BEAM DIAGNOSTICS FOR AREAL RF PHOTOGUN LINAC

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Abstract

Advanced Research Electron Accelerator Laboratory (AREAL) based on photocathode RF gun is under construction at CANDLE. The basic approach to the new facility is the photocathode S-band RF electron gun followed by two 1 m long S-band travelling wave accelerating sections. Linac will operate in single bunch mode with final beam energy up to 20 MeV and the bunch charge 10 –200 pC. In this paper the main approaches and characteristics of transverse and longitudinal beam diagnostics are presented.

INTRODUCTION

The beam diagnostic section for AREAL linac [1] can be divided into two sections

- Gun section diagnostics
- Linac diagnostics

The commissioning of the AREAL linac will proceed in two stages: in a first step (phase 1), the gun section with additional diagnostics will be put into operation. For phase 2 the full accelerator will be assembled.

The beam transport line between the electron gun and the first accelerating structure (energy < 4 MeV) has a length of almost 0.95 m, which is completely occupied by diagnostic devices. In this diagnostic line electron beam charge, position, transverse profile, emittance (phase 1), energy and energy spread must be measured. In a gun commissioning phase the gun section with additional diagnostics (pepperpot) will be put into operation. The schematic layout of the gun section with diagnostics is presented in Fig. 1.

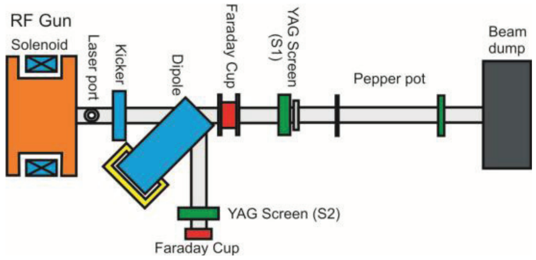

Figure 1: Layout of AREAL gun section with diagnostics (phase 1).

After gun commissioning the pepperpot will be moved to the end of the linac. Also high resolution Cavity BPM will be installed in the straight arm of the gun section. In linac diagnostics it is foreseen to measure electron beam charge, position, emittance, energy, energy spread and longitudinal profile. The schematic layout of the linac with diagnostics is presented in Fig. 2.

BEAM CHARGE

The task for the beam current and charge measurement is to verify that the charge produced at the cathode is completely transported along the whole beamline to the beam dumps. In AREAL linac the charge of individual bunches will be measured using Faraday Cups and Integrating Current Transformers (ICT) [2] (see Fig. 1, 2). Three Faraday cups are intended to be used to collect and measure the beam charge. Two of them will be installed in the end of the spectrometer arms. The third one is an insertable faraday cup which will be installed in the gun section. Electrical connections are made to the base of the Faraday cups, terminating in a BNC connector. The output signal is integrated on the oscilloscope and divided by the termination to give a reading of the charge.

Specifications of Faraday cups are presented in Table 1.

Table 1: Specifications of ARIAL linac Faraday cups.

	Non insertable	Insertable
Cup Diameter (mm)	15.1	9.5
Cup Length (mm)	75	69.5
Maximum Power (W)	10	4
Impedance	50 Ω	
Signal Output	BNC	

Also two in-air ICTs are planned to be used as non-destructive devices for electron bunch charge monitoring. Typical installations include bellows, a wall current bypass and an electromagnetic shield covering the ICT completely.

BEAM POSITION

Three BPMs are intended to be installed in AREAL linac. High resolution Cavity BPM (CBPM) will be installed in the gun diagnostic line in phase 2. It will provide about 1~3 μm resolution for electron beam trajectory measurements.

A cylindrical “pillbox” with conductive walls of length l and radius R resonates at its eigenfrequencies

$$f_{mnp} = \frac{1}{2\pi\sqrt{\mu_0\varepsilon_0}}\sqrt{\left(\frac{j_{mn}}{R}\right)^2 + \left(\frac{p\pi}{l}\right)^2} ,$$

with j_{mn} - the n-th zero of the Bessel function J_m of order m, p is an integer number. For the application as BPM the lowest transverse magnetic fundamental TM_{010} monopole and TM_{110} dipole modes are of interest. The X and Y

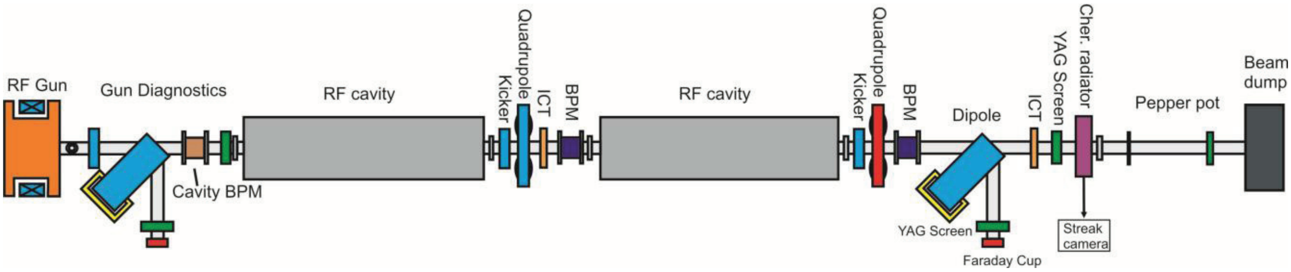

Figure 2: Layout of AREAL linac with diagnostics (phase 2).

offset dependent (as well as the bunch charge dependent) TM_{110} dipole modes provide information about beam displacements. The cavity fundamental mode TM_{010}, which is at a lower frequency compared with dipole modes, provides the reference signal to obtain the bunch charge and phase. For more details we refer to [2-3].

For the beam position monitoring after accelerating sections two stripline type BPMs [2-3] will be installed in AREAL linac (Fig. 2). Stripline BPMs (SBPM) are well suited for short bunch observation. A stripline pick-up consists of a transmission line of several cm length, having at both ends a feed-through matched to 50 Ω.

Using three low energy corrector magnets, a beam position feedback for the AREAL linac will be implemented (see Fig. 1, 2). The corrector magnets must have maximum peak field of about 35 G and maximum 10 cm magnetic length.

TRANSVERSE BEAM PROFILE

In the AREAL linac (for energies up to 20 MeV) only scintillating crystals will be installed, because the other systems (such as OTR screen or the wire scanner) would not generate sufficient signal-to-noise ratio. Profile monitors (scintillation screen monitored by CCD camera) are almost always the simplest beam profile measurement devices [2, 4]. A full horizontal/vertical profile can be produced by a single beam pulse. The image is digitized, projected onto orthogonal axes, and fitted with an appropriate function. A "background image" (obtained without beam) is subtracted from the data. The calibration is obtained using reference grid lines etched directly on the screen.

Four optical screen monitors will allow the control, monitoring and optimization of the transverse beam envelope in the AREAL linac. Two of them will be placed in the low energy diagnostic line (Fig. 1) and the next two - after the accelerating section (see Fig. 2).

The YAG: Ce scintillation screens of 30x30 mm^2 and 20μm thick will be used for the profile measurements. The screens are mounted to a ladder and positioned in the beam with a vacuum feedthrough by a stepper motor actuator. The position is monitored by an absolute encoder mounted to the feedthrough. The scintillators will be mounted at right angle to the beam. A mirror reflects the light out of the vacuum chamber.

The readout system of the screen monitors consist of two selectable optical branches: an overview system that images an area covering 28 × 37 mm^2 and a system that covers the central 5 × 8 mm^2. The overview camera will be used during initial commissioning and covers an area large enough to detect unfocused or misaligned beams. It has a projected pixel size of 23 μm. The camera that images the central part of the screens has a projected pixel size of 4.5 μm.

The radiation will be detected with a room-temperature monochrome CCD sensor digitized with a 12-bit ADC.

TRANSVERSE BEAM EMITTANCE

As a diagnostic of the first step of commissioning, when only gun will be installed, it is planned to use a pepperpot technique for emittance measurement. Because of space charge dominated, low energy beam this method is most convenient. Detailed analyze of principles of work of pepper pot technique are described in [5].

A tungsten "pepperpot" mask of 5 mm diameter, with 150 μm hole spacing and 20 μm hole diameter is planned to be used. The mask thickness of 0.5 mm stops electrons with energies up to 4 MeV and should thus provide background suppression. YAG:Ce have been selected as scintillation material to visualize the electron beamlets, which are passing through the "pepperpot" holes. Their predominant emission in the green spectral range (535 – 550 nm) is well matched to the maximum sensitivity of CCD cameras. For least scattering of electrons in the material and highest spatial resolution, screen thicknesses of 50 μm at 5 mm diameter have been chosen. Both, "pepperpot" mask and scintillation screen are mounted on stainless steel sliders inside of a 900 mm long DN100CF UHV chamber. Cable winches, which are driven by a pair of rotary feedthroughs and deflection rollers at back end of the monitor, allow travel of the sliders along the entire length of the UHV chamber. In this way, "pepperpot" and scintillation screen can be moved at any location along the emittance monitor and the distance between both can be freely selected depending on the divergence of the electron beam. "Pepperpot" mask and scintillation screen can both be moved out of the beam, when reaching a "parking position" at the front end of the UHV chamber. An out-coupling mirror (90 mm in diameter, λ/20 planarity) at the back end of the monitor deflects the transmitted light from the scintillation screen under an angle of 90° out of the UHV chamber.

At the second stage, when the gun section commissioning will be completed the pepperpot will be moved to the high energy electron beam diagnostic line (after accelerating sections). In this section it is also planned to measure electron beam emittance using quadrupole scan technique.

BEAM ENERGY, ENERGY SPREAD AND LONGITUDINAL PROFILE

The momentum and momentum spread of the electron beam can be measured through dispersion created by a dipole magnet. Due to limited space for diagnostics at gun section, 90° bending magnet is chosen (see Fig. 1). Absolute momentum measurement is given by the geometry and calibration of the dipole and the subsequent drift length (about 20 cm).

The energy spread can be inferred by observing the beam in a dispersive section. The spot size is a convolution of the emittance contribution and the dispersion contribution and can be written to first order as:

$$\sigma_x \approx \sqrt{\beta_x \varepsilon_x + D_x^2 \sigma_E^2} \ .$$

In order to maximize the momentum resolution of the spectrometer, the dispersive contribution to beam size should be large compared to the emittance contribution. The energy spread measured is then:

$$\sigma_E \approx \frac{\sigma_x}{D_x} \ .$$

This is achieved by providing horizontal focus at YAG:Ce doped screen (S1), behind the bending at spectrometer arm. The setting for the focus is not known a priori, since space charge effects will perturb the beam transport matrix transformation, and the focus will be hard to find on the S1 where the beam is widened by dispersion. As we have another screen (S2), located in the non-dispersive straight beam path before the accelerating section (for solenoid field scan and achievement of minimum beam spot size), we provide horizontal focus at S1 installing it with the same path distance from the gun as S2. The dipole is a gradient free rectangular magnet, which behaves like a drift horizontally, so a focus produced at S2 and well observable there, will be moved to S1 after switching on the bending magnet.

The same technique will be applied after accelerating sections for energy and energy spread measurements (see Fig. 2).

The electron beam longitudinal phase profile is planned to be measured using the partial conversion of the energy of the electron bunch via cherenkov radiation [6] into a flux of photons with the same time properties as the electron bunch. These light pulses are then measured with a streak camera which is placed at some distance to the injector. To obtain a good time resolution high light yield in a small opening angle is required. The opening angle of the cherenkov radiation and the light yield depend on the refractive index of the material. A high refractive index results in high light yield but poor time resolution. Aerogel is considered for this task. The setup is shown in Fig. 3.

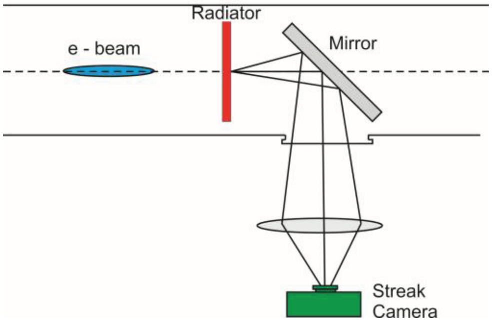

Figure 3: Setup of the bunch length monitor system with the Cherenkov radiator aerogel.

SUMMARY

The diagnostics system of the AREAL linac is presented. Electron beam charge, position, emittance, energy, energy spread and longitudinal profile measurement techniques, which will be applied, are described in details. The gun section (phase one) of AREAL linac will be commissioned in summer 2013.

ACKNOWLEDGMENT

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