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AREAL test facility for advanced accelerator and radiation source concepts

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A B S T R A C T

Advanced Research Electron Accelerator Laboratory (AREAL) is a 50 MeV electron linear accelerator project with a laser driven RF gun being constructed at the CANDLE Synchrotron Research Institute. In addition to applications in life and materials sciences, the project aims as a test facility for advanced accelerator and radiation source concepts. In this paper, the AREAL RF photoinjector performance, the facility design considerations and its highlights in the fields of free electron laser, the study of new high frequency accelerating structures, the beam microbunching and wakefield acceleration concepts are presented.

1. Introduction

In the last decades the development of advanced accelerator and radiation source concepts has been on the frontier of accelerator physics researches. The AREAL linear accelerator project is aimed for the generation and acceleration of ultrashort electron pulses with small emittance [1]. After the successful operation of the 5 MeV RF photoinjector [2], the facility energy upgrade to 20–50 MeV to be delivered to ALPHA (Amplified Light Pulse for High-end Applications) and BETA (Booster for Emerging Technology Accelerators) experimental stations is foreseen. ALPHA station is designated for the creation of a free electron laser (FEL) [3] and BETA station is designated as a test stand for advanced particle acceleration schemes and tailored beam formation for coherent radiation.

In this paper, the AREAL project main design consideration and the anticipated experimental program in the fields of particle radiation and accelerator technology are presented. The design specificiations of the RF photoinjector along with the commissioning results are given. The main outlooks for the self-amplified spontaneous emission (SASE) FEL beam line based on the planar and helical undulators at the ALPHA station are discussed. The experimental program at BETA station is presented, which implies the study of high frequency accelerating structures, the wakefield induced beam energy modulation schemes and the high transformer ratio wakefield accelerator (WFA) concepts.

2. Facility design and performance

The AREAL facility design consists of the 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 Fig. 1.

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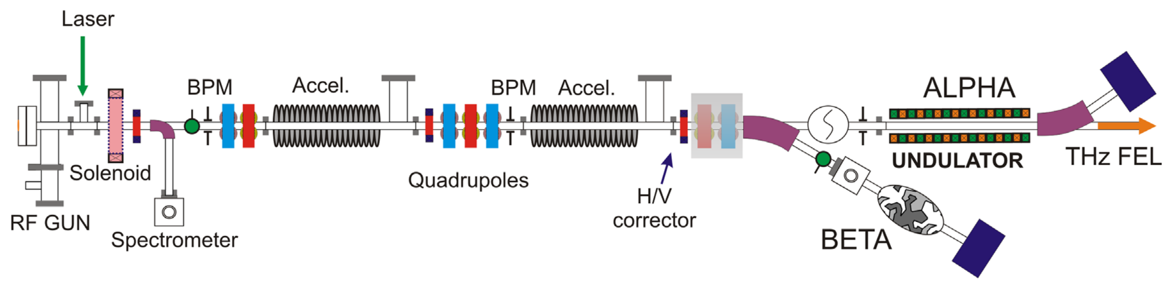

Fig. 1. Schematic layout of the AREAL linear accelerator.

Table 1
AREAL beam parameters.

Energy (MeV)	20–50
Bunch charge (pC)	10–250
Bunch length (ps)	0.4–9
Norm. emittance (mm-mrad)	<0.5
RMS energy spread	$<0.15\%$
Number of bunches per pulse	1/16
Repetition rate (Hz)	1–50

The main design parameters of the AREAL project are presented in Table 1.

2.1. AREAL design considerations

The design specification of the RF photogun implies the usage of the metallic photocathode and ultrafast UV laser. The choice of a metalic (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 provide the facility reliable operation with sub-picosecond electron pulses at the gun exit.

The AREAL 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 $>250\ \mu$J at 258 nm wavelength and 0.4–9 ps tunable pulse duration (FWHM). The laser beam is TEM_{00} mode with Gaussian intensity profile and the quality factor of $M^2<1.3$. 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 (0.4 ps duration, $>10\ \mu$J energy) with a repetition rate of 49.9654 MHz.

The RF gun is an S-band 1.5-cell standing wave cavity designed for REGAE facility at DESY [4] with 2.12 MΩ shunt impedance, unloaded quality factor of $\sim$15,000 and filling time of about 0.7 μs. The electric fields of TM_{010} cavity accelerating mode, computed by CST Microwave Studio [5], is given in Fig. 2. The AREAL linac RF gun operates with 7 MW power klystron (pulse duration $\sim$ 4 μs). To obtain flat-top cavity voltage, the cavity is charged with 7 MW input power in the beginning and then is switched to 6 MW (Fig. 3). Thus, in the cavity, a 6 MW RF power of $\sim$2 μs flat-top duration can be obtained. The maximum cavity voltage is about 5 MV, which corresponds to peak accelerating electric field of 117 MV/m. The maximum of electric field at the photocathode provides an effective capture of the emitted photoelectrons into acceleration regime.

Following the emittance and correlated energy spread simulations at the gun exit (Fig. 4), the nominal operating RF phase is 32° for 1 ps bunch length. Following the gun section two 1.6 m long S-Band traveling wave structures accelerate the beam up to 50 MeV energy with maximum acceleration gradient of 15 MV/m. Fig. 5 presents the ASTRA [6] simulations of the beam emittance and rms transverse size evolution for 25 MeV accelerated beam with bunch charge of 250 pC. A normalized beam emittance of about 0.3 mm-mrad and rms energy spread below 0.15% are designed.

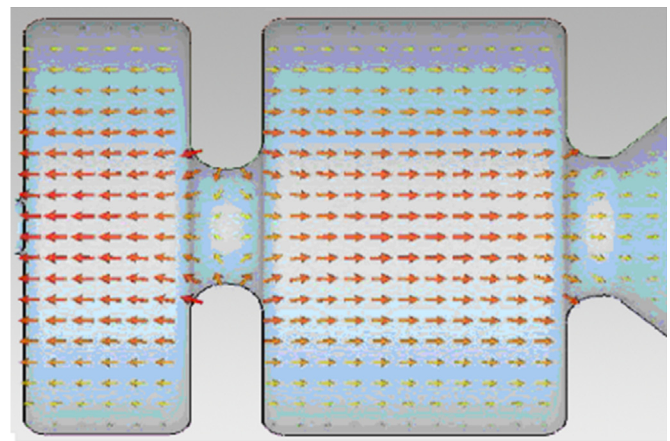

Fig. 2. TM_{010} accelerating mode of the gun cavity.

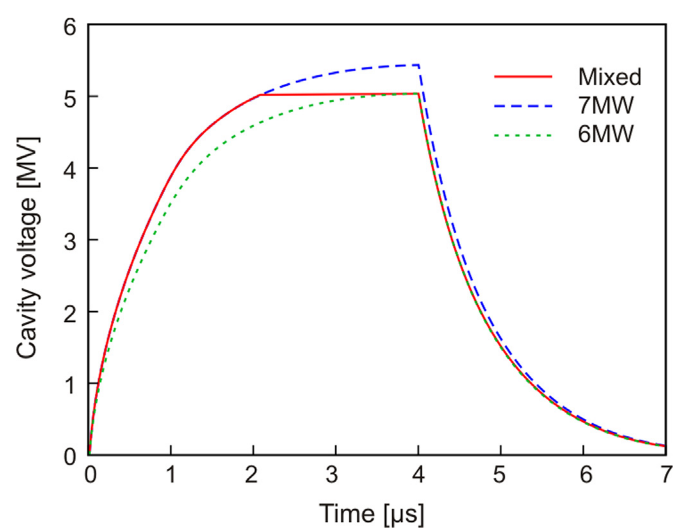

Fig. 3. Transient cavity voltage in 6 MW flat-top regime.

2.2. RF photoinjector performance

The first stage of the AREAL facility – a 5 MeV RF photoinjector – is completed [2] along with the diagnostic units for beam energy, energy spread, beam charge and profile measurements. The gun section contains the focusing solenoid, magnetic spectrometer, horizontal/vertical corrector magnet, Faraday Cups (FC) and YAG screens. The charge of individual bunches was measured using two FCs. One of them is located at the end of spectrometer and the second one, an insertable FC, is installed downstream after the