Available online at www.sciencedirect.com
SCIENCE DIRECT®
Nuclear Instruments and Methods in Physics Research A 562 (2006) 638–641
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Advanced design of high-intensity beam transport line in J-PARC

Shinichi Sakamoto[a,*], Shin-ichiro Meigo[a], Hiroshi Fujimori[b], Masahide Harada[a], Chikara Konno[a], Yoshimi Kasugai[a], Tetsuya Kai[a], Yasuhiro Miyake[b], Yujiro Ikeda[a]

[a]*Japan Atomic Energy Agency (JAEA), Tokai, Ibaraki 319-1195, Japan*
[b]*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*

Available online 6 March 2006

Abstract

A 3-GeV proton beam transport (3NBT) line provides high-intensity proton beam for an experimental facility of Japan Proton Accelerator Research Complex (J-PARC). Its beam optics and components were intensively designed to transport the proton beam of large emittance with extremely low loss rate. The 3NBT accommodates an intermediate target that causes large beam loss. The scheme of the cascade target system was carefully devised to overcome difficulties due to high radiation.

PACS: 29.27.Eg; 29.27.Fh; 29.25.Dz

Keywords: Beam transport line; Beam optics; Beam loss; Electromagnet; Proton beam monitor; Cascade targets

1. Introduction

Japan Proton Accelerator Research Complex (J-PARC) is being built in Japan Atomic Energy Agency (JAEA) as a joint project with High Energy Accelerator Research Organization (KEK) and due to start its operation in 2008. In Materials and Life Science Facility (MLF) [1], neutron beams and muon beams are utilized in wide research fields. These secondary beams are generated with 1-MW proton beam that is transported along a 3-GeV beam transport (3NBT) line [2] from a 3-GeV rapid-cycling synchrotron (RCS) [3].

One of the key issues is beam transport with quite low beam loss. The average loss rate should be less than ~1 W/m to conduct hands-on maintenance of the components in the tunnel. The total loss rate in the whole line would be in the order of 10^{-4}, more than one order of magnitude lower than the present proton beam transport lines in the world. The beam optics was intensively studied to transport the beam of large emittance under the condition of long and complex line layout. The components were thus designed to satisfy tough requirements from the beam optics for realizing ultimately low beam loss. Another issue is to take fundamental measures for large beam loss at a muon production target placed in cascade [4,5] along the proton beam line. Intricate problems on activated air, corrosive gas and cooling function were fully examined and a practical scheme was established.

2. Beam optics

The accelerator facilities and the experimental buildings are not necessarily placed in an ideal manner, since J-PARC is being built in the present site of Nuclear Science Research Institute, JAEA. The beam transport line from RCS to MLF extends as long as ~300 m and has complicated geometry with horizontal and vertical bend sections (Fig. 1).

The transverse emittance of the beam from RCS is rather large [3], compared with other proton accelerators in the world. The beam core has the emittance of 81 π mm mrad and its halo may extend up to 324 π mm mrad. To realize very low beam loss rate, the 3NBT line was designed to transport the beam up to the maximal halo rather than to scrape the halo part. The relation among beam size, phase advance in FODO lattice, total number of beam line magnets and its magnetic field strength was thoroughly

*Corresponding author. Tel.: +81 29 282 5356; fax: +81 29 282 6496.
E-mail address: sakamoto.shinichi@jaea.go.jp (S. Sakamoto).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2006.02.076

studied [6]. It is not wise that the beam size is made smaller, since more magnets of higher magnetic field are necessary. The best solution was found that the beam is weakly focused and transported with less magnets of large aperture. This increases the margin for controlling the beam and provides the room for future upgrading.

The envelope of the beam with the emittance of 324 π mm mrad is shown in Fig. 2 as a function of *S*, the distance along the beam line from the RCS extraction point. The most upstream part works as a matching section to absorb the variation of Twiss parameters due to the tune shift in RCS. In the horizontal bend section the dispersion is wiped out with DBA (double bend achromat) method and FODO lattice is employed in the last straight section to the MLF building. The beam is once focused on the muon target sharply (24 mm in diameter). The beam is reshaped in the following short section into wide rectangle (130 mm wide, 50 mm high) and injected into the neutron production target [2,6]. The beam current density is accordingly lowered to reduce serious effect of high-intensity beam on the neutron target.

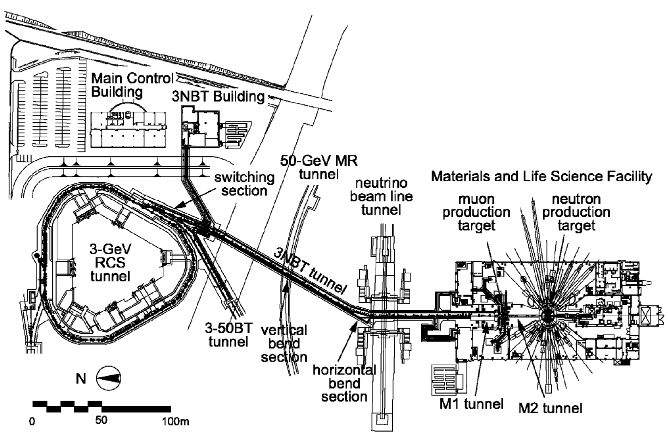

Fig. 1. Plan of the 3NBT facility in J-PARC.

As far as beam operation is maintained as planned with the optics design, beam loss would not take place at all. In reality the beam condition may fluctuate and drift away from the best. The performance of the components is not perfect either. The apertures of te beam line components were taken at least 10 mm larger than the envelope of the maximal beam halo [2]. The allowances for the beam parameters at RCS extraction were determined with this margin. The goal accuracy of magnet alignment in the beam line and the uniformity of their magnetic field were also specified so that the deviation and distortion of the beam orbit should stay well within this margin.

3. Main beam line components

The hardware components were designed to satisfy the requirements from the beam optics [2]. The integration of well-designed components and their efficient operation

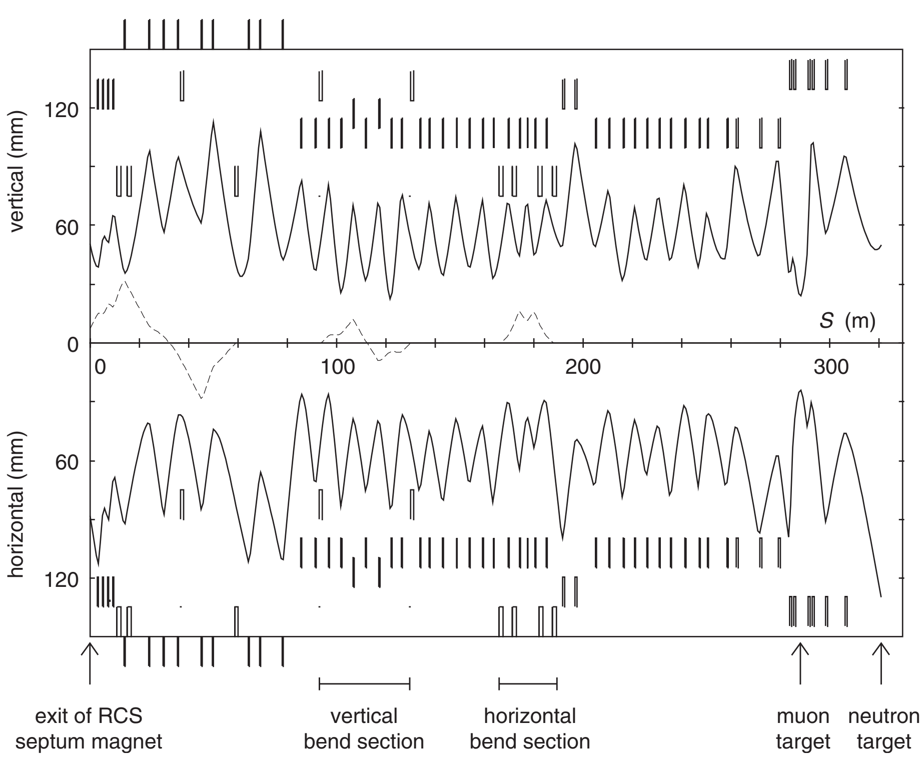

Fig. 2. Beam envelopes from RCS extraction to neutron target. The horizontal axis is the distance (*S*) from the last extraction septum magnet. Solid curves are the beam envelopes of the emittance 324 πmm rad, dashed curves the increase of beam size due to dispersion when $\Delta p/p = \pm 1.0\%$. Bars outside the beam envelopes indicates the positions of magnet poles.