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CHARACTERIZATION OF LASER-PLASMA ACCELERATED ELECTRON BEAM FOR A COMPACT STORAGE RING*

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Abstract

A compact radiation source can be utilized by an electron beam from a Laser-plasma acceleration combined with localized shielding in a small laboratory. The stability of synchrotron radiation in wavelength and power depends on the shot-to-shot jitters of the energy and charge of an electron beam, which is strongly influenced by the plasma density of target and the jitters of a laser beam. With the 30 TW fs laser in KAERI, the optimization for generating the electron beam have done using the different shape of gas nozzle. We also present the pointing stability of the laser-accelerated electron beams.

INTRODUCTIONS

Laser-plasma electron acceleration has been attracted for high energy injectors, synchrotron radiation, XFEL, and so on, for a decade. The energy of laser-accelerated electrons is recorded over 4.2 GeV[1] and the energy spread is down to 1%. It is dramatically rapid developments in quality of electron beam generated by laser plasma interaction since the success of quasi-monochromatic electron beam generation in early 2000s. The more stable operation and/or the better quality of electron beams have been developed, the more diverse applications has been suggested and studied.

As like the conventional electron accelerators, there are many applications using it. The property of ultrashort pulse and compactness in radiation shielding can be strong advantages of newly developed applications. We can also consider it as an injector for storage ring such as an ultimate storage ring, which is recently under development to reduce the emittance. In aspect of compactness, we can develop as radiation sources using tens of TW laser system. Tens of TW laser system can be used for the generation of tens to hundreds of MeV electron beams, by either reducing the laser intensity or increasing the interaction length with plasma. We may use simple gas target, capillary discharge plasma, or possibly laser evaporated plasma using metal target.

Usage of metal target has been suggested for a compact storage ring using Laser-accelerated electron beam [2], in order to keep high vacuum inside storage ring. With gas targets, the injector should be separated by thin window to keep high vacuum inside the storage ring. However, laser induced plasma will generate small amount of plasma enough for laser acceleration, even in few mm long plasma density. Under the WCI Program, KERI and KAERI are developing the Laser-induced electron acceleration using the solid target.

To utilize Laser-accelerated electron beam as an injector, more detail studies for reliability are required. The pointing jitter of electron beam is recently done with KAERI 30TW laser system using the gas target. Optimization study of electron beam generation depending on laser and plasma density can apply to the case of solid target except exponentially decreasing plasma density along the vertical direction.

EXPERIMENTAL SET-UP

A 30 TW Ti:sapphire laser system at KAERI has been developed to utilize for laser-induced particle accelerations. Using total pumping energy of 4 J from two 2nd harmonic Nd:YAG lasers, the energy of 1.1 J is achieved with three staged amplifiers. The limitation of laser energy is mainly due to the limited size of gratings presently installed. New set of gratings including the compression chamber should be required to increase the laser power. After compression, the energy at target chamber is 60% of 1.1 J with pulse duration of 25 fs, yielding a 25-TW peak power.

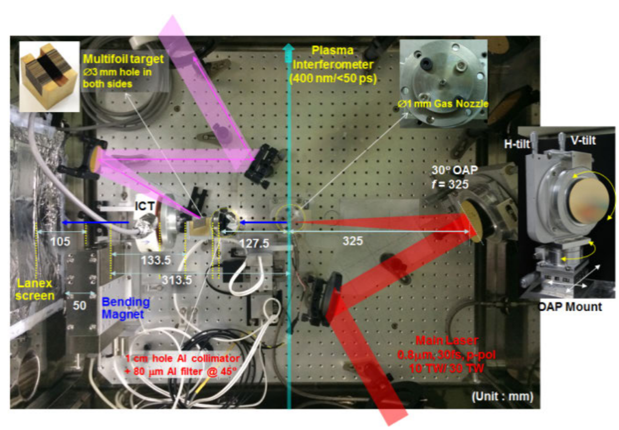

Figure 1: Layout of Experimental set-up

The laser beam was focused on a helium gas jet target using an off-axis parabola (OAP) mirror with a focal length of 326 mm. To vary the size of focal spot and the Rayleigh range, an iris is placed at the entrance to the target chamber and the laser pulse passing through the iris

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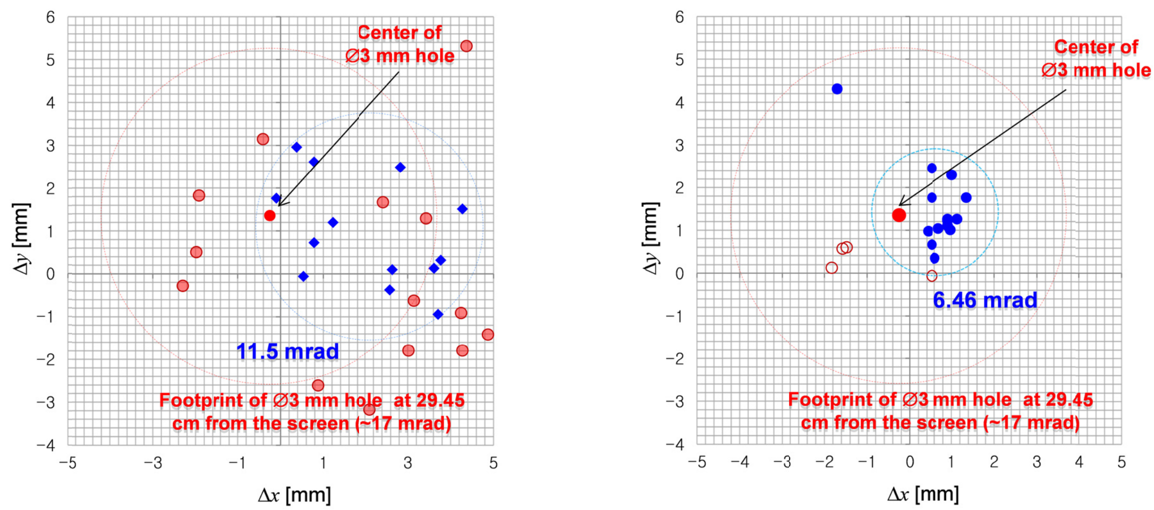

(a)
Open red circle at h = 3.0 mm, x-scan
Solid blue diamond at h = 3.0 mm, x-fixed, z-scan

(b)
Open red circle at h = 3.98 mm
Solid blue disk at h = 4.0 mm

Figure 2: Shot-to-shot Pointing jitter of Electron Beam measured at 47 cm from the nozzle

be reflected by the flat mirror followed by focusing mirror.

The focal spot is ~7.5 µm without iris and ~9 µm with 35 mm opening iris in full width half maximum, respectively. We used two types of nozzle: one is 1 mm diameter circular type, the other is 2×3 mm^2 rectangular type. The C-type bending magnet with bypassing iron installed can vary the field strength in the gap keeping the gap size same. The peak field strength and the effective length of magnet with field area of 6×5 mm^2 is 0.5 T and 6.3 mm, respectively.

LASER-ACCELERATED ELECTRON BEAM

Pointing Jitters of Laser

The pointing jitter of main laser in horizontal direction had been measured with an all-reflective single-shot autocorrelator after the compressor. The pointing jitter in the horizontal direction is about ± 2.4 µrad in the standard deviation. The expected focal-point shift is roughly ± 3 µm for a focal length of 300 mm and shifted pointing angle of ±10 µrad. If considering only the position of laser focal spot in plasma, it is acceptable. However, the alignment of OAP mirror should be precisely done since the laser beam profile is very sensitive to the incident angle.

Pointing Jitters of Electron Beam

The pointing jitter of electron beam was measured at different plasma density with 1 mm diameter circular type of gas nozzle. Figure 2 (a) shows the pointing jitter at higher plasma density, while (b) shows that at lower plasma density. As we expected, the pointing jitter as well as the divergence are greater at higher density than those at lower density. At lower density, the pointing jitter is 6.46 mrad with beam divergence of ~ 4 mrad. In Figure 2 (a) the red circle is data during the horizontal scan of nozzle position with respect to the main laser.

Electron Beam Generation with Two Different Nozzles

The energy of electron beam generated is about 62 MeV with circular type and 110 MeV with rectangular type. The divergence is reduced for high energy electron beam and pulse charge is also reduced due to low density of plasma. For our applications of compact storage ring, the energy range of 50 MeV to 100 MeV is good for 1 T bending magnet. However the energy spread is still broad, so it needs further optimization.

DESIGN OF BENDING MAGNET FOR COMPACT STORAGE RING

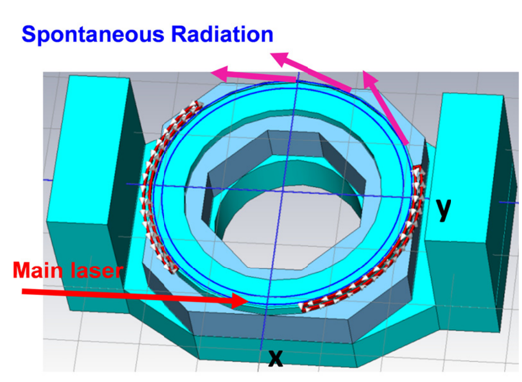

Figure 3: Schematic of 360° Bending Magnet

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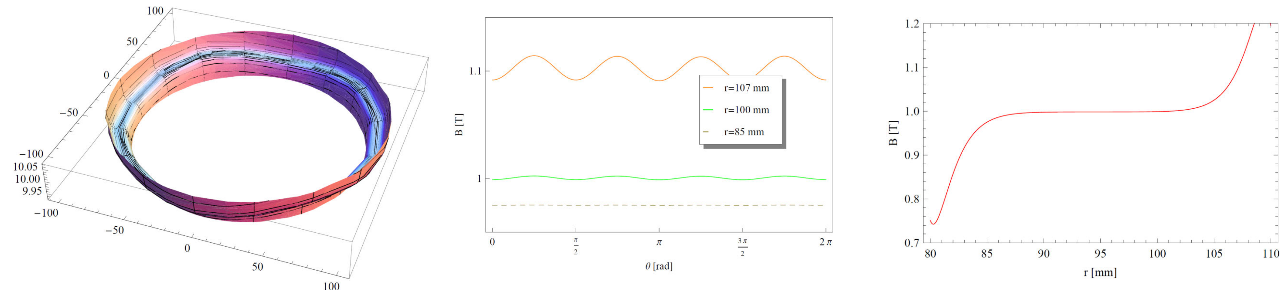

(a) 3D plot of B-field at the mid plane of the gap (b) B-field along the trajactoriy at the different radius. (c) B-field along radial direction at the mid plane

Figure 4: B-field distribution of 360° Bending Magnet (All are calculated curves and graph using fitting equation).

The 360° bending magnet is comprised with ring-shape pole and permanent magnet blocks. To reduce the cost of fabrication, we used the two shapes of magnet block to construct one turn. The geometrical difference, but with repeated structure, gives the periodicity in magnetic field inside the dipole.

We expect that the periodic modulation of B-field will cause the betatron oscillation, resulting in more stable orbit. The theoretical simulation is under way.

SUMMARY

We characterized laser-accelerated electron beam and found more optimization is needed for injection to compact storage ring. Electron beam divergence and pointing stability is better for higher energy, but it will dramatically increase the cost as well as the weight of 360° bending magnet. To compromise it, the optimal condition at its energy of 50 ~ 70 MeV should be re-settled and stabilized.

ACKNOWLEDGMENT

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