimator in the first place. Then, the generated proton is separated from a main beam by a bending magnet to be delivered to a dedicated beam dump. As this scheme is advantageous in localizing the beam loss away from the main beam line, it has recently been adopted for both transverse and longitudinal collimators in high-intensity proton linacs [6,7].

The low-loss transport of the charge-exchanged particles is a prerequisite for this type of collimation system, because the beam loss of only a small fraction can cause severe residual radiation as mentioned above. Especially, the simultaneous beam transport of protons and negative hydrogen ions is supposed to be prone to an excess beam loss, because a certain transverse mismatch is unavoidable at the charge-exchange [7]. This mismatch arises from the fact that a focusing (defocusing) quadrupole magnet for negative hydrogen ions acts as a defocusing (focusing) magnet for protons, and it may lead to a large amplitude oscillation of the beam envelope usually for the generated protons. Then, careful estimation of the uncontrolled beam loss with a rigorous macro-particle simulation is essential in the design of this type of collimator. Above all, more accurate simulation is required for J-PARC, because the transverse collimator for its linac is accompanied with an extremely long beam transport of 67 m for the charge-exchanged protons.

The simulation code for charge-exchange collimator is required to have the following three capabilities, namely, tracking of a multi-species beam consisting of negative hydrogen ions and protons, modeling of space-charge effects, and modeling of scattering processes at the foil collimator.

A charge-exchange foil is often assumed in a heavy ion accelerator. Then, a number of tracking codes have been developed for the beam dynamics studies including the scattering effects, and some of them have capability of handling space-charge effects [8,9]. However, the scattering at the foil is often modeled with a random number generator with a specific probability distribution function [10–12]. In those modelings, the probability distribution function is determined by fitting the data obtained with a Monte-Carlo simulation of a scattering process. As shown

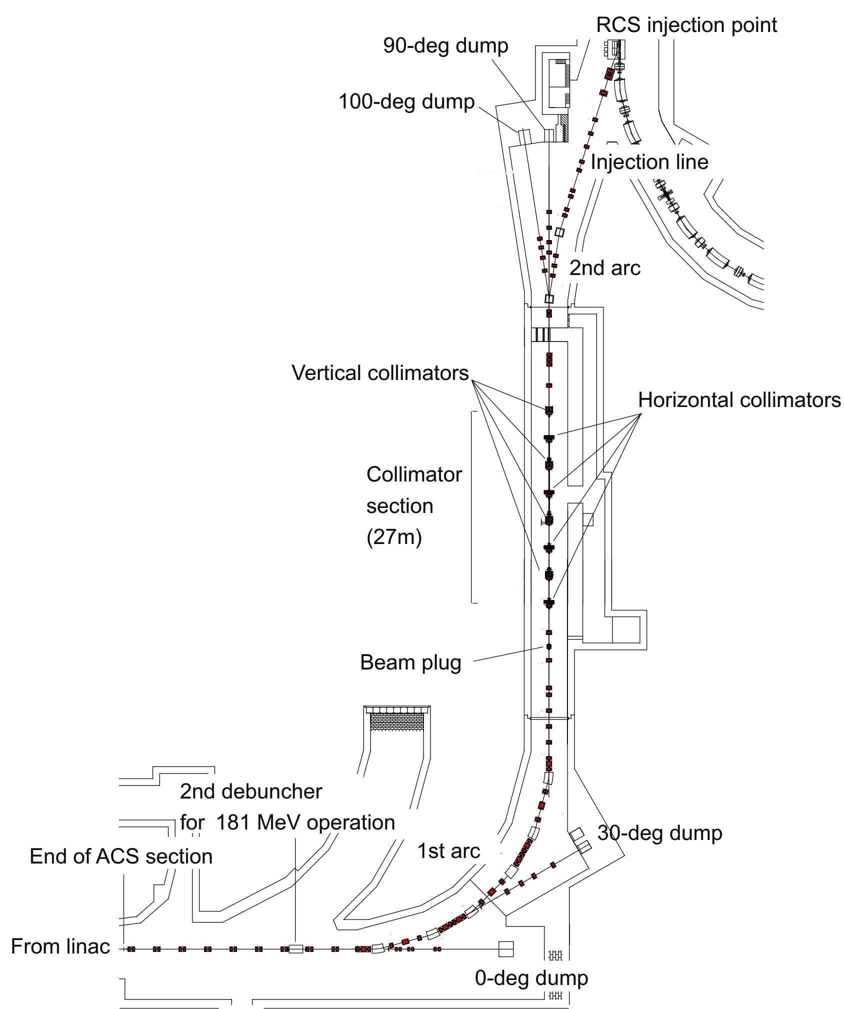

Fig. 1. The layout of J-PARC L3BT.