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High energy electron radiography system design and simulation study of beam angle-position correlation and aperture effect on the images

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A B S T R A C T

A beam line dedicated to high-energy electron radiography experimental research with linear achromat and imaging lens systems has been designed. The field of view requirement on the target and the beam angle-position correlation correction can be achieved by fine-tuning the fields of the quadrupoles used in the achromat in combination with already existing six quadrupoles before the achromat. The radiography system is designed by fully considering the space limitation of the laboratory and the beam diagnostics devices. Two kinds of imaging lens system, a quadruplet and an octuplet system are integrated into one beam line with the same object plane and image plane but with different magnification factor. The beam angle-position correlation on the target required by the imaging lens system and the aperture effect on the images are studied with particle tracking simulation. It is shown that the aperture position is also correlated to the beam angle-position on the target. With matched beam on the target, corresponding aperture position and suitable aperture radius, clear pictures can be imaged by both lens systems. The aperture is very important for the imaging. The details of the beam optical requirements, optimized parameters and the simulation results are presented.

1. Introduction

A new scheme based on high-energy electron beam as a probe was proposed for time-resolved imaging measurement of high energy density materials, especially for high energy density matter and inertial confinement fusion (ICF) [1,2]. High Energy Density Physics aims to study the properties of matters under extreme temperature and pressure conditions, which is also called Warm Dense Matter (WDM). The WDM properties require the high energy density exceeding 1 Mbar and the transiently produced in laboratory experiment on the 10 ns to 1 μs time scale. The diagnostics system should have a large dynamic range and high spatial resolution.

Furthermore, it is essential to measure the moving boundary for ICF; therefore a time-dependent imaging system is highly desirable. Comparing with proton and other x-ray diagnostics systems, electron radiography based on photo-injector linear accelerator systems (LINAC) is expected to gain high spatial and temporal resolution at lower cost. Los Alamos National Lab developed the first high-energy electron radiography (eRad) concept [3] with a 30 MeV electron beam achieving a resolution of 100 um. The first high-energy eRad experiment with picosecond pulse-width was achieved by collaboration between the Institute of Modern Physics (IMP), the Chinese Academy of Sciences (CAS) and Tsinghua University (THU). The eRad system was based on the THU LINAC [4] with 46 MeV beam and the spatial resolution reached 10 μm, which demonstrated that this kind of LINAC with ultra-short pulse-width electron bunches can be used for eRad. Although the quadrupoles lenses for this radiographic experiment are not fully optimized, the experimental results, such as magnifying factor and the imaging distortion, agree very well with the beam optics theoretical results.

For further and more detailed eRad experiment studies, such as areal density resolution, spatial resolution and ultra-fast dynamic imaging, a new special and optimized beam line has been designed and installed in THU LINAC laboratory. The LINAC [5] consists of normal s-band photocathode Radio Frequency electron gun and an s-band accelerating tube. The gun provides low emittance and picoseconds pulse-width electron bunches with energy of

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about 3 MeV. The highest beam energy of the LINAC is 50 MeV. For the eRad experiment design, the energy of 40 MeV is chosen for LINAC stable running.

2. Beam optics layout and design

To prevent interruptions to other experiments, the beam is extracted from the LINAC beam line with achromat and imaging lens system for the eRad experiment. The beam line design is mainly constrained by the limited space of the laboratory, and therefore the beam line layout should be planned firstly. The layout of the beam line according to the available laboratory space is shown in Fig. 1(a). A linear achromat consisting of two rectangular dipoles and three quadrupoles is used for deflecting the beam to −90 degrees. The target is placed after the achromat in the object plane position. After the target, there are imaging lens systems. For more detailed optical properties studies, two kinds of imaging lens systems have been designed with different magnification factor in the same beam line; a Russian quadruplet lens and an octuplet lens with the aperture placed on the Fourier plane position. The middle two quadrupoles of the octuplet are set to the same gradients (including sign) so they could be replaced by a single quadrupole, effectively resulting in a quadrupole sextuplet (6 quadrupoles) lens. In this paper, it is named octuplet imaging lens instead for convenience. The installed beam line is shown in Fig. 1 (b).

Due to the special requirements of the achromat from the imaging lens system, such as field of view and beam angle-position correction (phase space matching) at the target, the parameters of the imaging lens system are designed first.

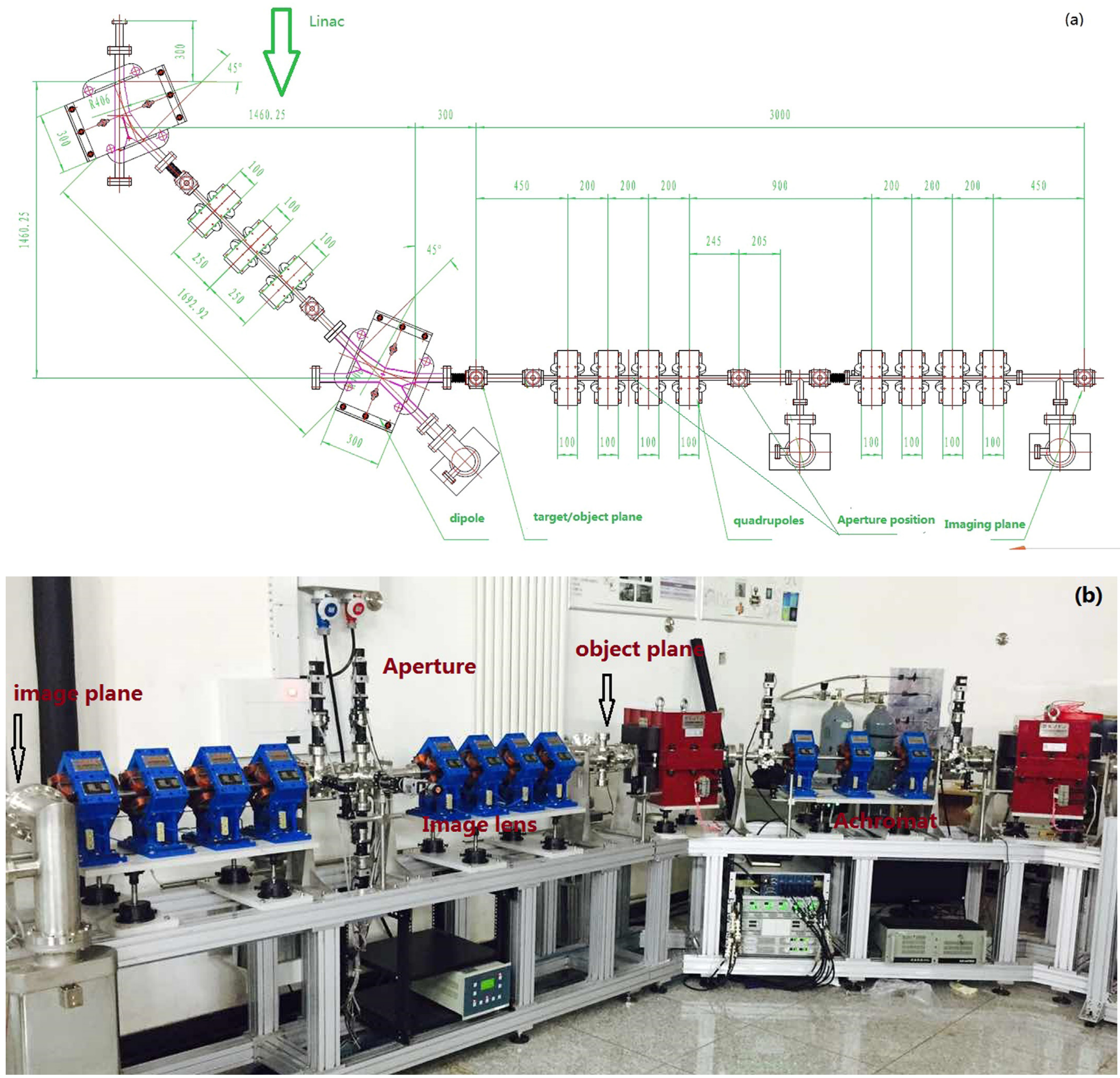

Fig. 1. (a) The layout of the designed eRad beam line and (b) The installed imaging beam line on THU linac beam line.