BEAM DIAGNOSTIC AND CONTROL SYSTEMS FOR AREAL 50 MeV LINAC

V. V. Sahakyan*, G. A. Amatuni, A. A. Azatyan, B. A. Grigoryan, N. W. Martirosyan, A. A. Sargsyan, V. M. Tsakanov, G. S. Zanyan
CANDLE Synchrotron Research Institute, Yerevan, Armenia

Abstract

Advanced Research Electron Accelerator Laboratory (AREAL) is an electron linear accelerator project with a laser driven RF gun that has been constructed at CANDLE Synchrotron Research Institute. After the completion of the first phase, which implies the operation of a 5 MeV gun section, the second phase of facility development (energy enhancement up to 50 MeV) is in progress. In the present paper the description of corresponding upgrades for diagnostic and control systems is given.

INTRODUCTION

Photo cathode RF gun based AREAL linac at CANDLE Synchrotron Research Institute [1] is already under operation at 5 MeV electron beam energy. The basic aim of this facility is to generate electron bunches of sub-picosecond duration with an extremely small beam emittance for advanced experimental studies in the fields of accelerator technology and dynamics of ultrafast processes. Currently, the facility energy upgrade up to 50 MeV is in progress. The upgrade program includes the construction of two advanced experimental stations: ALPHA [2] and BETA [3]. The aim of ALPHA project is to create middle infrared coherent radiation experimental station based on SASE FEL principle [4]. BETA station is designated for the generation of elliptically polarized high brightness coherent undulator radiation in THz range of the spectrum.

The main parameters of AREAL electron beam are listed in Table 1.

Table 1: Beam Parameter List

Parameter	Value
Energy (MeV)	≤ 50
Bunch charge (pC)	10 - 250
ε_{norm} (mm.mrad)	< 0.5
RMS bunch length (ps)	0.4 - 9
RMS energy spread (%)	< 0.15
Repetition rate (Hz)	1-50

For AREAL linac operation an appropriate beam diagnostic system should be implemented, which will register and control low emittance short electron bunches, that have small energy spread and high peak current. The scope of diagnostic tasks covers transverse beam shape, size, phase-space distribution, beam energy, energy spread and bunch length measurements.

Currently, beam energy, energy spread, charge and transverse beam profile measurements are being performed.

The charge of individual bunches is measured using two 50 Ω impedance-matched Faraday cups. During the gun section operation, depending on the laser intensity, beam charges in the range of 10-250 pC were registered.

For beam spot measurements two screen stations are allocated in AREAL gun section [6]. In these profile monitors YAG:Ce scintillating crystals, having 35x25 mm^2 area and 200 μm thickness, are used. The readout systems of these stations consist of 0.16, 0.24 magnification optics and Point Gray Flea2 08S2, Flea2 20S4 CCD cameras. The horizontal/vertical beam profile is calculated by the projection of a digitized image onto corresponding axes. The observable areas of these both systems are about 30×23 mm^2.

The energy and energy spread of an electron beam are measured using the dipole-based spectrometer with the YAG screen. The dipole is a 90^o bending magnet designed to measure maximum energy of about 6 MeV. Absolute momentum measurement is done on the basis of the dipole geometry and calibration. The energy spread is estimated by observing the beam in a dispersive section where the beam horizontal spot size is a convolution of the emittance and dispersion contributions. During gun section operation the maximum observed energy was 5 MeV and the rms energy spread was below 2% [6].

In this paper approaches of the intended diagnostic and control systems for AREAL 50 MeV upgrade program are described.

50 MEV UPGRADE PROGRAM

After a successful operation of the gun section, AREAL facility upgrade has been launched, which presumes the increase of beam energy up to 50 MeV. According to the current schedule the upgrade program will be completed in 2018. The schematic layout of AREAL linac after the upgrade is shown in Fig. 1 [3].

Two 1.6 m long S-Band traveling wave accelerating structures with maximum gradient of 15 MV/m will be installed after the gun section. Two quadrupole doublets and one triplet, combined with corrector magnets, will be used for beam focusing and trajectory control (Fig. 1). After the second quadrupole doublet a non-dispersive bending system will be installed allowing to switch the electron beam between ALPAHA and BETA stations. This part of the linac will also serve for electron beam energy, energy spread and bunch length measurements. In addition, two other bending magnets will be located after undulator sections for electron and photon beam separation.

* sahakyan@asls.candle.am

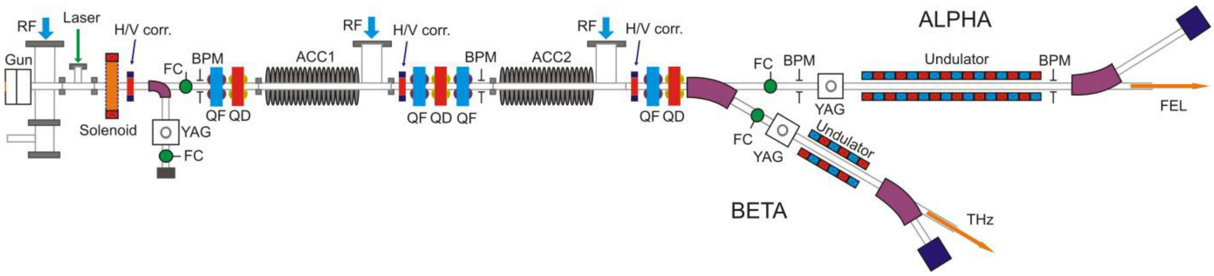

Figure 1: The schematic layout of AREAL linear accelerator.

BEAM DIAGNOSTICS

For the predefined operation of both ALPHA and BETA undulator lines, well-aligned, short electron bunches with high peak currents and small emittances are required. Therefore, four beam position monitors (BPM), one YAG screen and two insertable Faraday cups will be added to the existing diagnostic stations for the above-mentioned parameters' measurement and control.

According to the upgrade program, besides the transverse beam profile, charge, energy and energy spread measurements, beam position, emittance and bunch length are also planned to be measured using the methods being described below.

Beam Position Measurement

Four 500 MHz resonant stripline BPMs are planned to be used for beam transverse position measurement and stabilization during its propagation along the linac. Two of them will be placed before accelerating sections and the other two - before and after the undulator of ALPHA station (Fig. 1). These BPMs, being developed at PSI, provide single-bunch RMS resolution below 10µm [5] and are optimized for sensitivity in bunch charge range of 10-250 pC. The pickups consist of four λ/4 stripline resonators that are located parallel to the electron beam alongside the inner beam pipe wall, with 90° axial rotation symmetry. The resonators are excited in the gap at the open-circuit end, and the signal is extracted by direct tapping near the short-circuit end. The four beam-induced pickup signals consist of decaying sinusoids' superposition, having frequencies around the fundamental resonance (500 MHz) and odd order harmonics. The schematic layout of four resonant stripline electrodes (two per plane) is shown in Fig. 2.

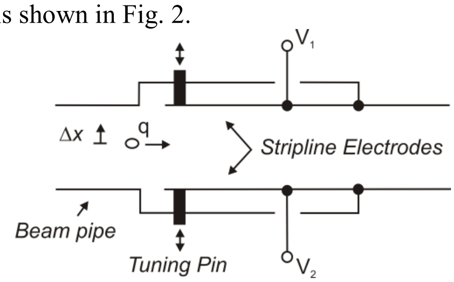

Figure 2: Resonant stripline pickup, one plane only.

The transverse beam position is determined using the ratio of the signal voltages from opposing electrodes:

$$\frac{V_2 - V_1}{V_2 + V_1} \sim x.$$

Transverse Beam Emittance Measurement

One of the main diagnostic tasks in AREAL upgrade program is the measurement of beam emittance. For this purpose a common magnet scan method will be used which is, in case of low charged bunches, most sensitive to beam size determination. The trace space emittance for a well-cantered and aligned beam ($\langle x \rangle = \langle x' \rangle = 0$) is determined as:

$$\varepsilon_x = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2}\ ,$$

where $\langle\ \rangle$ denotes the central moment of a distribution.

The phase advance between the last quadrupole magnet and a downstream YAG screen (Fig. 1) will be changed by varying the magnet current in order to measure the transverse beam emittance. To evaluate the rms beam size ($x_{rms} = \sqrt{\langle x^2 \rangle}$) on the screen the envelope equation

$$\langle x^2 \rangle = R_{11}^2 \langle x^2 \rangle_0 + 2R_{11}R_{12} \langle xx' \rangle_0 + R_{12}^2 \langle x'^2 \rangle_0, \quad (1)$$

can be used, where the index 0 refers to the position of the quadrupole, and R_{ij} are elements of point-to-point transfer matrix between the quadrupole and the screen. Measuring the beam size as a function of quadrupole field strength (which should be quadratic according to the model underlying the equation (1)), and fitting the results with parabolic function, using least squares, yields the emittance [6].

Bunch Length Measurement

The measurement of electron bunch longitudinal characteristics is one of the complicated tasks in beam diagnostics. The commonly used methods are based on expensive specialized technologies, such as a radiator with streak camera or an RF deflector. In our case the "RF phasing" scheme [7] will be used, which does not require any additional hardware. Using a section of linac with nominal

ISBN 978-3-95450-182-3

off-crest RF phase (ACC2 in our case), the method is first calibrated by fitting the linear slope of beam position, measured on a screen at a dispersive location after the linac (YAG station at BETA beamline), versus small RF phase variations. The dispersed beam size is then measured on the same screen (where the dispersion dominates the beam size) at the nominal off-crest RF phase and later again at the nominal, but opposite sign phase (preserving the electron energy) and finally, at the crest phase, requiring a voltage reduction (in some cases a faster, 2-point measurement is also possible, ignoring the crest phase beam size if it is much smaller than the other two). A parabola is fitted to these three data points, and the bunch length is extracted from one of the three fitted parabolic coefficients, using the calibration coefficient.

Thus, the application of this method requires just a simple and fast calibration, which eliminates the need for knowledge of the RF voltage, the scale of the screen or the dispersion value at the screen. Only the RF frequency should be known. Precise RF phase knowledge is not mandatory as well, since it is part of the calibration, and the actual RF phase flip can be guided by keeping the beam centred on the screen.

CONTROL SYSTEM

The current control system of AREAL linear accelerator has three layers of hierarchy and is based on "client-server" model. The connection between layers is performed via TCP/IP protocol [3]. The first layer is an interface to which the devices are connected. The readings from various devices are then transferred and stored in the data base (second layer). The third layer represents an operator interface.

During the realization of AREAL upgrade program the control system architectural will be transformed to a new Micro Telecommunications Computing Architecture (MicroTCA 4) [11], which has rapidly evolved in recent years to become a viable standard for demanding applications in particle accelerators, high-energy physics, plasma fusion sources, etc. The MicroTCA module for AREAL control system was jointly developed with DESY control group. It consists of 9 ADC boards, 3 RTM down converter boards and X2TIMER. ADC boards will be used for retrieving signals from diagnostic devices, namely, Faraday cups and BPMs. RTM down converter boards will be used for LLRF and accelerating sections monitoring and control [12]. Currently, the LLRF control is performed via LIBERA digital low level RF stabilization system, on which EPICS and all required IOCs are installed. After the machine upgrade all signals will be synchronized via X2TIMER board. The global control system will be DOOCS.

At the first stage BPM signal processing will be handled by electronics, which consists of RF front-end and digitizer FPGA VME board (plus commercial EPICS IOC VME board, timing card, VME crate, and some VME RTMs). The 500 MHz decaying sinusoidal signals of stripline pickups will be amplified and filtered by a low-noise RF front-end (RFFE) board. The 500 MHz RFFE output signals will be digitized by a PMC mezzanine module that uses a cost-efficient 5 GSa/s waveform digitizer chip (DRS4 domino ring sampler). The digitizer waveforms will be processed by a generic FPGA PMC carrier VME64x board [5] (see Fig. 3).

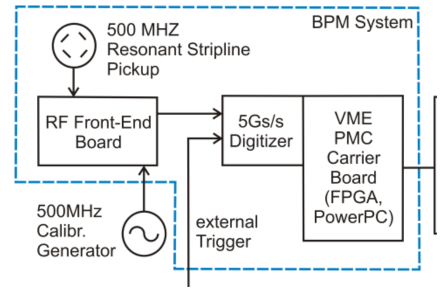

Figure 3: The BPM system block scheme.

During the control system upgrade it is foreseen to develop an appropriate electronics to migrate BPMs control from VME to MicroTCA.

SUMMARY

The paper presents the upcoming modifications in diagnostic and control systems, that are included in AREAL 50 MeV energy upgrade program. In addition to electron beam energy, energy spread, bunch charge and transverse profile measurements, which are currently being performed, electron beam transverse position, emittance and bunch length measurements are also planned to be realized. The approaches and description of new diagnostic units, as well as the corresponding changes of the control system are given.

AKNOWLEDGMENTS

This work was supported by the RA MES State Committee of Science, in the frame of the research project № 16YR-1C009 and was made possible in part by a research grant from the Armenian National Science and Education Fund (ANSEF) based in New York, USA.

REFERENCES

[1] B. A. Grigoryan *et al.*, in *Proc. IPAC'14*, pp. 620-623.
[2] A. A. Sargsyan *et al.*, "AREAL Test Facility for Advanced Accelerator and Radiation Source Concepts", Nucl. Instr. Meth. A, 2016, 829, 284-290.
[3] G. A. Amatuni *et al.*, in *Proc. IPAC'14*, pp. 3418-3420.
[4] V. V. Sahakyan *et al.*, "An overview of beam diagnostic and control systems for 50 MeV AREAL Linac", Journal of Instrumentation, v. 12, (2017), doi:10.1088/1748-0221/12/03/T03004.
[5] B. Keil *et al.*, in *Proc. FEL'10*, pp. 429-432.
[6] M. Hachmann, K. Floettmann, in *Proc. IPAC'15*, pp. 837-840.
[7] P. Emma, H. Loos, C. Behrens, in *Proc. FEL'15*, pp. 602-605.
[8] MicroTCA® is a trademark of PICMG, MTCA.4 specifications: http://www.picmg.org.