AREAL 50 MEV ELECTRON ACCELERATOR PROJECT FOR THZ AND MIDDLE IR FEL

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Abstract

Advanced Research Electron Accelerator Laboratory (AREAL) is an electron accelerator project based on photocathode RF gun. The first phase of the facility is a 5 MeV energy RF phototgun, which is currently under operation. The facility developments imply energy upgrade to 50 MeV with further delivery of the electron beam to the undulator sections for Free Electron Laser and coherent undulator radiation in MIR and THz frequency ranges, respectively. In this report the design study of AREAL 50 MeV facility main systems along with the beam dynamics and characteristics of expected radiation are presented.

INTRODUCTION

AREAL 50 MeV linear electron accelerator project is aimed for the generation and acceleration of ultrashort, electron pulses with a small emittance for coherent radiation sources and advanced accelerator concepts [1]. The project first phase – a 5 MeV RF photo injector [2] – was successfully completed in 2014. The facility delivers an electron beam for the irradiation experiments in diverse fields of life and materials sciences [3].

The facility upgrade implies installation of two 1.6 m long accelerating sections with further beam delivery to ALPHA (Amplified Light Pulse for High-end Applications) and BETA (Booster for Emerging Technology Accelerators) experimental stations [1]. ALPHA station is designated for the creation of a free electron laser (FEL) in Mid-Infrared and THz regions. The last topic has become increasingly important in recent years with a wide range of potential applications in the fields of life, materials and environmental sciences. In this report, the main design considerations, the project status and highlights are presented.

FACILITY DESIGN AND PERFORMANCE

AREAL facility design consists of a laser driven RF gun, two S-band accelerating sections, focusing quadrupoles, horizontal/vertical correctors, diagnostic units and beam delivery system. The schematic layout of the facility with ALPHA and BETA experimental stations is presented in Figure 1. The main design parameters of AREAL project are presented in Table 1.

Table 1: AREAL 50 MeV design parameters

Energy (MeV)	20-50
Bunch charge (pC)	10-250
Bunch length (ps)	0.5-9
Norm. emittance (mm-mrad)	< 0.5
RMS energy spread	<0.15%
Number of bunches per pulse	1/16
Repetition rate (Hz)	1-50

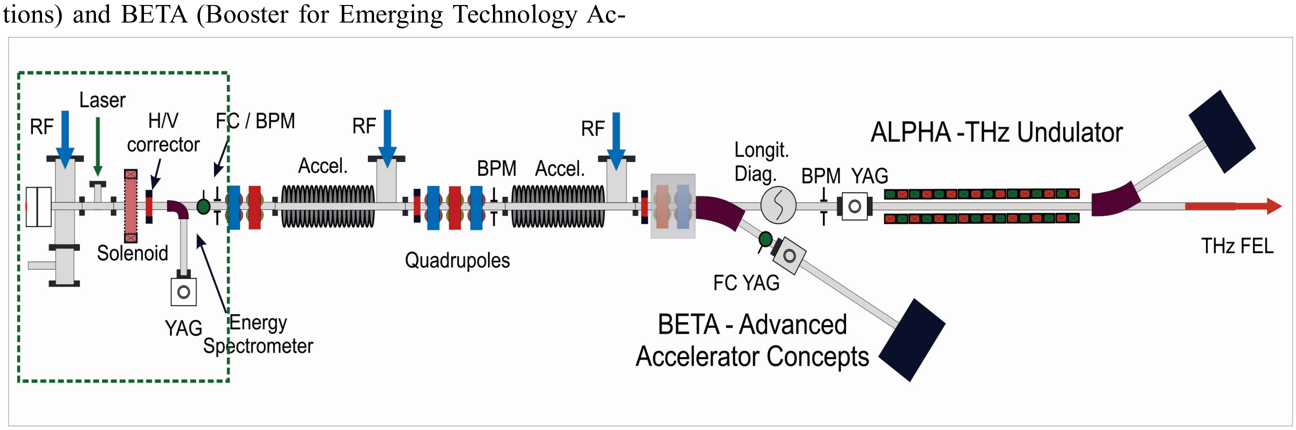

Figure 1: Schematic overview of existing (marked) and future upgrade parts of AREAL accelerator.

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Laser Driven RF Photogun

The choice of a metallic (copper) photocathode is stipulated by a high-damage threshold (100 mJ/cm^2), short response time (<0.02 ps) and a long lifetime (~1 year), which provides a reliable operation of the facility with sub-picosecond electron pulses at the gun exit.

The RF gun is driven by the Yb doped high energy UV ultrafast laser system (gain material -Yb:KGW). The laser system is capable to provide UV pulse energy of >250 µJ at 258 nm wavelength and tunable 0.5-9 ps (FWHM) pulse duration. The laser system design implies single- and multibunch operation modes. In multibunch operation mode each pulse of the amplifier is converted into a train of 16 sub-pulses (0.5 ps duration, >10 µJ energy) with a repetition rate of 49.9654 MHz.

AREAL RF gun is an S-band 1.5-cell standing wave cavity designed for REGAE facility at DESY. The main characteristics of the gun are the following: shunt impedance - 2.12 MΩ, the unloaded quality factor is ~15000 and the filling time is ~0.7 µs. The gun is fed by the7 MW klystron. Obtained cavity maximum voltage is about 5 MV, what corresponds to peak accelerating electric field of 117 MV/m. Located at the photocathode surface, the maximum of electric field provides an effective capture of the emitted photoelectrons into acceleration regime.

The first stage of AREAL facility is completed [2] including the diagnostic units for beam energy, energy spread, charge and profile measurements. The gun section contains the focusing solenoid, magnetic spectrometer, horizontal/vertical corrector magnet, Faraday Cups (FC) and YAG screens. Currently, there are two in-air experimental stations for applied researches in the fields of life and materials sciences.

Accelerating Structures

For AREAL accelerating sections, a conventional constant impedance travelling wave structure has been chosen due to its simplicity, easy production and tuning. Following the well-known theory of TW disc loaded structures for the same shunt impedance, the energy gain in the constant impedance structure is only 1 % less compared to constant gradient. The CST microwave studio [4] is used for the design and simulation of the accelerating structures with input and output couplers [5]. Figure 2 presents the accelerating field amplitude, along the structure, consisting of 42 periodic cells.

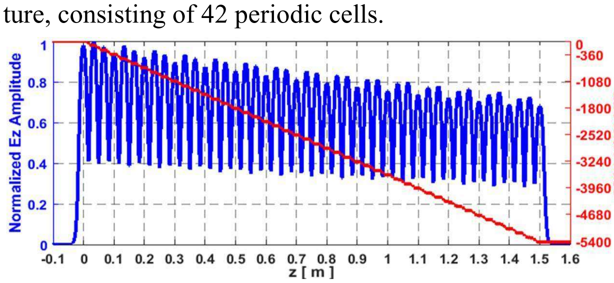

Figure 2: On-axis accelerating field along the AREAL travelling wave structure

The design specification of the RF photogun implies the usage of the metallic photocathode and ultrafast UV laser.

The complete cavity has an effective length of ~1.5 m and a filling time of about 0.61 µs. For the 40 MW input power the energy gain of about 30 MeV per accelerating section is foreseen, with an average acceleration gradient of about 25 MV/m. Following the design specifications, a 5-cell prototype structure has been constructed and tested at the mechanical workshop of CANDLE (Fig. 3). To obtain structure high performance, the final machining of cups has been proceeded with the CNC milling machine. Based on the design and first test results, the production of full length accelerating section is in process.

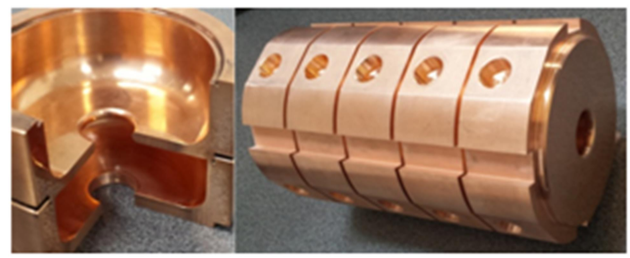

Figure 3: Brazing test with 2-cell (left) and 5-cell prototypes (right).

Beam Dynamics,Diagnostics and Control

Based on the normalized emittance requirements, for the machine upgrade a new optical system including the gun solenoid option, has been studied. Figure 4 presents the optimal horizontal beam size and the normalized emittance evolution along the linac without the space charge effects. After the second accelerating section, the beam energy is 53.8 MeV, the normalized transverse emittance is 0.17 mm-mrad, the rms beamsize is 0.046 mm, the rms energy spread is below 0.1 %.

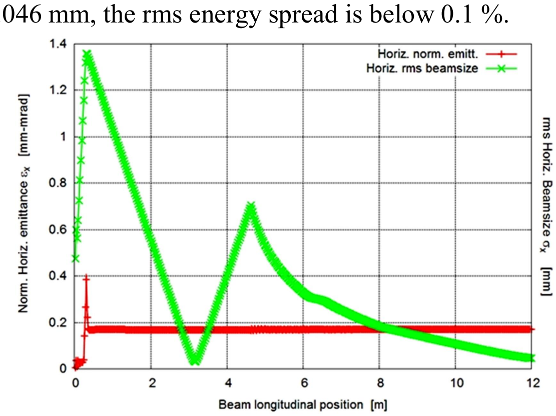

Figure 4: The beam size and normalized beam emittance evolution along the linac, without space charge.

The current beam diagnostic system of RF gun section provides a good basis for the facility development. The upgraded diagnostic system will include beam charge measurements, energy and energy spread, transverse position and profile, emittance and bunch length.

To obtain the desired beam position resolution, four 500 MHz resonant strip line BPMs are foreseen to measure and stabilize the beam central trajectory. Being developed at PSI, they are optimized for a high dynamic range and sensitivity in the bunch charge range of 10-250 pC, and provide single-bunch rms resolution below 10 µm.

For beam emittance measurement the magnet scan method will be used. The method is based on beam size measurements versus quadrupole field strength.

For bunch length measurements, various methods are under consideration, including the "RF phasing" scheme with a dispersive section.

Being a part of AREAL upgrade program the current control system will undergo architectural modifications. A new Micro Telecommunications Computing Architecture (µTCA) will be implemented.

ALPHA Station

The ALPHA station for the FEL, based on self-amplified spontaneous emission (SASE) principle [6] is one of the promising outlooks of AREAL facility.

The successful generation of SASE FEL implies a small electron beam natural emittance ε and energy spread, in order to match with diffraction limited photon beam phase-space and to avoid radiation spectrum broadening. AREAL electron beam parameters at energies 10-50 MeV enable the effective SASE FEL generation of tens MW power in a several meters long undulator.

AREAL SASE FEL performance for the fixed gap planar and helical undulators has been studied for 35 MeV energy electron beam with a normalized emittance of 0.3 mm-mrad, energy spread of 0.2 %, bunch charge of 250 pC and rms bunch length of 2 ps. Numerical simulations have been performed by the GENESIS 3D time-dependent simulation code [7]. In simulations 20 initial seeds for the random number generator, used for particle phase fluctuation (shot noise), have been considered.

The planar undulator period is taken 3 cm and the magnetic field $B=0.72$ *T* (undulator parameter $K=2.02$). Figure 5 presents the average radiation power evolution along the undulator at radiation wavelength λ=10 µm (~30 THz). The radiation saturation is reached at about 3.5 m with the average radiation peak power of 27 MW (averaged over 20 seeds).

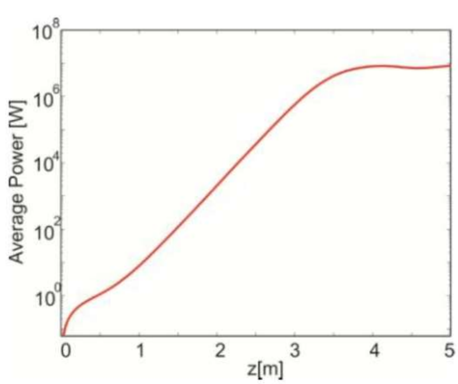

Figure 5: The SASE FEL radiation power along the undulator for 10 µm radiation wavelength

Figure 6 presents the power distribution along the bunch and the radiation spectrum at the saturation point for one particular seed. The radiation pulse energy is about 60 mJ. For the given undulator parameters the radiation wavelength is tuneable in the range of 5-120 µm for the beam energy variation within 10-50 MeV.

For the helical undulator the SASE FEL with 24 MW radiation peak power, at the wavelength of 16.2 µm, is predicted with saturation length of 2.73 m. The tunability is within the range 8-200 µm.

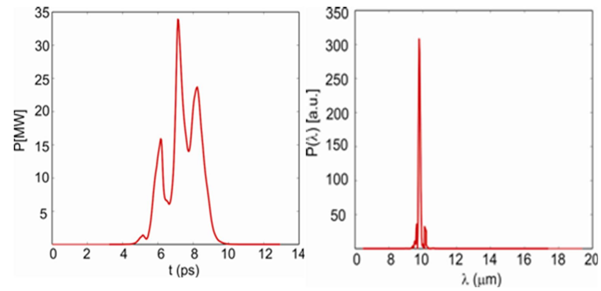

Figure 6: Power distribution along the bunch (left) and the radiation spectrum (right) at the saturation point for radiation wavelength of 10 µm.

CONCLUSION

An upgrade of AREAL facility is planned to increase the energy of the facility to 50 MeV, leading to obtain FEL radiation in the THZ and mid IR regions. The layout, upgrade plans and design considerations for machine and components are summarized. Obtained from simulations the expected radiation properties are presented.

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