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THE INFLUENCE OF SOLENOID FIELD ON OFF-AXIS TRAVELLING BEAM IN AREAL ACCELERATOR

H.D. Davtyan*, A.H. Asoyan, G.A. Amatuni, M.G. Yazichyan, A.H. Grigoryan[1], Center for the Advancement of Natural Discoveries using Light Emission (CANDLE SRI), Yerevan, Armenia
[1]also at Yerevan State University, Yerevan, Armenia

Abstract

A wide range of experiments are being held at AREAL accelerator in the fields of materials science and life science by generating ultra-short 5 MeV electron beams. Beam parameter formation and stability preservation during the experiments are one of the key tasks of stable operation of the accelerator. Laser spot displacement on the photocathode could be one of the beam parameter distortion sources, which causes off-axis bunch travel also through the solenoid. The influences of laser spot horizontal displacement and the solenoid horizontal misalignment on the beam position at the experiment location are investigated separately via computer simulations. Using a laser spot mover and solenoid movers, an experiment has been carried out to compare simulation results with experiment.

INTRODUCTION

AREAL (Advanced Research Electron Accelerator Laboratory) is an RF gun-based laser-driven 20-50 MeV electron linear accelerator with low emittance (<0.3 mm-mrad) and ultrashort bunches (~500 fs) for advanced experimental studies in the area of novel accelerator concepts and coherent radiation sources, material and life science [1]. The AREAL RF gun operated in the S-band frequency (2.998 GHz), with the accelerating section 1.5 cell (total length 7.5 cm) and the maximum 110 MV/m accelerating gradient field. The RF gun, resulting to beam energies with up to 5 MeV energy. The focusing solenoid magnet is located in 0.586 m from the cathode (Fig. 1).

The off-axis beam can be the result of both laser spot displacement on photocathode and solenoid misalignment. For well aligned solenoid field the laser spot misalignment causes an off-axis traveling of electron bunches, due to initial offset and non-zero RF cavity radial field influence. The misaligned from the cathode beam is passing off-axis through the solenoid, thus causing additional distortion from magnetic fields. Besides, in the off-axis beams solenoid magnet causes the beam parameters distortion [2,3]. In the case of solenoid misalignment, only solenoid magnet causes beam parameters distortion. And therefore, the beam-based alignment of solenoid magnets is of great importance.

The integral distortions due to laser spot offset and off-axis magnetic fields were considered both by simulations and by experiments, as well. The beam centroid position and transfer rms sizes were in focus for observations. For the simulations, the ASTRA particle tracking code has been used [4].

davtyan@asls.candle.am

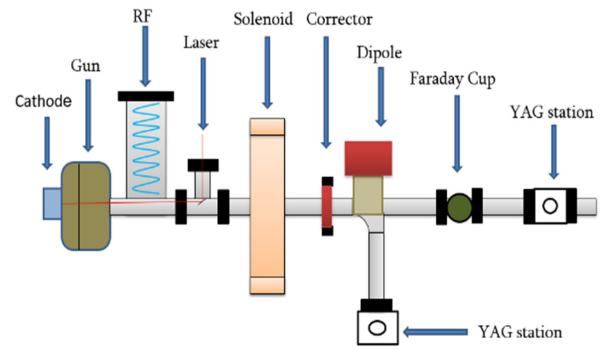

Figure 1: AREAL RF Gun layout.

THEORETICAL BASES

The transportation of electron beams in accelerator sections can be described by transfer matrices. The transfer matrices of a solenoid magnet cannot be divided into vertical and horizontal matrices, because there is a coupling between the two transverse planes in the solenoid magnet. For the hard-edge solenoid magnets, the rotational and focusing transverse matrix is well known [5]. The position of the particle with the initial coordinate of $X_0 = (x_0, x_0', y_0, y_0')$ at the exit of solenoid magnets can be found by relation

$$X_f = M_{rot} M_f X_0$$

where M_{rot} and M_f are rotational and focusing transfer matrices accordingly. The real solenoid can be presented by a series of hard-edge solenoids with various magnetic fields.

In a case of off-axis beams, the positions of particle will be

$$\breve{X}_0 = X_0 + \delta X$$

where δX is deviation of the beam center from the axis. And hence δX is driving the beam center and rms sizes deviation respect to on-axis ones.

It is important to note that δX is a deviation of position and the momentum. It means that even if position deviations are zero, the slops can drive the beam position and emittance distortions.

COMPARISONS OF SIMULATION AND EXPERIMENTAL RESULTS

ASTRA Simulations

ASTRA particle tracking code based on non-adaptive Runge-Kutta integration of 4th order [4]. The

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electromagnetic fields of RF gun and solenoid provided as external data based on EM simulations and measurements for the devices operated in AREAL accelerator. The code is using cylindrical symmetric and fully 3D option for space charge calculations [4]. The macro particle concept is used. For the simulations 2000 particles with a total 0.150 nC charge were generated. The generated initial particles are located at central transverse position with no initial transverse momentum spread. For initial beams, Gaussian distribution for both x and y spatial distributions and for the p_x and p_y momentum distributions are chosen. The bunch length of beam is set according to laser pulse length. The main parameters of initial beams are presented in Table 1.

The transverse profile of the beam observed on a distance of 1.485 m from the cathode which corresponds to the position of YAG screen in AREAL accelerator. The accelerating maximum gradient is set 65 MV/m for the 3 MeV electron beam in the end of accelerating field which is corresponding to normal operation regime of AREAL accelerator. The maximum magnetic field strength for solenoid is set 0.161 T for the minimum spot sizes on the position of screen.

During the simulations first the effect of solenoid on off axis beam due to laser spot misalignment was observed. The laser spot was moved in x-axis by 0.5 mm step, in a range of -3 mm to 3 mm. The beam transverse shape and centroid positions in a position of YAG screen are presented in Fig. 2 (top). Next the effect of solenoid magnet misalignment by x-axis on on-axis beam was observed. Solenoid positions are changed by step of 0.5 mm in a range of -3 mm to 3 mm. In Fig. 2 (bottom) presented the beam transverse shape and beam centroid positions in a position of YAG screen.

Experimental Setup

In AREAL electron linear accelerator RF gun with the copper photocathode with 10 mm diameter is used for electron bunch generation. The transverse distributions of the laser spot are Gaussian with the spot size of diameter 2 mm. The pulse duration is about 500 fs. The 258 nm (4th harmonic) is used for electron beam generation with the laser pulse energy of 360 μJ [6].

Table 1: Initial Beams Parameters

Initial beam parameters	Value
total charge, Q	0.150 nC
Total number, N	2000
horizontal beam rms, σ_x	0.33 mm
vertical beam rms, σ_y	0.33 mm
total emission time, t_e	480 fs
energy spread, δE	$3.67 \times 10^{-4} keV$

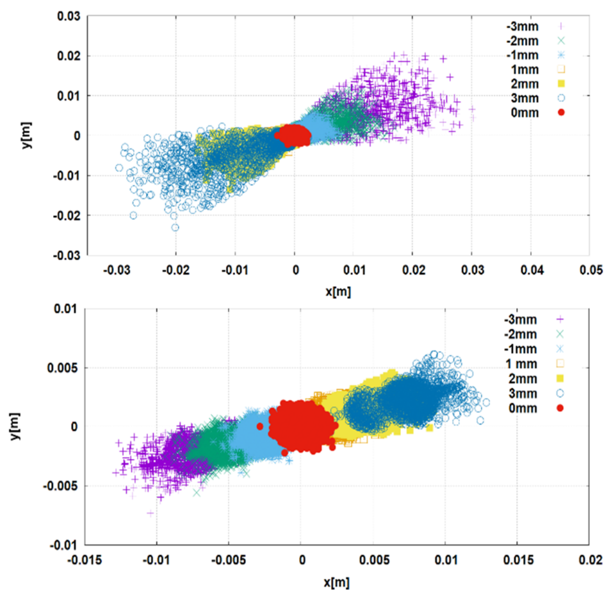

Figure 2: The beam transverse shape, beam centroid positions and transverse rms length in a case of laser spot misalignment (top) and solenoid magnet misalignment (bottom).

The magnet spectrometer is used for beam energy measurement. The 3 MeV beam was generated for the experiment. The charge was measured by Faraday Cup which is behind the YAG screen where beam profile is recorded (Fig. 3). The python code was used to analyze the collected screen matrix data. In the python code the beam was fit to Gaussian distributions in both axes. After mathematical operations from the python code the beam center position and transverse rms sizes as output parameters was obtained. The beam charge and energy chosen to be the same for both simulation and experiment. The maximum strength of magnetic field of solenoid magnet is set 0.161 T according to simulations.

During the experiment the laser spot was moved on x axis in a range of -3 mm to 3 mm by step of 1 mm. Next, the laser spot was put to initial zero position and solenoid magnet was moved on x axis in a range of -3 mm to 3 mm by step 1 mm.

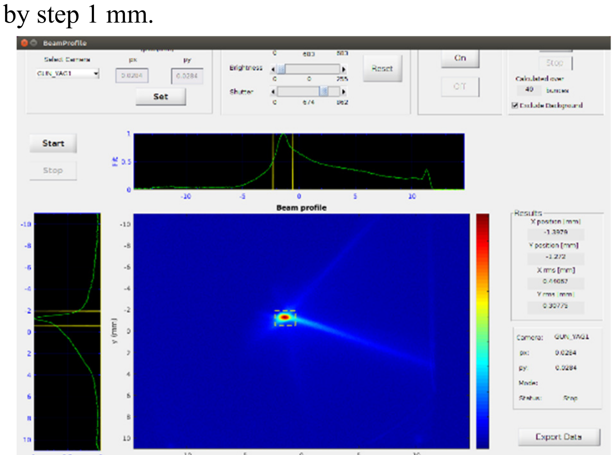

Figure 3: The beam transverse profile on YAG screen in minimum spot size and beam energy was generated about 3 MeV.

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Results and Discussions

In Fig. 4 the comparison of beam rms sizes (top) and centroid position (bottom) of experiment and simulation correspondingly for the case of laser spot misalignment were presented. Simulations show increase of beam rms size from 1.2 mm up to 4 mm on x axis and up to 2.8 mm on y axis, and beam centroid movement up to 4.5 mm in x axis and up to 2.2 mm in y axis. The measurements resulted in an increase in beam rms size from 1.03 mm to 2.6 mm on x axis, and from 0.56 mm to 2 mm on y axis. The centroid position deviation on x and y axis, and rms sizes differences in a case of initial position of laser spot and solenoid magnet may be the result of elliptic beam or solenoid rotational or tilt misalignments, which were not taken into account for simulations. The high value of the error in the case of a laser beam deviation of 3 mm is due to the resolution limit of the device. Decreasing rms values for laser spot -3mm misalignment is a result of beam losses.

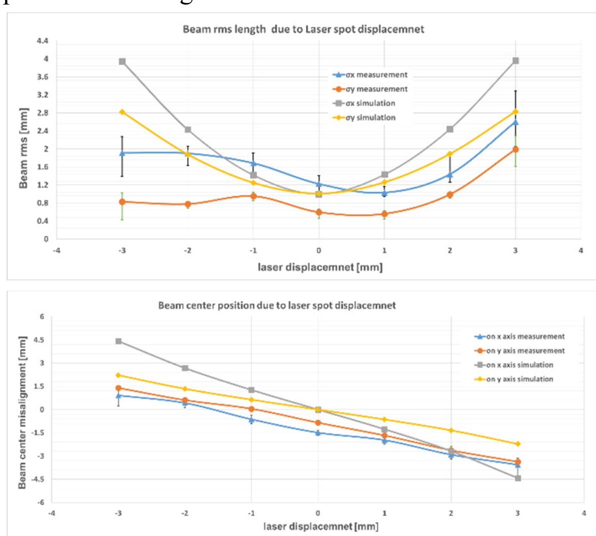

Figure 4: The rms length (top), centroid position (bottom) of the beam in a case of laser spot misalignment.

Figure 5 present the comparison of beam rms sizes (top) and centroid position (bottom) of experiment and simulation correspondingly for a case of solenoid magnet transverse misalignment. By the simulations increasing of beam rms size from 1.2 mm up to 4 mm on x axis and up to 2.8 mm on y axis, and beam centroid movement up to 4.5mm in x axis and up to 2.2 mm in y axis for the 3 mm misalignment of solenoid magnets were predicted. The measurements resulted in an increase in beam rms size from 1.03 mm to 1.7 mm on x axis, and from 0.56 mm to 1.4 mm on y axis. Centroid position movement is 4 mm in both x and y axis in a case of 3 mm movement of solenoid magnets. The high value of the errors in the case of a maximum misalignment could be due to resolution limits. The simulations and experiments qualitatively are in a good agreement, but there is a quantitative discrepancy between the simulation and the experiment results.

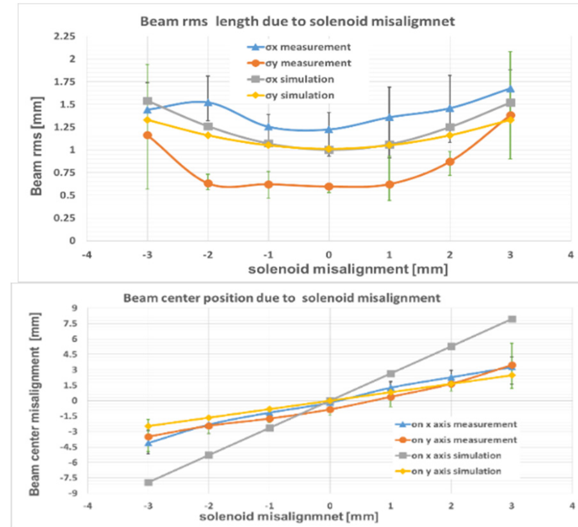

Figure 5: The rms length (top), centroid position (bottom) of the beam in a case of solenoid magnet misalignment.

The discrepancy can be caused by the initial misalignment and tilt of solenoid magnet, magnetic field heterogeneity and coupling between the two transverse planes. The above-mentioned effects are under investigation.

CONCLUSION

In this paper the solenoid effect on off axis beams due to both laser spot displacement and solenoid magnet misalignment has been observed. The experiment revealed a deviation of the laser beam and magnetic field from beam line. Deviation from the results of the experiment and simulation suggests that other factors mentioned above may contribute to the final formation of the beam, which opens the new field for further study. The results can be used for beam-based solenoid magnet adjustment and beam dynamics studies.

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