EFFECTS ON EMITTANCE ASYMMETRY CAUSED BY ASYMMETRY FIELDS OF TRAVELING WAVE ACCELERATOR STRUCTURE

A. Mizuno*, H. Dewa, T. Taniuchi, H. Tomizawa, H. Hanaki
JASRI/SPring-8, 1-1-1, Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5198, Japan

Abstract

Improving transverse emittance asymmetry is one of the most important issues for high-brightness photoinjectors. Especially, in the SPring-8 photocathode RF gun, we have observed that the vertical emittance is always larger than the other. We have tried to get rid of some possible causes of the asymmetry for last decade. However, the asymmetry of transverse emittance has not been improved yet. In this paper, we investigate the transverse emittance asymmetry caused by the geometrical asymmetry of a conventional single-feed coupler cell of the traveling wave accelerator structure. Emittance behaviors were simulated by fully 3D tracking code with 3D field data of the accelerator structure. According to the simulation results, off-centered magnetic field in the coupler cell is turned out the most probable cause of emittance asymmetry discussed here. A slice emittance in the bunch is kept constant, however projected emittance of the whole bunch becomes larger in the coupler cell, since the off-centering varies with the RF phase. From our simulation results, the asymmetry is drastically reduced in the case of a double-feed coupler.

INTRODUCTION

The asymmetry between horizontal (X) and vertical (Y) emittance of the photocathode RF gun is well-known and widely observed. These asymmetries in transverse emittance should be minimized as a high brightness injector for the Linac-based futures light sources. In our experiments of the SPring-8 photocathode RF gun until 2003, the apparatus consists of single cell S-band (2856 MHz) RF gun cavity which beam energy of 3.6 MeV, two solenoid coils and double slits for emittance measurements located downstream. In this case, large emittance asymmetry was observed as shown in Fig. 1. Since the laser incident angle to the cathode surface was 66 degrees to the beam axis, entire wave front of the laser pulse does not reach the cathode surface simultaneously. Therefore, a large emittance asymmetry was appeared. The tendency of asymmetry effects is explained by our self-made 3D tracking simulation code. The both experimental and simulation results are simultaneously shown in Fig. 1 [1].

In the upgrade of our photocathode RF gun system in 2004, one S-band traveling wave accelerator structure was installed downstream as shown in Fig. 3. The beam energy was upgraded to 26 MeV and a quadrupole scanning was applied as an emittance measurement method instead of the former double slits, since accuracy of measurements becomes worse in double slits with higher energy. In order to get rid of the emittance asymmetry, the laser incidence method was changed to quasi-normal incidence. Contrary to expectation, the Y emittances were still larger than X emittances as shown in Fig. 2.

POSSIBLE CAUSES OF EMITTANCE ASYMMETRY

Possible causes for the asymmetry are listed as follows;

- Imperfect laser spatial profile shaping
- Accuracy on emittance measurement system and data evaluation
- Field’s asymmetry of the gun cavity, or solenoid coils
- Miss alignment of laser spot position on the cathode, field of cavity and solenoid coils
- Affects of the laser incident mirror

*mizuno@spring8.or.jp
Figure 3: The SPring-8 RF gun system setup.

Figure 4: A cavity and a chamber for quasi-normal laser incident system. A laser mirror is located outside of the vacuum chamber.

NUMERICAL APPROACH ON EMITTANCE ASYMMETRY

Our accelerator structure has single-feed couplers whose RF ports are in the Y direction. In order to reduce asymmetry of longitudinal electric field in the coupler cell, crescentic shape cut is positioned at the opposite side of the RF feed port as shown in Fig. 5, though magnetic field is slightly off-centered.

Theoretical estimations of an emittance growth in the RF coupler cell was reported [3]. They pointed out that time dependent difference of head-tail deflection angle in the bunch results a emittance growth. We investigate these effects numerically, using self-made 3D beam tracking code and 3D field data of accelerator structure.

The field of whole 3 m long accelerator structure is hard for calculation. So we divide the structure into 3 parts, which are from the coupler cell to the third cell, last 3 cells, and the other normal cell section. The first and the last section data are calculated three-dimensionally using MWSTUDIO [4]. The normal cell section is calculated two-dimensionally using POISSON-SUPERFISH. Then, three data are connected smoothly. For each section, two kinds of...
data are calculated which boundary conditions for both longitudinal ends are the Neumann and the Dirichlet boundary. Fields at the given time is described as composition of these two data;

\[
\begin{align*}
E_z &= N_E(z) \cos(\omega t) - D_E(z) \sin(\omega t) \\
B_\theta &= N_B(z) \sin(\omega t) + D_B(z) \cos(\omega t)
\end{align*}
\]

(1)

where, \(N_E(z)\) and \(N_B(z)\) are the Neumann condition data, \(D_E(z)\) and \(D_B(z)\) are the Dirichlet condition data.

Simulation was applied on our RF gun setup as shown in Fig. 3. Initial laser temporal shape is square with full width of 20 ps and beam bunch width at the entrance of the accelerator structure is 10 ps FWHM. Charge is 0.3 nC/bunch. Beam energy is 3.6 MeV at the entrance and 26.0 MeV at the exit of the accelerator structure. Beam size at the accelerator structure can be varied with the field strength of the solenoid coils.

The upper graph of Fig. 6 shows a result using single-feed coupler structure, and the lower is a result of double-feed coupler structure. In each figure, simulated emittance at the exit of the accelerator structure are plotted as a function of beam size at the entrance of the accelerator structure.

With the single-feed coupler structure, asymmetry is large and this effect is one of the causes of our experimental emittance asymmetry. Using the double-feed coupler cell, this asymmetry is able to be reduced.

Figure 7: Time evolution of emittance with the single-feed coupler structure.

The cause of the shifts in \(Y'\) direction is an off-centering of magnetic fields in \(Y\) direction. That is, the field center is displaced in the coupler. This displacements are different for each slice plot because the off-centering varies with RF time evolution.

From Fig. 8, beam is defocused at A and focused at B. This is due to a focusing effect of the accelerator structure. Figure 9 shows time evolution of the beam size. Integration of \(\frac{dv_y}{dt} = e/\gamma m_0 (E + v \times B)_y\) from the entrance of the accelerator structure, which is acted on certain electron in the bunch is also plotted. The electron is basically defocused at the exit of a cell and focused at the entrance of the next cell by \(B_\theta\) and \(E_r\). These focusing and defocusing forces are canceled each other, and result an oscillation of integration of \(\frac{dv_y}{dt}\) in Fig. 9. So there are no focusing effects in the normal cell section. Though at the entrance of the input coupler, strong focusing force is remained, because the forces at the entrance are not canceled. In the same manner, defocusing force remained at the output coupler cell, however the defocusing effect on the beam is small because of higher beam energy. These focusing effects vary with RF time evolution in the bunch. So that the slice plot’s rotation in Fig. 8 is occurred.
As shown in Fig. 6, emittance asymmetry becomes lower as the beam size is smaller, because of the growing process of projected emittance mentioned above. The emittance of the smallest beam size in Fig. 6 grows larger. In this case, beam size at the entrance is small enough that waist point of the beam exists in the accelerator structure, then the beam size at the output coupler becomes large, and the emittance grows.

**The Case of the Double-Feed Coupler**

The emittance asymmetry appears slightly when the beam size is large as shown in Fig. 6.

Figure 10 shows time evolution of emittance with the double feed coupler structure. Slice emittances at point A, B, and C is also plotted simultaneously in Fig. 11. The beam size at the entrance is equivalent to the single feed coupler case.

As for the double-feed coupler, the shift of each slice plot in the phase space disappears because of no geometrical asymmetry exists. However, the rotations are remained because it is not related to the fields’ asymmetry. If we use a quadru-feed coupler, emittance asymmetry can be removed, though emittance growth due to the rotations of the slice plots will remain.

**SUMMARY**

The causes of the emittance asymmetry and emittance growth mechanism are investigated. The emittance asymmetry due to the coupler cell of the accelerator structure is considered as one of the most dominant effects on this issue. The X and Y emittance differences of $1 \sim 2 \pi \text{mm-mrad}$ in our experimental results are able to be explained by the off-centering field in the coupler at the both ends of accelerator structure. Even if we use the double-feed coupler cell, the asymmetry is not perfectly removed, however it will be negligible if the beam size is not large.

In the next step, we are planning to introduce an accelerator structure with double-feed couplers. We expected that this is the final solution for the imperfect emittance symmetry.

**REFERENCES**

[4] [http://www.cst.com/Content/Products/MWS/Overview.aspx](http://www.cst.com/Content/Products/MWS/Overview.aspx)