Miniature Magnetic Devices for Laser-Based, Table-Top Free-Electron Lasers ◇

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There is a new boom in laser plasma physics, where the generation of intense quasi-monoenergetic electron bunches up to the GeV range has been achieved [1,2,3,4]. As reported last year, our group aims to use this new source of high-energy electrons to drive a table-top Free-Electron Laser (FEL) with the prospect that laser-plasma accelerator-based FELs are of only meter-scale [5]. The key parameter here is the much higher peak current delivered by laser-plasma accelerators than compared with conventional accelerators. In the first case one can expect peak currents of up to 100 kA, i.e., far beyond the Alfven current of 17 kA, whereas the latter cannot deliver more than 5 kA. An FEL is driven by the peak current density, hence the focusing of the diverging beam behind the laser-plasma accelerator is of crucial importance, and first (unpublished) results will be reported here.

As a first step towards realising a table-top FEL, our group has built a 5mm period undulator and characterised its spontaneous radiation. By testing the undulator with conventionally accelerated electrons at the Mainz Microtron (MAMI), we were able to determine the suitability of the undulator for further experiments with laser-accelerated electrons. Two complementary performance tests were carried out. The first beam time was used to characterise the spatial emission of the different harmonics of the undulator radiation n [6]. A second beam time with a grating spectrometer was carried out to obtain a higher resolution of only the first harmonic. The theoretically expected energy linewidths and spatial emission of the undulator radiation compare well with the experimentally measured values giving confidence in the design and construction of the undulator. By modifying the MAMI beam to have larger divergence, we could also qualitatively observe the high sensitivity of the undulator spectrum to divergence. This becomes important for future experiments with laser-accelerated electrons with much larger divergences where suitable beam transport will be required.

To provide the necessary beam transport our group has also carried out tests with miniature quadrupole lenses made with segments of rare-earth magnets at MAMI [6]. The magnetic lenses have a high field gradient of the order of 500 T/m to allow a compact lense design for focusing high energy electrons. A line focus was achieved with a single lense approximately below 1 μ m. A second experiment using a pair of quadrupole lenses showed that focusing in both planes to be more difficult, leading to a more precise measurement of the magnetic field in the lenses. Recently we have conducted experiments using laser-accelerated electrons and achieved very promising results. Using results from simulations [9], a pair of quadrupole lenses was positioned in the beam and dramatically improved both the pointing (by a factor of up to five) and divergence of the electron beam (see Fig. 1 and Fig. 2). Crucially, this preliminary result proved to be reproducible indicating a stabile electron beam can be relied on for undulator experiments.

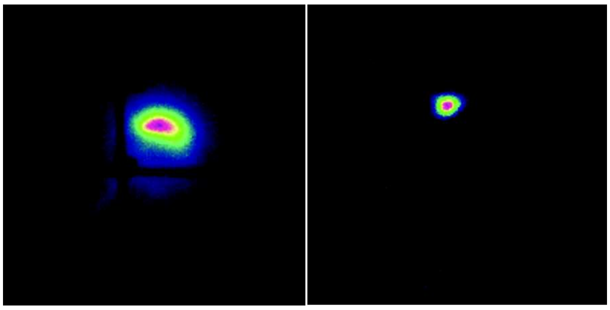

Fig. 1: Beam spot of two separate shots observed on a scintillating screen 1.12m behind the source of the laser-accelerated electrons: without lenses (left), with a pair of focusing quadrupole lenses (right). The correspoding FWHM divergences are 1.85 and 0.96 mrad respectively.

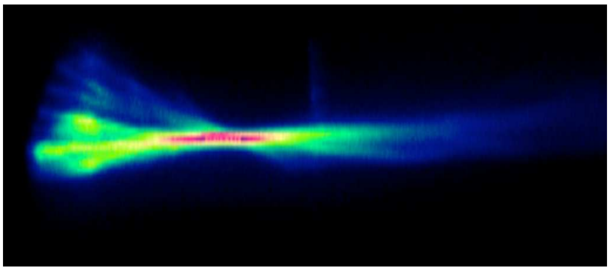

Fig. 2: Scintillating screen after the electron spectrometer, 2m behind the electron source. The horizontal axis is the dispersive direction for energy. One can clearly see that the beam is focused at a particular energy by the narrowing of the beam and the increased intensity observed by the camera.

The next step is to safely transport the laser-accelerated electrons through the undulator and to measure the undulator radiation around 30 nm, for which we are developing a dedicated spectrometer.

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