STATUS OF AREAL RF PHOTOGUN TEST FACILITY

B. Grigoryan#, G. Amatuni, V. Avagyan, H. Avdishyan, H. Davtyan, A. Gevorgyan, L. Hakobyan, M. Ivanyan, V. Khachatryan, E. Laziev, A. Lorsabyan, M. Manukyan, I. Margaryan, N. Martirosyan, T. Mkrtchyan, S. Naghdalyan, V. Petrosyan, H. Poladyan, V. Sahakyan, A. Sargsyan, A. Tsakanian, V. Tsakanov, A. Vardanyan, V. Vardanyan, G. Zanyan
CANDLE SRI, Yerevan,
T. Sargsyan, LT-PYRKAL cjsc, Yerevan

Abstract

Advanced Research Electron Accelerator Laboratory (AREAL) is a 20 MeV laser driven RF linear accelerator which is being constructed in the CANDLE institute. The construction of phase-1 is finished and at present the machine commissioning is in progress. In phase-1 a photocathode RF gun provides a 5 MeV small emittance electron beam with the 100 pC bunch charge and variable electron bunch length from 0.5 to 8 ps. Two main operation modes are foreseen for this phase – single and multibunch regimes to satisfy experimental demands. We report the status of linac, first experience and nearest machine run schedule. The brief review of the facility, main parameters, performance and first results are presented.

AREAL. PHASE 1

A 20 MeV AREAL electron linear accelerator with photocathode RF gun was proposed and designed at the CANDLE Synchrotron Research Institute [1]. It aims to provide a base for advanced experimental study in the field of accelerator technology and dynamics of ultrafast processes. The construction and commissioning of RF photogun and diagnostic stations have been finished recently. Such machine set-up has provided a good basis for the facility development and the start-up for first experiments [2]. The construction of two satellite laser based laboratories for two-photon microscopy and micro-fabrication is in progress. The main peculiarities of the AREAL facility are the relatively broad range of beam parameters variation and stable machine operation within this range. This was demonstrated by the machine run devoted to machine study and beam parameters measurement during the May 2014 [3]. Moreover, the laser system is able to provide simultaneous photon experiments and electron bunch generation. Main parameters of AREAL facility (phase 1) are presented in Table 1. Two operating modes, multi and single bunch, with nominal pulse operation frequency of 0-50 Hz expand the experimental possibilities of AREAL. Depending on the experimental demands main systems easily and quickly tuned to operate within specified range. The schematic layout of AREAL facility phase 1 is presented in Figure 1.

#grigory@asls.candle.am

Table 1: Main Parameters for AREAL Facility (Phase 1)

Parameter	Single bunch	Multi-bunch
Beam energy	< 5 MeV	< 5MeV
Bunch length (FWHM)	0.4 – 9 ps	0.4 ps
Beam diameter at photocathode	> 4 mm	> 4 mm
Bunch charge	< 200 pC	< 15 pC
Emittance $\varepsilon_{n\,x,y}$ (mm-mrad)	< 0.35	< 0.35

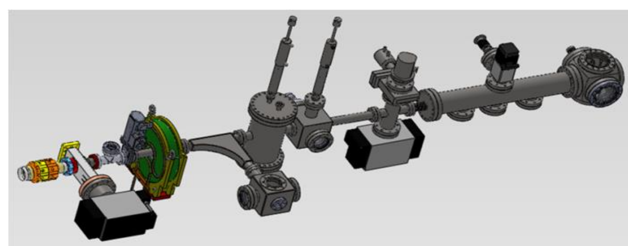

Figure 1: The schematic layout of AREAL machine.

SYSTEMS AND SUB-SYSTEMS

For stable operation the performance of different systems and sub-systems has been tested under laboratory conditions before final assembly. The final assembly and commissioning of sub-systems was finished in December 2013. As a result, we got the first beam through RF gun and experimental diagnostic beamline. After final commissioning of accelerator components machine studies were planned during May 2014 to accomplish measurements of main parameters of electron beam and the laser system along with observation of performance for different systems during long run. We operate entire month with 24/7 operation regime in single bunch mode with 1-10Hz repetition rates. The performance and measurement results for all systems are presented below.

Laser System and Synchronization

Laser system used for generation of ultra-short electron bunch from copper photocathode consists of four modules. The main parameters of laser system are presented in Table 2. In Figure 2 the laser beam transverse profile measured at laser laboratory is presented.

Table 2: Main Parameters of Laser System

Parameter	Single bunch	Multi bunch
Wavelength	258 nm	258 nm
Pulse Energy	≤ 300 μJ	< 15 μJ
Operating frequency	≤ 100 Hz (1Hz step)	≤ 50 Hz (1 Hz step)
Beam diameter	≤ 4.5 mm	≤ 1 mm
Number of pulses per train	1	16
Energy stability (per 8 hours)	< 2%	In progress

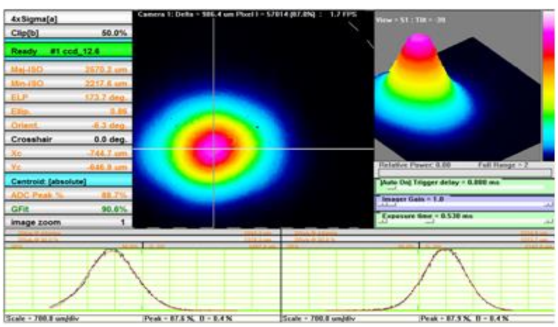

Figure 2: Measured laser beam transverse profile.

More detailed description of AREAL laser system is presented at this conference [4]. Both long and short term energy stability were observed during the machine run. Results of analysis show the energy stability of < 3 % for a period of month. The average obtained timing stability was < 4 ps, which corresponds to deviation of about 3.5° in RF phase. Pulse to pulse RF phase correction is applied via adaptive feed-forward of LLRF control system. The overall electron bunch energy stability of < 5 % was observed during the last month of machine operation.

RF System

For the AREAL facility design the numerous simulations have been performed to optimize the RF parameters at the gun and accelerating sections [5]. The RF parameters have been optimized for the facility single bunch operation mode from the beam emittance and energy spread points of view. The gun gradient scan was performed to get the minimum transverse emittance and energy spread at the gun exit. The minimum energy spread with the space charge effects is achieved for the RF gradient of about 90 MV/m (Figure 3).

To provide an accelerating field in electron gun a composite RF station [6] based on 7 MW klystron with European S-band frequency was used. After conditioning and final tests of RF system and electron gun more than 6.2 out of supplied 7 MW of RF power was injected into gun. Operating in π-mode standing wave RF gun resonator according to injected power implies peak accelerating gradient of about 90 MV/m and as a result

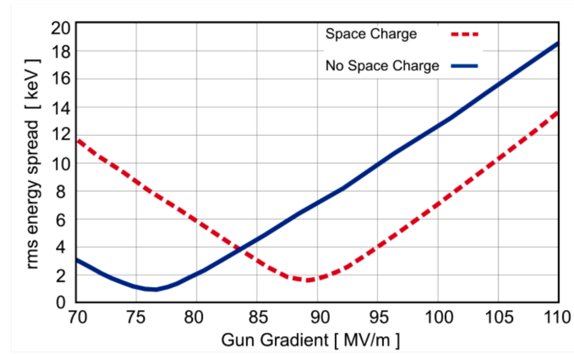

Figure 3: The beam RMS energy spread at the gun exit versus acceleration gradient. The results with (red) and without (blue) space charge effects are shown.

the electron bunch energy of 3.7 MeV was measured on spectrometer.

The main parameters of AREAL gun RF system are presented in Table 3. The profile measurement for 4μs klystron pulse is presented in Figure 4.

Table 3: Main Parameters of Gun RF System

Parameter	Single / Multi bunch
RF pulse length	4μs
RF peak power	7 MW
Peak acc. gradient	~95 MV/m
Phase stabilization	< 0.5°
Amplitude stability	< 0.1 %

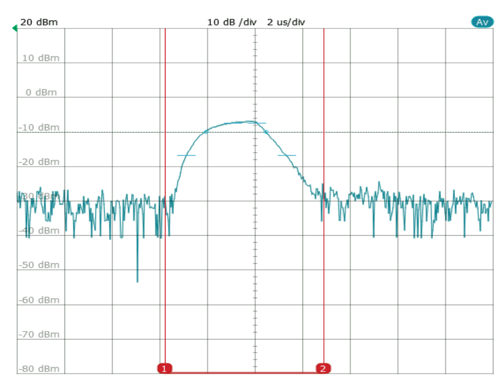

Figure 4: RF pulse profile measurement.

Cooling and Vacuum Systems

Thermal stabilization and cooling systems are providing the stable resonant conditions for electron gun and heat removal with stable operation for klystron and solenoid magnet. The design and fabrication of the thermal stabilization system for electron was done in-house. The gun resonance frequency dependence on body

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temperature was measured during several weeks. Observed temperature fluctuations were within ± 0.1° C, which corresponds to gun resonant frequency deviation of less than 10 kHz.

Stable operation of ion pumps providing UHV at level 10^{-9} Torr during operation was another criterion for machine best performance. AREAL machine vacuum system was pre-assembled and tested in laboratory before final assembly. After final assembly the vacuum system provided ultra-high stable vacuum and quick response on RF sparks during conditioning of RF window and electron gun..

Control and Beam Diagnostics Systems

Together with the laboratory tests of all the sub-systems control, the general control system philosophy has been developed. Tests and final integration of local sub-systems into global control are performed using EPICS based platforms.

To measure and observe main beam parameters several diagnostic units such as Faraday Cups, YAG screens, and pepper-pot station for transverse emittance measurements were placed along the beamline [3].

Operating in single bunch regime with shot frequency 10 Hz beam characterizing parameters measurements set was accomplished for beam profile and charge, energy and energy spread. The emittance measurement set-up is in progress at present. Obtained results of the last set of measurements are presented in Table 4. Beam profile pictures from straight and spectrometer YAG screens are presented in Figure 5.

Table 4: Machine Studies Operation Results

Parameter	Single bunch
Beam energy	2 – 4 MeV
Laser pulse length FWHM	400 fs
Laser pulse energy	< 270 µJ
Bunch charge	30 – 200 pC
Beam profile (transv. rms)	0.3 – 0.6 mm
Energy spread rms	<30 keV

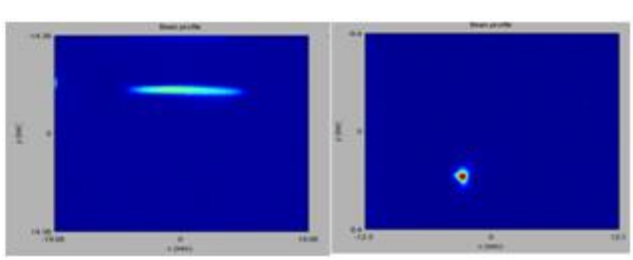

Figure 5: Electron beam image at straight (left) and spectrometer (right) screens.

Magnets & Power Supplies

Magnets used at the AREAL facility were designed and fabricated in-house [7]. After fabrication complete magnetic measurements for both: solenoid and dipole were accomplished. Good agreement between design simulations and final measurements at magnetic bench stand was obtained. The results of measurements are shown in Figure 6. After finishing calibration and performance tests for power supplies magnets were assembled at final location.

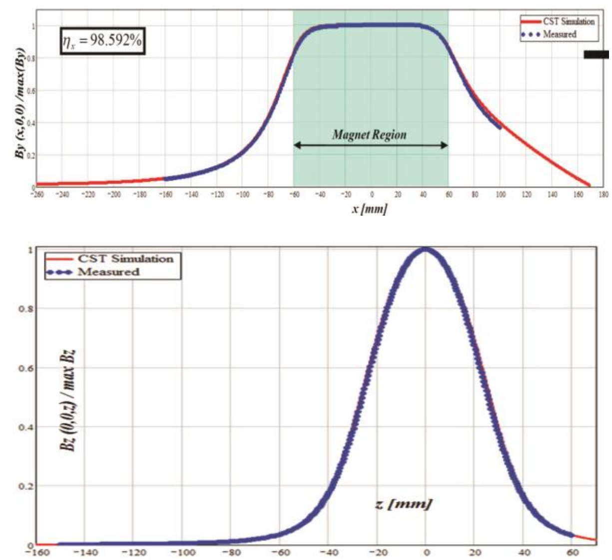

Figure 6: Simulation results (line) and measurements of magnetic field (dots) for dipole (top) and solenoid (bottom) magnets.

CONCLUSION

The first phase of the AREAL linear accelerator construction was finished at the end of 2013. The results of the facility commissioning show the reliable operation of the machine subsystems. The measured beam parameters are within the expected facility performance. The further optimization and development of the project are in progress

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