BEAM-BASED PROCEDURES FOR RF GUNS*

M. Krasilnikov†, J. Bähr, H.-J. Grabosch, J.H. Han, V. Miltchev, A. Oppelt,
B. Petrosyan, L. Staykov, F. Stephan, DESY, D-15738 Zeuthen, Germany
M.v. Hartrott, BESSY GmbH, Berlin, Germany

Abstract

A wide range of rf photo injector parameters has to be optimized in order to achieve an electron source performance as required for linac based high gain FELs. Some of the machine parameters can not be precisely controlled by direct measurements, whereas the tolerances on them are extremely tight. Therefore, this should be met with beam-based techniques. Procedures for beam-based alignment (BBA) of the laser on the photocathode as well as solenoid alignment have been developed. They were applied at the Photo Injector Test facility at DESY at Zeuthen (PITZ) and at the photo injector of the VUV-FEL at DESY at Hamburg. The field balance of the accelerating mode in the 1 1/2 cell gun cavity is one of the key beam dynamics issues of the rf gun. Since no direct field measurement in the half and full cell of the cavity is available for the PITZ gun, a beam-based technique to determine the field balance has been proposed. A beam-based rf phase monitoring procedure has been developed as well.

INTRODUCTION

Since not all of accelerator properties can be measured directly, beam-based (BB) procedures are needed in order to obtain important parameters from available beam measurements. Misalignment in the rf gun results in the electron beam offset and can lead to emittance growth. To determine and correct rf gun misalignments, it is necessary to use the electron beam as the alignment tool. The beam-based alignment (BBA) uses measurements of the electron beam offset as a function of the rf gun launch phase or main solenoid current. Since no direct measurement of the rf gun field and launch phase is available, BB procedures to obtain these parameters have been developed. A method for determination of the field balance in the gun cavity is based on measurements of the longitudinal electron beam momentum. Measurements of the transverse beam size have been used for the reference rf phase monitoring.

BEAM-BASED ALIGNMENT

The PITZ rf gun setup is shown schematically in Fig. 1a: an L-band (1.3 GHz) cavity supplied with a Cs_2Te photocathode. The longitudinal position of the main solenoid is $z = 0.276\ m$ from the cathode plane.

* This work has partly been supported by the European Community, Contract Number RII3-CT-2004-506008, and by the 'Impuls- und Vernetzungsfonds' of the Helmholtz Association, contract number VH-FZ-005.
† mikhail.krasilnikov@desy.de

For the case of the VUV-FEL photo injector [1] emittance growth has been simulated at $z = 15\ m$ using ASTRA [2] (beam energy after the first accelerating module $150\ MeV$). Misalignments of the cathode laser and main solenoid result in a steering of the electron beam. This can cause distortions in the bean transverse phase space. The misalignment impact onto the beam emittance in the photo injector is shown in Fig. 1b.

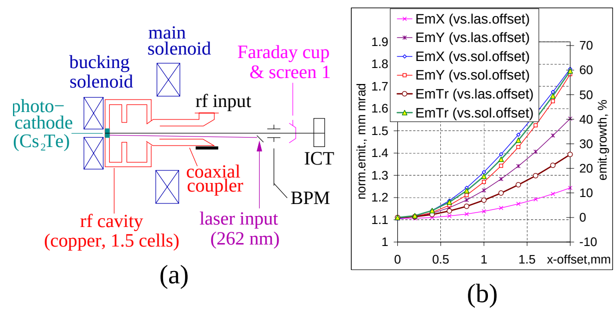


Figure 1: a) RF gun schematic setup. b) Transverse emittance (ε_x, ε_y, $\varepsilon_{tr} = \sqrt{\varepsilon_x \cdot \varepsilon_y}$) growth with rf gun misalignment: horizontal offsets of the photocathode laser and the main solenoid.

Cathode Laser Alignment

A laser spot adjustment on the cathode center is realized by using a system of remotely controlled movable mirrors. The cathode laser profile is monitored using a so-called virtual cathode (VC). The position can be controlled at the VC as well.

A method for the laser centering onto the photocathode is based on a measurement of the electron beam position as a function of the rf phase. Solenoids and all other magnets should be switched off during these measurements. The measurements are done using YAG screen 1 at the first diagnostic cross ($z = 0.78\ m$ from the cathode). Moderate rf gun gradients should provide a low level of dark current background. This implies also low beam energies and, therefore, a better BBA resolution. Low beam charges ($\sim 5\ pC$) are required to fit the whole beam onto the screen without additional focusing (i.e. only rf focusing is used). For sufficient intensity of the beam spot a pulse train of 30-50 pulses has to be used. Under these conditions the electron beam is steered by transverse rf fields and has trajectories developing in the cavity radial direction.

The trajectory projection onto the x-y plane of screen 1 (Fig. 2) belongs to a line $a_1x + b_1y = c_1$ passing through the laser offset from the cavity electrical axis (the cathode center). For the alignment a test laser spot displacement

0-7803-8859-3/05/$20.00

has to be performed. For the best accuracy the laser has to be shifted mainly perpendicular to the initial beam position line. A test relative displacement in the mm range ($\Delta\ x = -1\ mm$ in Fig. 2) results in a new line of beam positions for various rf phases – line $a_2 x + b_2 y = c_2$. This relative laser displacement $\vec{\Delta} = \{\Delta_x, \Delta_y\}$ can be monitored by mirror micromover controls and measured at the VC as well. After obtaining the corresponding coefficients the vector of the laser relative displacement for its centering is given by

$$\vec{V} = \begin{pmatrix} V_x \\ V_y \end{pmatrix} = \frac{a_1 \Delta_x + b_1 \Delta_y}{a_1 b_2 - a_2 b_1} \begin{pmatrix} -b_2 \\ a_2 \end{pmatrix}. \qquad (1)$$

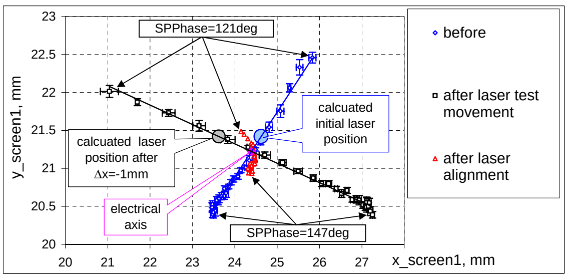
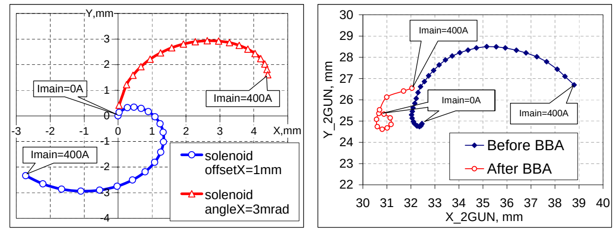


Figure 2: BBA of the photocathode laser. Average positions of the electron beam for various set point (SP) phases. SP phase is a relative launch rf phase used in the rf gun control system.

After applying the calculated relative laser shift one can achieve a better laser centering on the cathode (red triangles in Fig. 2). Remnant beam offsets can be explained mainly by two factors. First, the change of the beam average position due to the non-homogeneous cathode laser (and therefore electron beam) distribution at "high phases" (rf phases with beam energies 2.0..2.8 MeV). Second, the earth magnetic field can steer low energy beams at "low rf phases" (beam energy $\sim 1\ MeV$), when the beam is well-focused. Another important result of the laser BBA is obtaining screen coordinates of the gun cavity electric axis. This point serves as a reference one for the BBA of the main solenoid.

Main Solenoid Alignment

Whereas the cathode laser alignment is principally a one-dimensional problem, the solenoid misalignment implies coupling between both transverse directions. Besides this, possible tilt angles (yaw and pitch) of the solenoid complicates the problem. Since the rf field ($0 < z < 0.3\ m$) overlaps the solenoid field ($-0.1\ m < z < 0.7\ m$) mainly numerical methods are available for the misalignment study. Main solenoid misalignments are transverse offsets (X^{sol}, Y^{sol}), yaw α_X^{sol} and pitch α_Y^{sol} angles. The simulated electron beam offset at $z = 0.78\ m$ as a function of the main solenoid current for $\alpha_X^{sol} \approx\ 3\ mrad$ is shown in Fig. 3a in comparison with a curve obtained for $1\ mm$ horizontal solenoid offset. The beam offset bounding boxes for both cases are similar, so equivalence relations between offset and tilt angle influence can be estimated ($3\ mrad\ \rightarrow\ 1\ mm$). The beam energy for these simulations was chosen to be about $3\ MeV$ (electric field at the cathode $\sim\ 25\ MV/m$), which corresponds to the BBA experimental conditions.



(a) (b)

Figure 3: a) Beam offset as a function of main solenoid current for $X^{sol} = 1\ mm$ and $\alpha_X^{sol} = 3\ mrad$. b) Beam offset at screen 2GUN (VUV FEL photo injector) as a function based of the main solenoid current before and after the BBA.

The BBA of the main solenoid has been performed as an iteration of beam position measurements as a function of the main solenoid current, simulations of the obtained curve by applying correspondent misalignments, followed by a correction of the largest misalignment.

The beam offset has been measured at the YAG screen (screen 1 at PITZ, screen 2GUN at VUV FEL rf gun), also used for the cathode laser BBA. Moderate rf gradients were used to get rid of a dark current background. The launch rf phase has been chosen close to the maximum energy gain. A low bunch charge ($\sim 50\ pC$) allows measurements for a wide range of solenoid currents ($I_{main} = 0\ A \rightarrow 400\ A$). An example of the solenoid BBA (VUV FEL rf gun) is shown in Fig. 3b.

Table 1: RF gun misalignments during BBA (simulations)

BBA step	X^{sol} mm	Y^{sol} mm	α_X^{sol} $mrad$	α_Y^{sol} $mrad$	X^{las} mm	Y^{las} mm
...	...	...	...	...	...	...
2	0.14	**-1.09**	-0.03	0.96	-0.17	-0.33
...	...	...	...	...	...	...
7	0.07	0.03	-0.16	0.37	-0.10	-0.17

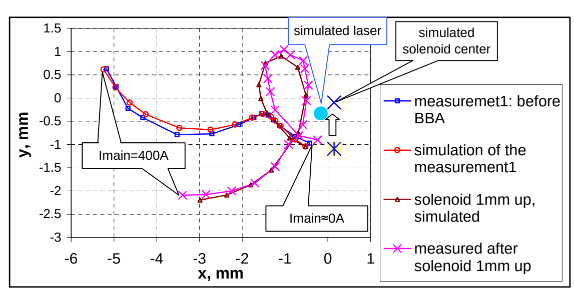


Figure 4: BBA of the laser on the photocathode.

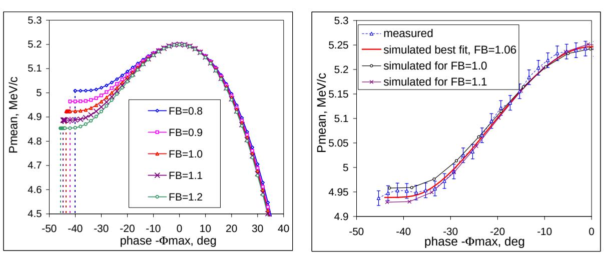
A typical iteration in the main solenoid BBA is illustrated by Fig. 4. After the simulation of the beam offsets the following misalignment list has been obtained (step 2 in Table 1). Before the largest misalignment ($Y^{sol} = 1.09\ mm$) was corrected the correspondent curve has been simulated (expected beam offsets denoted with triangle markers in Fig. 4). After the solenoid has been moved $1\ mm$ up using remotely controlled micromovers the measured curve was in a good agreement with the curve expected from the simulations.

The result of the solenoid BBA is illustrated by the second row in the Table 1, where results after seven iterations of the BBA are shown.

As it can be seen from the Table 1, the simulated yaw angle increased. This can be explained by simulation discrepancies or (and) probable parasitic coupling in micromover system, when transverse displacement of the solenoid could also cause some changes in its tilting.

FIELD BALANCE OF RF GUN CAVITY

The idea of a BB determination of the field balance in the rf gun cavity originates from the simulations of the beam longitudinal momentum vs. rf phase for different ratios of the electric field at the cathode to the full cell amplitude: $FB = |E_{Cath}/E_{FullCell}|$ (Fig. 5a). Fig.5b shows the best fit to the measurements done at PITZ with a simulated curve, obtained by applying $FB = 1.06$.



(a) (b)

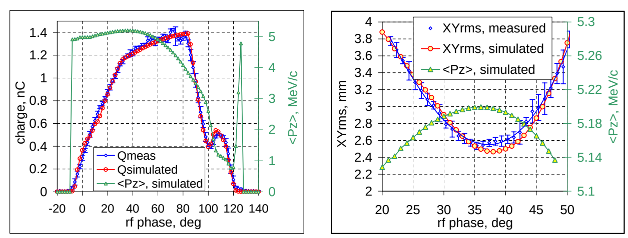
Figure 5: a) Electron beam longitudinal momentum vs. rf phase for various field balances in the rf gun cavity. b) Measured and simulated mean momentum of the electron beam. The best fit yields $FB = 1.06$.

REFERENCE RF PHASE MONITORING

Determination and regular monitoring of the reference phase (related to the launch rf phase yielding maximum energy gain) is one of the important rf gun procedures. Since no direct phase measurement is available for the PITZ rf gun, a BB procedure has been applied. A monitoring method based on the beam momentum measurements (Fig. 5b) is rather time consuming. The dipole has to be cycled for every measurement. Another conventional method is a phase scan - measurement of the bunch charge vs. rf phase [3]. The phase scan for high intensity beams is influenced by space charge and other effects (Schottky etc.) and its shape is strongly dependent on the space charge density (i.e. cathode laser profiles). A typical phase scan measured at PITZ is shown in Fig. 6a together with ASTRA simulation.

An alternative method for the reference phase monitoring has been suggested at PITZ [4]. It is based on beam size measurements at a screen located at $z = 2.628\ m$ vs. rf phase under applied overfocusing solenoid current ($I_{main} = 320A$ for the maximum beam energy of $\sim 4.7\ MeV$). The rf phase of the transverse beam size minimum is close to the phase with a maximum energy gain, because an electron beam with maximum energy is less overfocused. The measured dependence is shown in Fig. 6b together with a simulated curve. The minimum of the rms beam size is in a $\sim 2\ deg$ offset from the phase of the maximum energy gain. Simulations show that this relation is valid for laser parameters within a practical range of the cathode laser parameters.

The suggested method has evident advantages: it is rather fast and reliable. Since the rf gun power is almost independent on the rf phase the dark current can be subtracted only once before the scan for beam rms sizes. The variation range of the rf phase is also smaller than during a standard charge phase scan.



(a) (b)

Figure 6: a) Phase scan - bunch charge vs. rf phase. b) Measured and simulated beam rms size $R_{rms} = \sqrt{X_{rms}^2 + Y_{rms}^2}$ vs. rf phase. Simulated mean momentum is depicted at the right axis at both plots.

CONCLUSIONS

A set of the beam-based procedures for rf guns has been developed. BBA of the rf gun has been successfully applied at the PITZ and at the VUV-FEL rf gun. A method for the determination of the field balance in the rf gun cavity and a procedure for the efficient monitoring of the reference rf phase have been proposed.

REFERENCES

[1] "SASE FEL at the TESLA Facility, Phase 2", TESLA-FEL 2002-01.

[2] K. Floetmann, A Space Charge Tracking Algorithm (ASTRA), http://www.desy.de/ mpyflo/.

[3] S. Schreiber et al. "Measurement of space charge effects and laser bunch length in the TTF RF gun using the phase scan technique", FEL 1999, p. 69.

[4] M. Krasilnikov el al. Experimental characterization of the electronsSource at the photo injector test facility at DESY Zeuthen, PAC 2003, Portland, May 2003, p.2114.