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Optimization of a beam line equipped with a laser ion source

Shinji Shibuya [a,*], Koji Noda [b], Syuh Nakamura [c], Akira Noda [c], Manfred Grieser [d]

[a] *Accelerator Engineering Corporation, 4-9-1 Anagawa, Chiba 263-8555, Japan*
[b] *National Institute of Radiological Sciences, 4-9-1 Anagawa, Chiba 263-8555, Japan*
[c] *Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan*
[d] *Max-Plank-Institute fur Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany*

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Abstract

Progress in high-power short-pulsed laser technology has enabled us to build a high-performance laser ion source, which can provide ion beams with rather high-energy from a high-density plasma. An ion beam produced by the laser source has a wide momentum spread, a small transverse emittance and a large divergence, like a white beam from a point source. A phase-rotation method has been proposed to reduce the momentum spread in order to use the laser-produced ion beam practically under the above conditions. This phase-rotation method inevitably increases the transverse emittance due to sudden compression of the momentum spread in a phase-rotation cavity. We report on beam optics optimization with two kinds of magnetic lens system, solenoid and quadrupole, and compare their performance.

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Keywords: Chromatic aberration; Laser ion source; Beam optics

1. Introduction

Ion sources based on laser plasma acceleration have been considerably improved through the rapid progress of high-power short-pulse laser technology [1]. A laser-based ion source can provide energetic ion beams from a high-density plasma [2,3]. Such devices can serve for ion beam applications, such as cancer therapy. Direct beam injection to a high-energy accelerator with an energy of a few MeV/n was proposed in a previous project [4]. The application of a laser-produced carbon beam to cancer therapy requires a beam intensity larger than 1×10^9 particles/

* Corresponding author. Tel.: +81 43 256 0122; fax: +81 43 251 6623.
E-mail address: shibuya@aec-beam.co.jp (S. Shibuya).

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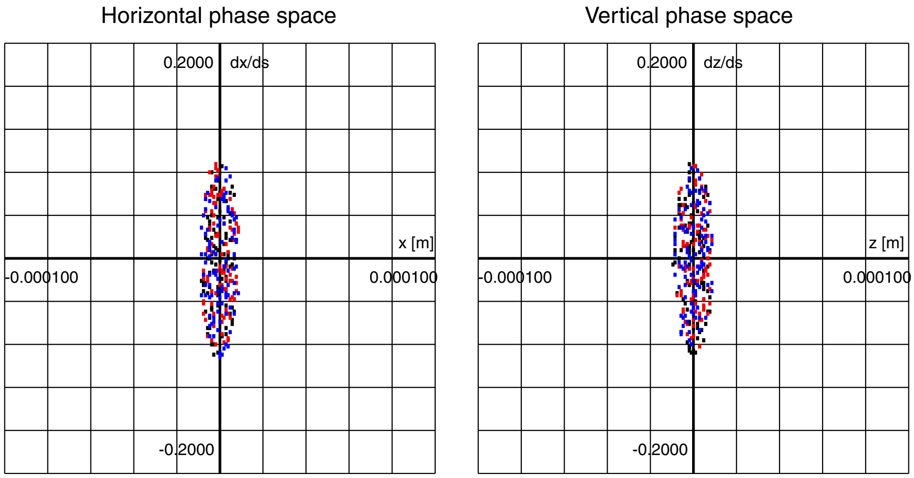

Fig. 1. Configuration in transverse phase-space at the source. Particles are created by the Win–Agile code [5]. On-momentum, 5% reduced-momentum and 5% increased-momentum particles are presented.

second (pps) at the source point. Since the beam intensity decreases exponentially with increasing energy, the energy window should be widened in order to obtain the required intensity. To reach this goal, laser-produced ions should be collected within a divergence angle of ±5° with a momentum spread of ±5%. Under this condition, the corresponding transverse emittance in the phase-space diagram at the source is shown in Fig. 1. Thus, the laser source produces an ion beam with a rather wide momentum spread compared with that of a conventional ion source. The beam has a small transverse emittance with a large divergence, because of the least target area irradiated by a laser of several tens of micrometers. A phase-rotation method [4] has been proposed to reduce the momentum spread from ±5% to ±1%. This method inevitably causes an increase of the transverse emittance, because the momentum spread is suddenly compressed in the phase-rotation cavity. Therefore, the beam optics is optimized by a solenoid-lens or a quadrupole-magnet lens as a focusing system set between the laser ion source and the phase-rotation cavity, under the conditions listed in Table 1. For a beam with a large divergence, it is essential to shorten the distance from the source point to the principal plane of the lens system. We report hereafter on beam optimization of this source.

Table 1
Conditions of our calculation

Ion species	12 C^{6+}
Beam energy	2 MeV/n
Maximum divergence angle	±87 mrad
Initial beam size	0.01 mm
Beam emittance	0.87 pi mm mrad
Distance between the source and the cavity	2 m

These conditions are applied to both the horizontal and vertical directions.

2. Beam optics and emittance growth

The beam optics is calculated in (A) a solenoid-lens system and (B) a quadrupole-magnet lens system, under three different momenta: 0 and ±5%. The distance between the phase-rotation cavity and the source is determined by the excited RF frequency. The cavity that we use has an RF frequency of 83 MHz, which should be placed at a distance of around 2 m from the source. Assuming a momentum-spread from ±5% to 0 at the phase-rotation cavity, transverse emittance growth should occur at the cavity position because of the chromatic aberration produced by the lens system. Thus, the growing emittance is calculated by superposing three emittance values with different momenta. At the cavity position, we have assumed that the beam is parallel with the same size in both