ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF001

BEAM DYNAMICS STUDIES FOR BEAM FOCUSING AND SOLENOID ALIGNMENT AT SINBAD

S. Yamin*, R. Assmann, B. Marchetti, J. Zhu, DESY, 22607 Hamburg, Germany
*University of Hamburg, 20148, Hamburg, Germany

Abstract

SINBAD facility (Short INnovative Bunches and Accelerators at DESY) under construction at DESY plans to host several experiments for the production of ultra-short bunches and will be a test facility for high-gradient compact novel acceleration techniques. The ARES (Accelerator Research Experiment at SINBAD) linac is foreseen to produce ultra-short bunches to be injected e.g. into Novel Dielectric Laser Acceleration structures or Laser Wake-Field Acceleration experiments. The work presented in this paper is based on optimization of the focusing system consisting of solenoids for the ARES, which have been studied earlier in detail but is revisited for updated beamline. Moreover tolerances for the possible misalignment of solenoids are presented investigating the effect on the beam properties during the gun commissioning.

INTRODUCTION

SINBAD (Short INnovative Bunches and Accelerators at DESY) is a dedicated accelerator R&D facility currently under construction at DESY. SINBAD will have two main goals: study ultra-fast physics and perform novel acceleration technique experiments [1-3]. The ARES (Accelerator Research Experiment at SINBAD) linac [4] at SINBAD will be a conventional S-band accelerator providing ultra-short (FWHM, length <=1 fs-few fs) high brightness electron beam for injection into novel accelerators. The choice of the conventional photo-injector allows producing a stable and reproducible e-bunch with flexibility of widely tunable working points required for different experiments. Applications of the ARES linac have been discussed in detail in [4]. ARES also allows manipulation of the beam by different bunch length compression techniques which have been investigated in detail earlier [5-7]. The 5 MeV RF gun of the ARES will be commissioned this year [8], while the main linac is planned to be installed till the end of 2018. In this paper we focus on the gun and acceleration part for a working point having charge 25 pC. The beam is compressed in the linac by using velocity bunching. The solenoids are used for beam focusing directly at the linac exit.

ARES Layout

The schematic of the ARES and RF gun details are shown in Fig. 1. The entrance to first travelling wave structure is at 2.5 m and exit of the linac (including the space reserved for the energy upgrade) is at about 17.5 m. Also one experimental station for Dielectric acceleration will be temporarily located after the second travelling wave structure. The beam parameters in the results presented will be evaluated at these two points as indicated in Fig. 1.

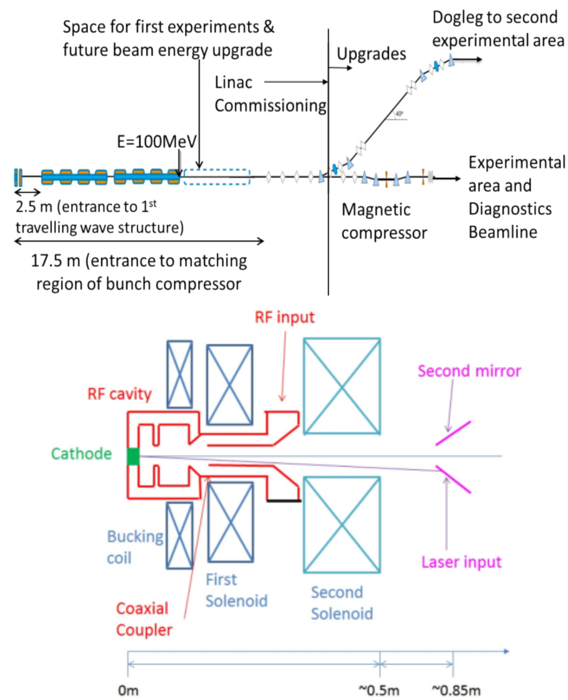

Figure 1: Layout of ARES LINAC (on top) and zoom of the RF gun region (bottom).

A focusing solenoid (named “Second Solenoid” in Fig. 1) located at 40.6 cm from the cathode will be used during the commissioning of the ARES gun for transverse focusing of electron bunches. The effect of misalignment of this solenoid will be investigated in this paper.

The solenoid named “First Solenoid” in Fig.1 and its bucking coil will be installed later on in 2019 to allow an improvement of the quality of the electrons. In the linac part, 4 solenoids for each travelling wave structure, will allow to optimize the beam quality while compressing the beam via velocity bunching. The effect of the misalignment of all these solenoids will be taken into account in a further study.

SIMULATIONS

ASTRA [9] was used to optimize and study evolution of beam parameters. An example of beam compression along the linac is shown in Fig. 2.

In the next section we will focus on the effects of misalignment of the RF gun solenoid on the beam properties.

*sumera.yamin@desy.de

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF001

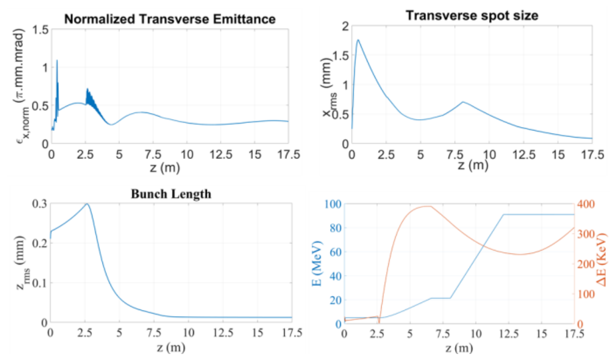

Figure 2: Evolution of (a) normalized transverse emittance (b) transverse spot size (c) bunch length (d) energy spread along the linac.

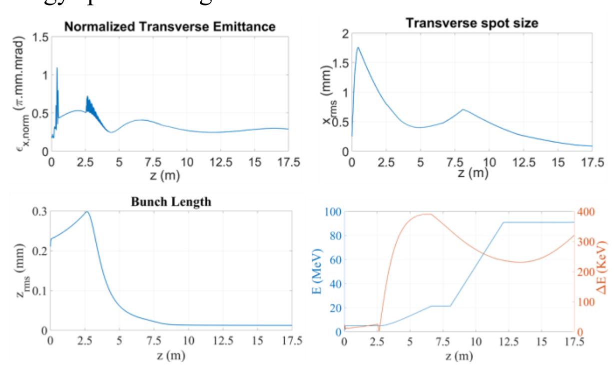

Figure 2: Evolution of (a) normalized transverse emittance (b) transverse spot size (c) bunch length (d) energy spread along the linac.

Solenoid Detail and Significance of Study of the Effects of the Misalignment

The solenoid discussed consists of two coils of equal length and there is possibility to change the polarity of each coil. The transfer matrix of 1 coil is given in Eq. 1 [10].

$$M_{sol} = \begin{bmatrix} \cos^2 KL & \frac{\sin KL\cos KL}{K} & \sin KL\cos KL & \frac{\sin^2 KL}{K} \\ -K\sin KL\cos KL & \cos^2 KL & -K\sin^2 KL & \sin KL\cos KL \\ -\sin KL\cos KL & -\frac{\sin^2 KL}{K} & \cos^2 KL & \frac{\sin KL\cos KL}{K} \\ K\sin^2 KL & -\sin KL\cos KL & -K\sin KL\cos KL & \cos^2 KL \end{bmatrix} \quad (1)$$

Where K is strength and L is the effective magnetic length of solenoid.

In the ideal case, if the beam is perfectly aligned with the solenoid magnetic axis, it experiences only rotationally symmetric transverse focusing field. In reality, due to misalignment beam experiences a kick and can result in emittance growth. Apart from the transverse offsets, we will also have parasitic tilts of the solenoid's angles in both x-z and y-z planes. Those can be corrected within the accuracy of the micro mover system which is expected to be roughly 100 µm. A MATLAB script is being developed for the alignment of solenoid based on transfer matrices of both coils. It is based on the fact that RF field and solenoidal field do not overlap. Changing the polarity of each coil of solenoid results in a different transfer matrix and this fact is exploited in the script to determine the solenoid misalignment during the gun commissioning of ARES Linac. ASTRA simulations presented in this paper forms the basis of the MATLAB script. A known misalignment and beam position from simulations can be used to determine the authenticity of the script being developed.

The same procedure will also be used to align the solenoids for the travelling wave structures. For the "First solenoid" (of Fig. 1), however, there is an overlapping of electric and magnetic fields and hence separate scheme will be adopted for its alignment.

ASTRA was used to study the effect of solenoid misalignment on the beam size and emittance for a space charge dominated beam. The nomenclature used for the offsets and tilts of the solenoids are as defined in the ASTRA manual. An ASTRA scan was performed to account for the particle lost as a function of solenoid offset in x-direction. It was noticed that most of the particles were lost for a misalignment bigger than 1 mm. The expected achievable precision for the alignment of our solenoid is within 100µm, and the length of the solenoid is 0.19 m. So the angular precision is within 0.526 mrad. The coils in these simulations have opposite polarities and were assumed to be perfectly aligned with each other. Figure 3 and 4 gives the beam position as a function of solenoid misalignment in the horizontal and vertical direction respectively. In all figures, for one value of offset in solenoid position, solid line is for beam property in "x" and dashed line is for "y". Same colours for solid and dashed line correspond to equal offset value. "x_{avr}" and "y_{avr}" stands for beam centroids.

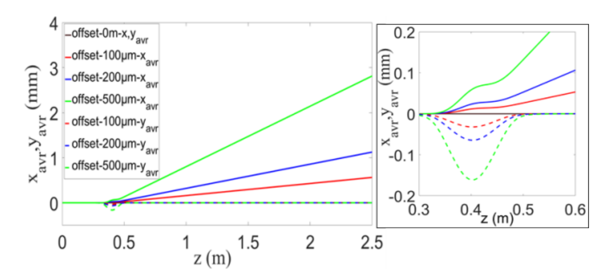

Figure 3: Beam position for misalignment in horizontal direction. Right image has change of scale to zoom in on beam positions. Solid line is for beam position in x and dashed line for beam position in y direction.

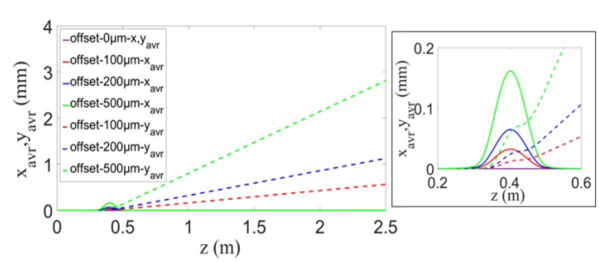

Figure 4: Beam position for misalignment in the vertical direction. Right image has change of scale to zoom in on beam positions.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF001

The effect of different coil polarities on beam position is shown in Fig. 5.

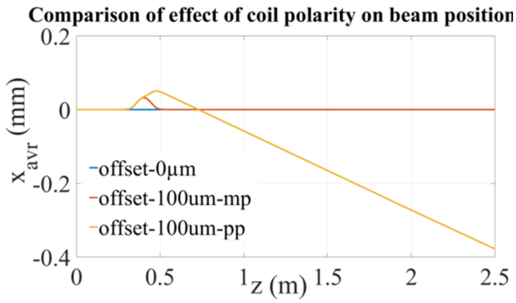

Figure 5: Beam position for plus-plus (pp) and minus-plus (mp) coil polarities for misalignment in vertical direction. Of course the beam trajectory can be corrected by using beam steerers along the beamline.

Effect of angular tilts on beam position and emittance were also studied. Also in this case, tilt around x-axis i-e in the y-z plane nullifies the effect in case of opposite polarities in x-direction. This cancellation effects only happens in one direction i-e transverse to direction of misalignment as expected. Figure 6 and 7 shows beam sizes. All angles are in radians. The smallest one corresponds to tolerance of 100 µm which is desired at ARES.

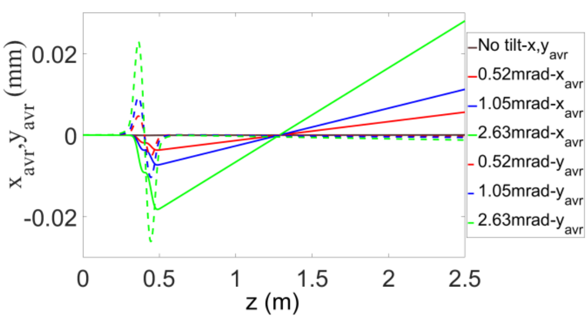

Figure 6: Angular offset in alignment: x-z plane.

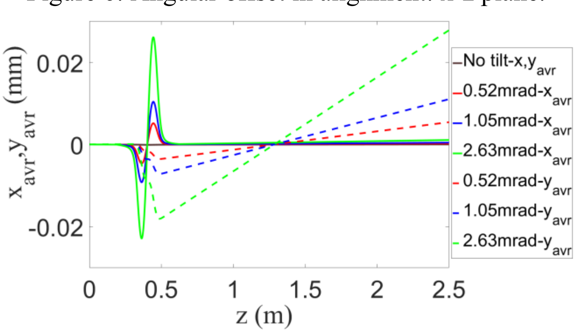

Figure 7: Angular offset in alignment: y-z plane.

Figure 8 and 9 gives the difference in emittance for offset in solenoid position with respect to a perfectly aligned solenoid. Emittance for bunch charge of 25pC at the entrance of travelling wave structure i-e at 2.5m is 1.2 π.mm.mrad. Maximum Emittance growth calculated for 500 µm in just one transverse direction is around 7% of the original value. It is noticed that just at the entrance of travelling wave structure, there is significance emittance growth which will eventually have much more stronger impact along the beam line and the experimental area (at 17.5 m and beyond) as shown in Fig. 1. Figure 10 gives the emittance growth as a function of misalignment in x-z plane. The two peaks correspond to two coil of the solenoid.

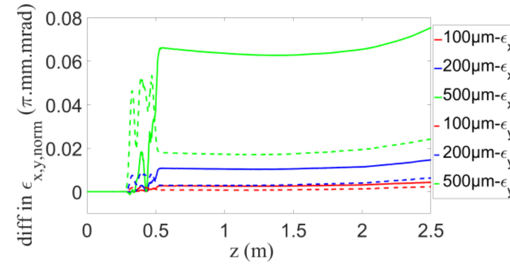

Figure 8: Difference in emittance for solenoid misalignment in x-direction.

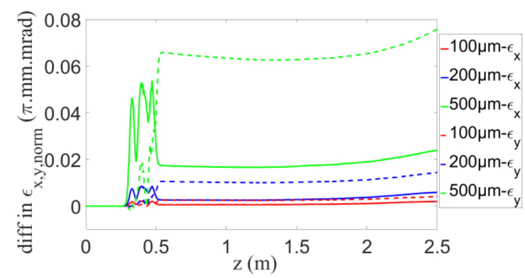

Figure 9: Difference in emittance for solenoid misalignment in y-direction.

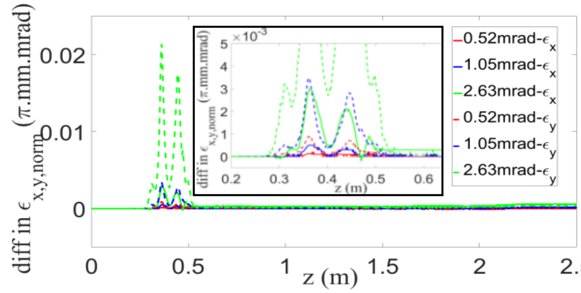

Figure 10: Emittance growth as a function of solenoid misalignment in x-z plane. Inset has change of scale to zoom in on emittance growth.

Since the tilts are associated with the offsets in transverse direction, Figure 11 gives the emittance growth for combination of misalignment for all four cases namely two transverse direction and tilts angles of x-z plane and y-z plane.

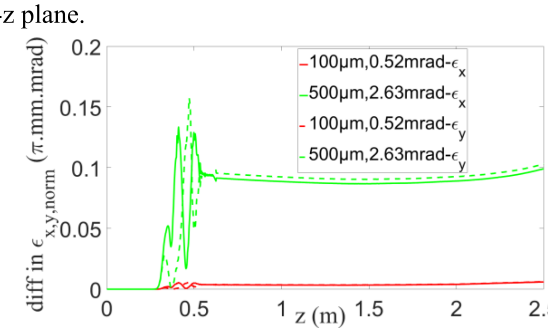

Figure 11: Misalignment and the error in emittance w.r.t them. Red line is for misalignment of 100 µm for both transverse direction and angular offset of 0.52 mrad. Green line is for 500 µm and 2.63 mrad.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF001

CONCLUSION AND OUTLOOK

We have presented a first study of the effects of misalignment of the gun solenoid on beam properties at ARES. Based on these studies, a script is being developed in MATLAB using transfer matrices of solenoid for the alignment which will be used during gun commissioning for ARES. The same procedure will also be adopted to align the solenoids of the two travelling wave structures of the Linac.

REFERENCES

[1] R. Assmann *et al.*, "SINBAD - A proposal for a dedicated accelerator research facility at DESY", *Proc. of IPAC'14*, Dresden, Germany, Jul 2014, paper TUPME047, pp 1466-1469.

[2] R. Assmann and J. Grebenyuk, "Accelerator physics challenges towards a plasma accelerator with usable beam quality", *Proc. of IPAC'2014*, Dresden, Germany, Jul 2014, paper TUOBB01, pp. 961-964.

[3] https://sites.stanford.edu/achip/.

[4] B. Marchetti *et al., "*Technical design considerations about the SINBAD-ARES linac*", Proc. of IPAC'2016,* Busan, Korea, May 2016, paper MOPMB015*,* pp. 112-114.

[5] B. Marchetti *et al.*, "Compression of an electron-bunch by means of velocity bunching at ARES", *Proc. of IPAC'2015*, Richmond, VA, USA, *May 2016,* paper TUPWA030 2015, pp. 112-114.

[6] J. Zhu *et al.*, " Sub-fs electron bunch generation using magnetic compressor at SINBAD" , *Proc. of IPAC'2015*, Richmond, VA, USA, May 2015, paper MOPWA042, pp. 207-209.

[7] J. Zhu, R. Assmann, U. Dorda, and B. Marchetti, "Matching sub-fs electron bunches for laser-driven plasma acceleration at SINBAD", *Nucl. Instrum. Methods Phys. Res. Sect. A*, Vol 829, p. 229, 2016, doi: 10.1016/j.nima.2016.01.066

[8] B. Marchetti *et al.*, "Status of the ARES RF gun at SINBAD: from its characterization and installation towards conditioning and commissioning", Vancouver, Canada, May 2018, paper TUPMF086, this conference.

[9] K. Floettmann, "A Space Charge Tracking Algorithm", Version 3.2, March 2017

[10] T. Rao *et al.*, "Photo injector theory", in "An Engineering Guide to photo injectors", ISBN-13: 978-1481943222, 2013, pp. 1-53.