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STRONGLY TAPERED HELICAL UNDULATOR SYSTEM FOR TESSA-266

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Abstract

RadiaBeam, in collaboration with University of California Los Angeles (UCLA) and Argonne National Laboratory (ANL)*, is developing a strongly tapered helical undulator system for the Tapering Enhanced Stimulated Superradiant Amplification experiment at 266 nm (TESSA-266). The experiment will be carried out at the Advanced Photon Source (APS) Linac Extension Area (LEA) facility at ANL and aims at the demonstration of very high energy conversion efficiency in the Ultraviolet (UV). The undulator system was designed by UCLA, engineered by RadiaBeam, and is presently in fabrication at RadiaBeam. The design is based on a permanent magnet Halbach scheme [1] and includes a short 30 cm long buncher section and four 1 m long undulator sections. 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 1.03 mm, offering up to 25% magnetic field tunability with a minimum gap of 5.58 mm. A custom designed 316L stainless steel beampipe runs through the center with a clear aperture of 4.5 mm. This paper discusses the design and engineering of the undulator system, fabrication status, and plans for magnetic measurements, and tuning.

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 (so called 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 TESSA-266 project, planned for construction at the APS linac at ANL, 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 (EUVL) [3].

A critical component in the project is the out of vacuum, strongly tapered helical undulator 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].

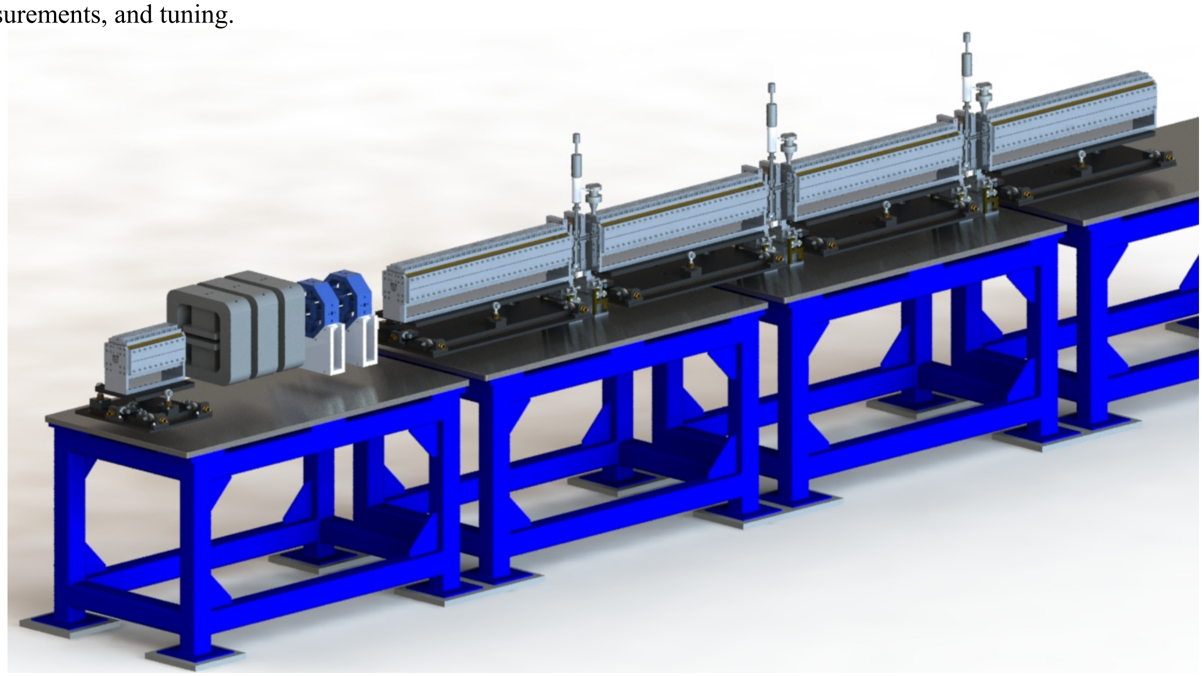

Figure 1: TESSA-266 overview showing, from left to right, the prebuncher, chicane (3 dipoles), quadrupole doublet, THESEUS 1, break section assembly 1 (quadrupole, phase shifter dipole, diagnostic, quadrupole), THESEUS 2, break section assembly 2, THESEUS 3, break section assembly 3, and THESEUS 4.

This paper discusses, in detail, the design of the THESEUS (Tapered HElical Segmented Undulator System), being developed for this experiment (Fig. 1).

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DESIGN

The undulator is based on two orthogonal permanent magnet Halbach arrays. Each period is formed by counter-facing (in the horizontal and vertical direction) sets of 4 magnets (8 mm or 1/4 period thick) with rotating magnetization vector (Fig. 2 left) for a total of 16 magnets per helical undulator period. Each magnet is mounted on a movable holder to allow for gap and magnetic field amplitude tunability. The system includes a short 8-period prebuncher, and four 28-period undulator section. More detailed specifications can be found on Table 1.

Table 1: THESEUS Specifications

Period	32 mm
Minimum Gap	5.58 mm
Number of Full Periods (prebuncher/undulator)	8/28
Nominal undulator K	2.82

Magnets and Magnet Holders

A total of 3000 NdFeB magnets with remnant field 1.2 T (including all needed magnetization directions) have been purchased. Each one has been measured and, excluding a few outliers (less than 2% of the elements in each batch), have been found to fit within the required specification of magnetization error less than 2 degrees. Each magnet has 2 angled portions; the top and the base. The top portion is angled to allow for the tips of the magnets to move in as close as possible to the axis without interfering. The bottom portion is angled to strengthen the mechanical bond between the holder and the magnet. This relieves the stress on the glued surfaces by relying on the aluminum holder for structural stability when the magnets are installed. In case of catastrophic glue failure, the magnets will not be pulled out of their holders.

A two-part epoxy was chosen to secure the magnets into their holders. The epoxy chosen was Loctite M-31CL [5] for its structural stability, radiation resistance, and working life. This epoxy was used in the permanent magnet Halbach type undulator for the THz radiation experiment at ANL's Injector Test Stand (ITS) [6]. The two parts are mixed using an epoxy gun and mixing tip for easy application. Shims are inserted between the magnet and the magnet holder to ensure that all glued magnets in their holders are the same height.

Each undulator section end is tapered to ensure that the trajectory wiggles around the undulator axis according to the scheme shown in Fig. 2 (left). For the entrance and exit magnets, which occupy the last 34 mm on each side of the undulator, special holders were made that allow for the thinner magnets (2mm, 4mm, and 6mm) to rest inside a pocket. During gluing, the thinner magnets are shimmed in their holders and held in place by c-clamps to prevent movement. A single holder with pockets on both sides is used to house the 2mm and 4mm thick magnets. These 4 entrance/exit holders are the only ones where two permanent magnets cannot be tuned independently as seen in Fig. 2 (right).

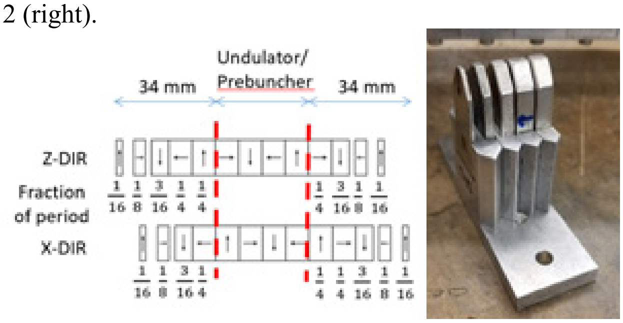

Figure 2: Left) Entrance and exit magnetization scheme. Right) Entrance tuning plate assembly.

Once shimming and gluing is complete, the magnets are cleaned, inspected, and labeled. Each one is inserted into the strongback assembly with holder blanks on each side to ensure form, fit, and function. Height is verified by inserting the glued part into a cleaned gluing fixture and checking with feeler gauges. The parts that pass inspection are entered in a spreadsheet with an assignment of where in the assembly they will be installed, starting with higher field magnets towards the front of the undulator assembly and lower field towards the back to ease the final tapering profile of the magnetic gap. The magnet holders have two large 82-degrees chamfers (shown in Fig. 2 right) on either side to allow for high accuracy and positioning within the strongback assembly.

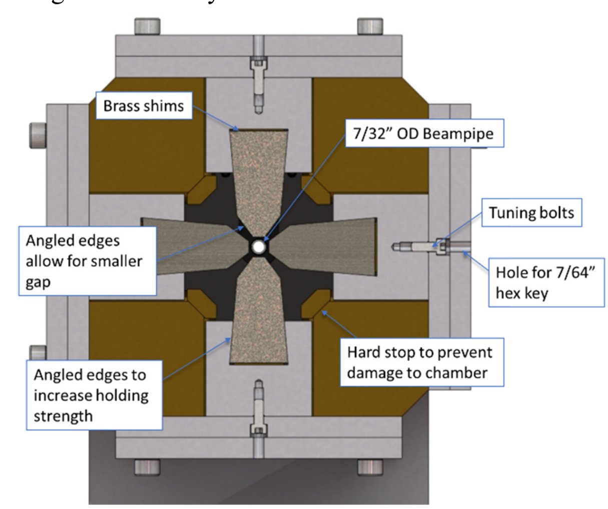

Figure 3: Cut view of undulator detailing internal components.

Tuning

Each group of 4 magnets (one period) is attached to a lower tuning plate (Fig. 3) with #6-32 socket head cap screws which are used as tuning bolts. When assembled, an upper tuning plate is bolted to the lower tuning plate. The upper tuning plate has holes for a 7/64" hex key to adjust the tuning bolts (Fig. 3). Each magnet is designed to be adjustable with a resolution of 800 um per full revolution of the tuning bolts. In order to maintain the resonance condi-

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tion along the interaction, the tolerable error on the magnetic field amplitude is less than 0.1%, which should be achievable controlling the tuning bolt by 1/8 of a turn. The magnetic field as a function of gap is shown in Fig. 4.

Strongbacks

The strongbacks are manufactured from 360 brass due to its machinability, structural strength, and nonmagnetic properties. Brass also helps create a bearing surface for the magnets when tuning. During inspection, the strongback v-cuts are checked on the optical comparator for periodicity and form. The strongbacks are also checked for flatness and orthogonality prior to installation.

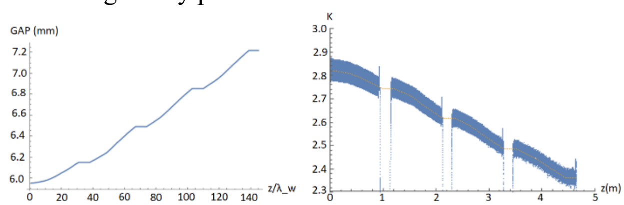

Figure 4: On axis magnetic field amplitude vs. gap in THESEUS undulators.

While the magnet holders are designed to be tunable by 1.5 mm, their motion is restricted by the strongbacks to protect the small diameter chamber. To achieve this, a strip of brass is bolted on the inside corner of each strongback (Fig. 3).

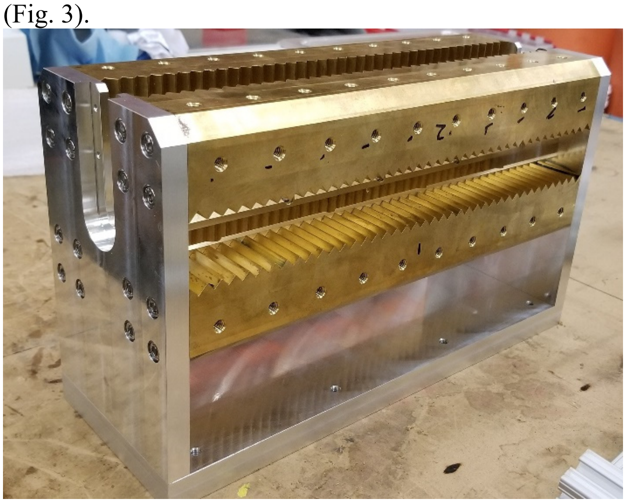

Figure 5: Prebuncher strongback assembly.

End Plates and Baseplate

The rectangular end plates are used to pin and bolt the strongbacks in place using captive dowel pins. They are installed while the upper two strongbacks are supported on 80/20 setup tooling. Once both end plates are on, the base plate is not installed until the bottom row of magnets and tuning plates are inserted. All of this is done with the assembly upside down.

Chamber

The chamber is designed to slide in from the top, through the opening in the end plates (Fig. 5) when the top row of magnets is not yet installed. Various chamber designs were considered. In the end, in order to simplify welding of the flanges and minimize the cost, the choice was made to use seamless 316L Stainless Steel tubing and two fixed, tapped 1.33” CF flanges made of 316LN Stainless Steel. The internal surface roughness of the chamber does not exceed 125ra with an average surface roughness of 63ra. The effect of the wakefield in the pipe has been estimated in simulations and found not particularly significant in the performances of the system.

Kinematic Stand

Each undulator will be placed on its own kinematic stand. The kinematic stand offers six manually adjustable degrees of freedom which can be adjusted with 850 um of travel per full revolution of the positioning nuts. The stand can travel up to 9 mm in each translational direction and up to 10 degrees in each rotational direction. Genesis simulations indicate that a relative alignment tolerance of ±50 um between each section may cause a drop in output power by 15%. Incidentally, this value sets a requirement for both the undulator stand as well as the magnetic measurements of the axis of the undulator.

MEASUREMENTS

The magnetic measurements are performed using a setup designed to precisely hold a narrow hall probe and guide it along the magnetic center of the assembly. This 2 mm wide hall probe and the guiding mechanism is designed to fit inside the small diameter beam pipe. This is important as the magnetic permeability of the tube is specified to be less than 1.05, however maximum values of 1.08 were measured close at the weld joints. For this reason, it has been decided that the final measurements and tuning of the magnetic field will be performed with the pipe installed. The setup will be used to tune the undulator section strong tapering effects needed for the TESSA-266 experiment.

CONCLUSION

This paper described the design and construction of the strongly tapered helical undulator which will be used for the TESSA-266 experiment. As the helical geometry is by far superior in coupling electromagnetic waves and relativistic beams it is envisioned that this technology might find other applications both in Inverse Free-Electron-Laser accelerators as well as in other high efficiency FEL projects.

ACKNOWLEDGEMENTS

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