STRONGLY TAPERED HELICAL UNDULATOR SYSTEM FOR FAST-GREENS INSTALLATION *

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Abstract

RadiaBeam, in collaboration with UCLA and Fermilab, is developing a strongly tapered helical undulator system for the Tapering Enhanced Stimulated Superradiant Amplification experiment at 515 nm (TESSA-515). The experiment will be carried out at the FAST facility at Fermilab as a Gamma-Ray high Efficiency ENhanced Source (FAST-GREENS). The undulator system was designed by UCLA, engineered by RadiaBeam, and will be installed on the beamline at Fermilab (FNAL). The design is based on a permanent magnet Halbach scheme of four 1-meter long undulator sections; two of which have been completed and installed. The undulator period is fixed at 32 mm and the magnetic field amplitude can be tapered by tuning the gap along the interaction. Each magnet can be individually adjusted by 1 mm, offering up to 25% magnetic field tunability with a minimum gap of 5.58 mm. This paper discusses the design and engineering of the undulator system and the stage 0 installation status.

INTRODUCTION

Recently, a novel regime of operation has been proposed to greatly increase Free-Electron-Laser (FEL) efficiency using prebunched electron beams, intense seed laser, and strongly tapered undulators (TESSA scheme) [1]. An experimental demonstration of the TESSA concept in the mid-infrared was carried out at Brookhaven National Lab (BNL) [2] where energy extraction efficiency as high as 30% was demonstrated. The current FAST-GREENS project, planned for construction at Fermilab's Nu Muon Lab (NML), aims at pushing the performances of the proof-of-principle BNL experiment, by exploring for the first time this interaction in the high gain regime and extending the scheme to shorter wavelengths where high efficiency radiation sources would be extremely attractive, such as EUVL [3].

A critical component in the project is the out of vacuum, strongly tapered helical undulator system which will be used to couple the electromagnetic waves and relativistic electron beams. Helical undulators have an important advantage over planar designs since the transverse component of the electron velocity is never zero enabling continuous energy transfer and much more efficient interaction [4]. Since this is such a large undertaking, the installation of the entire FAST-GREENS beamline has been broken out into two stages.

Figure 1: FAST-GREENS Stage 0 Installation Progress.

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STAGE 0 BEAMLINE INSTALLATION

The FAST-GREENS beamline is divided into four distinct sections: Injection, Prebuncher, Undulators, and Post Undulators. The first installation stage has been named Stage 0. For this stage, only two undulators and one break section have been installed. The rest will be included in subsequent stages of the project.

In this stage, the beamline will consist of the elements shown in Table 1 [5]. The D600 distance measurements in the third column are all taken from the center of the D600 dipole. Just after D600, a gate valve was installed to ensure the FAST-GREENS beamline can be isolated.

Dipoles 1 through 3 comprise the injection chicane. Dipoles 2 and 3 have a small gap of only 20 mm. Since the planned seed laser path will be injected off-center from the beam, the chamber going through those dipoles is rectangular. The first of these custom rectangular chambers can be seen in Figure 1. Dipole 2 is where the largest spacing between the beam and laser will occur with a maximum distance of 9.75 mm.

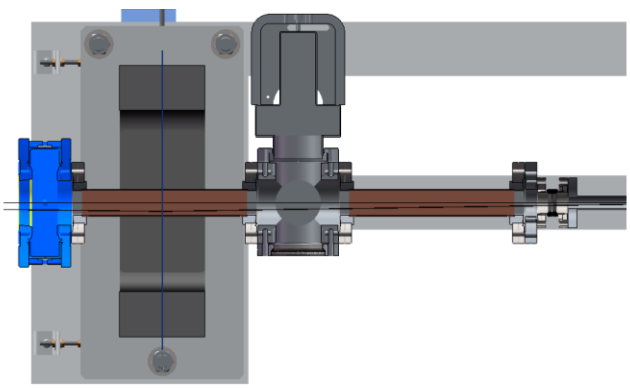

Figure 2. Injection Chicane top cut view with electron beam and laser path shown.

Currently, the magnets have all been split in preparation for the beam pipe installation. The height of each element will need to be adjusted using their respective kinematic stages. So far, only the section leading up to and including the injection cube have been attached and roughly aligned.

Upon arrival at FNAL, the undulators were pulse wired to ensure they did not shift during transport. The ultra compact inter-undulator break section, consisting of a permanent magnet quadrupole doublet, an electromagnetic dipole, and an aluminized YAG, was also pulse wired. All components have been fiducialized and will be moved onto the beamline during the next installation window. This break section serves to contain all the diagnostics needed within a space of only 170 mm.

Table 1: Stage 0 Lattice

Element Name	Physical Length	D600 Distance
Injection		
Dipole 1 (D600)	1200.15 mm	0
Dipole 2	146 mm	1.075 m
Injection Cube	114.3 mm	1.266 m
Dipole 3	146 mm	1.875 m
Quad 1	85.73 mm	2.459 m
Steerer 1	12.7 mm	2.516 m
Profile Monitor 1	69.85 mm	2.663 m
Prebuncher		
Prebuncher (PB)	324 mm	2.960 m
Dipole 4	146 mm	3.270 m
Dipole 5	146 mm	3.416 m
Dipole 6	146 mm	3.562 m
Quad 2	153 mm	3.832 m
Quad 3	153 mm	4.032 m
Profile Monitor 2	69.85 mm	4.330 m
THESEUS Undulators		
THESEUS 1	964 mm	4.944 m
Quad 4	30.7 mm	5.472 m
Dipole 7	26.3 mm	5.518 m
Profile Monitor 3	19.05 mm	5.540 m
Quad 5	30.7 mm	5.578 m
THESEUS 2	964 mm	6.108 m
Post Undulators		
Profile Monitor 4	69.85 mm	6.724 m
Dipole 8	153.9 mm	8.445 m
Dipole 9	153.9 mm	8.695 m
Quad 6	380 mm	9.170 m
Quad 7	380 mm	9.725 m
BPM	268.35 mm	10.176 m
Dipole 10 (D700)	1200.15 mm	11.199 m

STAGE 1 BEAMLINE INSTALLATION

In stage 1, the seed laser will be introduced into the beamline via the injection cube. A mirror will be installed into the cube as the injection point for the co-propagating laser. Significant preparation will be happening in summer of this year in order to have the laser transport installed and tested prior to advancing to stage 1.

A beam position monitor will be inserted into the system by replacing profile monitor 2 and one spool piece with the LEUTL Chamber (Fig. 3) obtained from Argonne National Lab (ANL). The assembly, as received, has only a beampipe on one end, so a 1.33” ConFlat flange will need to be welded on. The welding will be performed at RadiaBeam.

This chamber includes a Beam Position Monitor (BPM) and two 3-position pneumatically actuated diagnostic holders that will assist with alignment and measurements. The upstream diagnostic holder, Diagnostic 1, will contain an Optical Transition Radiation (OTR) foil, a Yttrium-Aluminum-Garnet (YAG) crystal, and beam clear position. Diagnostic 2 will contain a mirror for viewing the image on the YAG, a mirror for viewing the laser image, and a beam clear position.

Figure 3: LEUTL Diagnostic Chamber.

Stage 1 will also include the addition of the final two undulators and their corresponding break sections.

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