SIMULATIONS OF MODE SEPARATED RF PHOTO CATHODE GUN

Abhay Deshpande[a*], Sakae Araki[b], Masafumi Fukuda[b], Kazuyuki Sakaue[c], Nobuhiro Terunuma[b], Junji Urakawa[b], Noboru Sasao[d], Masakazu Washio[c]

[a] School of High Energy Accelerator Science, Graduate University for Advanced Studies, Shonan International Village, Hayama, Miura, Kanagawa 240-0193, Japan, [b]High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan, [c]Waseda University, Shinjuku-ku, Tokyo 169-8555, Japan; [d]Kyoto University, Kyoto 606-8502, Japan

Abstract

At Accelerator Test Facility (ATF), we have developed and successfully used RF Photocathode gun as the source of electrons. We have also used a similar gun in the Laser Undulator Compact X-ray source facility (LUCX), KEK (High Energy Accelerator Research Organization) for performing experiments to generate X-rays by inverse Compton scattering. Both the existing guns have mode separation of 4 MHz. We designed a new RF Gun with high mode separation of around 9 MHz and high Q value to achieve a low emittance beam of good quality. We are also modifying the power delivery scheme to the accelerator at LUCX to achieve the acceleration of 200 nC in 100 bunches with low emittance. This will help to increase the intensity of X-rays by the inverse Compton scattering

INTRODUCTION

At Accelerator Test Facility (ATF) at KEK we have designed and developed S-Band Compact 'Laser Undulator Compton X-ray Source' called as LUCX. This test bench has a RF photocathode gun to inject a low emittance beam of 50 nC in 100 bunches with bunch spacing of 2.8 ns in a 3 m long S-band travelling wave linear accelerator (linac). The linac then accelerates these bunches to 45 MeV energy with energy difference less than 0.13 % using ΔT compensation technique. This high energy beam then goes through a quadrupole doublet to reach a beam size of the order of 60 µm at the interaction point. The interaction point is inside a super-cavity where the beam interacts with pulsed laser to produce intense X-rays by Inverse Compton scattering principle. Recently we demonstrated 30 keV X-rays with a flux of 0.93×10^4 photons per train. To meet further challenge of increasing the flux, we started working on various systems to optimize various parameters to achieve a flux of the order of 1.0×10^7 photons per train.

Changes are initiated in the RF gun and accelerator to improve the performance of both the systems. We designed a new RF photo cathode gun cavity so as to increase the mode separation and the quality factor [1]. The mode separation between operating π mode and zero mode is increased from 3.5 MHz in the current setup to 8.6 MHz in the new gun. The higher mode separation will result in better stability and lower emittance thus helping to make a good beam at interaction point. In the linac section, the power delivery scheme is being modified to achieve 45 MeV energy with 200 nC in 100 bunches. Higher stability will also make it possible to go for higher repetition rates in future, thus further increasing the current. In addition to above changes, a new scheme is being worked out to achieve 5 MeV beam with 2µC in 1000 bunches in the same setup at the interaction point. The paper mentions briefly the proposed dual energy mode operation in the last section.

MODE SEPARATED RF GUN DESIGN

It has been experimentally verified that by increasing the separation between π and zero mode of RF gun, the emittance can be lowered [2][3]. At LUCX we re-designed the gun to achieve mode separation of 8.6 MHz. The iris diameter between half and full cell was iteratively increased to achieve the higher mode separation. Curved interior wall geometry was selected for the cells. The curved surface reduces the surface field nearly by 5% with respect to earlier non-curved interior wall design cavity. This will be useful to reduce the dark currents. Figure 1 shows the profile of RF gun cavity. The operating frequency is 2856 MHz at π mode with TM010 mode with a field balance of 1.0 in half cell and full cell.

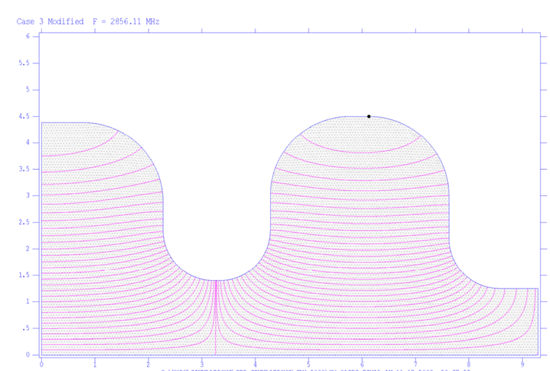

Figure 1: Super Fish Profile of RF gun cavity.

Figure 2 shows the effect of field balance on the mode separation. Field balance is defined in our case as the ratio of Half Cell to Full cell axial electric field. As seen from Fig. 2, higher mode separation can be achieved at the cost of field balance. But as the field balance goes away from

*abhay@post.kek.jp

unity the energy gain reduces, hence we opted for field balance of 1.0. A pair of tuner is available in half cell and 2 pairs of tuners are available in full cell for fine tuning to achieve the desired field balance.

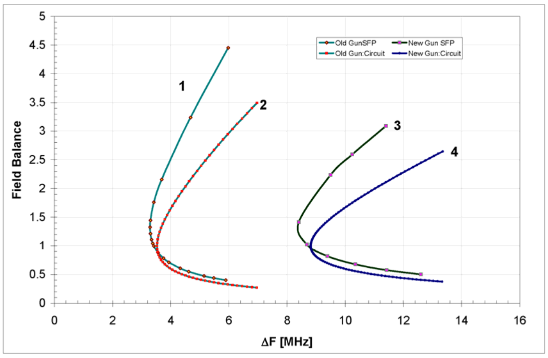

Figure 2: Field balance as a function of mode separation. Curve 1 and 2 are for the existing gun while the curve 3 and 4 are for the new gun. Super Fish (SFP) and circuit theory predictions are shown for comparison.

EQUIVALENT CIRCUIT ANALYSIS

The standard circuit theory for modelling cavities can be applied to RF gun, with little modifications [4][5][6]. For RF gun with only two cells the identification of the modes is bit complicated [7]. Further the presence of drift tube at the exit cell end also affects the analysis using the circuit model.

For our case, the analysis is carried out by adding an imaginary cell to the full cell. If i_0 is current in half cell, i_1 in full cell and i_2 is the current in the imaginary cell. Then the condition such that $i_1 = i_2$ makes an electrical mirror like situation and corresponding boundary condition is of Nuemann type. While with a condition $i_1 = - i_2$, leads to a magnetic mirror like situation with Dirichlet type boundary condition. By careful analysis, it can be shown that as far as nomenclature of modes is concerned π and Zero modes may not exist in two cell structure. Instead, π and π /3 modes or 0 and 2π/3 modes are identified as the modes. Now if we add the drift tube at the exit end and keep increasing the length of end tube, it is observed that which pair of modes is excited, depends on the length of the drift tube at the exit end.

Table 1: Modes with no end cell correction. Identified modes are in bracket.

End Tube Length mm	Higher Mode Frequency MHz	Lower Mode Frequency MHz
2.00	2854.6732 (3π/4)	2847.7295 (π /4)
4.922	2855.5035 (5 π /6)	2847.6875 (π /6)
7.605	2855.9507 (11 π /12)	2847.4517 (π /12)

In order to get π– like modes, full cell frequency should be increased. This tuning leads to π–like , π/3 like modes. This means that the lower mode is not zero but π/3 like. The zero mode offers less field at cathode than π/3 mode. Since the field on the cathode can dilute the emittance, hence the analysis is important. The analysis shows that to optimize the effect of modes, the full cell frequency should be increased by 1 MHz.

BEAM DYNAMIC SIMULATION

The axial field obtained from Super Fish was used for studying the effect of laser spot size, solenoid magnetic field and amplitude of axial electric field on the emittance using ASTRA code [7]. The axial electric field was optimized to 140 MV/m and the peak magnetic field is 0.24T. The solenoid is positioned immediately after the RF gun to compensate for emittance dilution due to exit kick. The layout is shown in Fig 3.

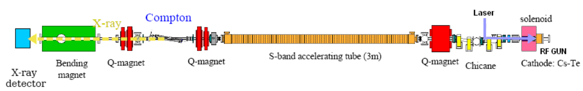

Figure 3: Current Lay out of LUCX.

Figure 4 shows the effect of varying transverse laser size on the emittance at the focal point of solenoid, for a fixed longitudinal laser size. Fig. 5 shows the variation of longitudinal energy spread with laser pulse length. Using data from the simulations, the optimum laser size of σ_x, σ_y of 0.3191 mm and σ_z of 5.5 ps was selected as optimum operating condition.

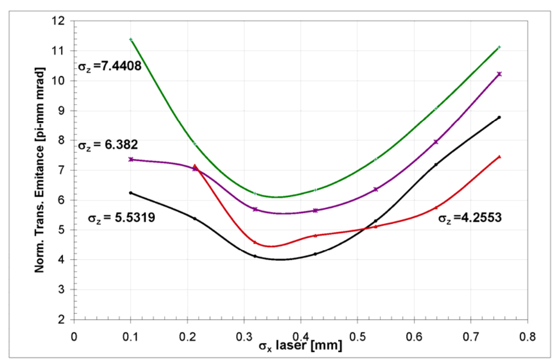

Figure 4: Variation in emittance with transverse laser size for fixed longitudinal laser pulse length.

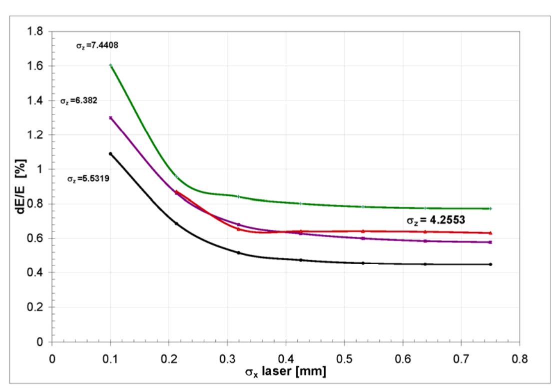

Figure 5: Variation of longitudinal energy spread with laser pulse length.

After the solenoid, a Chicane magnet deflects the beam out of plane and back to centre. This is helpful to locate the mirror such that Laser is incident head-on to the cathode. The acceptance at Chicane is less than 1 MeV. At the position of minima, a 3 m travelling wave linac is inserted. At present we are able to accelerate the beam to 45 MeV and we achieve emittance of 8 pi-mm-mrad with 50nC in 100 bunches. We plan to enhance the charge to achieve 200 nC in 100 bunches. The details are listed in next section.

POWER DELIVERY SCHEME

In the current setup a single klystron drives the gun and the linac. This makes less power available at the linac port. As mentioned earlier the current charge is 50 nC in 100 bunch. In Fig. 6 curve 2 shows the achievable beam with ΔT beam loading compensation scheme for 200 nC in 100 bunches, if we use same power scheme. Compensation, as seen from the figure, is possible but with a low energy of around 30 MeV. Hence we initiated modifications of the power delivery scheme. In the new scheme, two klystrons will drive the gun and linac, independently making more power available at gun and linac port. Curve 1 in Fig. 6 shows the beam for new scheme with high power input. We expect a well compensated, high energy beam with 200 nC in 100 bunches with bunch spacing of 2.8 ns.

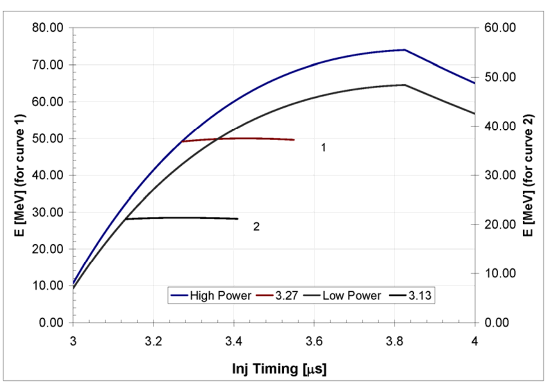

Figure 6: Beam Loading Compensation for 200 nC in 100 bunches for two power schemes. Curve 1 corresponds to High input power while Curve 2 corresponds to Low power input.

LOW ENERGY, HIGH CHARGE OPTION

The final modification will be to replace the accelerating tube by a 3 meter long drift tube and use a solenoid to maintain the beam parameters. With this setup, we plan to achieve a beam charge to 2nC per bunch and use 1000 bunches with bunch spacing of 2.8 ns to make 5 MeV, 2 μC beam available in the diagnostic region. Figure 7 shows simulation of emittance evolution from cathode position with and with out the accelerating tube. This high charge beam will be then used to perform collision experiments and also coherent diffraction radiation experiments. With the accelerating tube replacement mechanism, we will be able to achieve dual mode operation with 45 MeV 200 nC in 100 bunches as high energy mode and 5 MeV 2 μC in 1000 bunches as low energy mode.

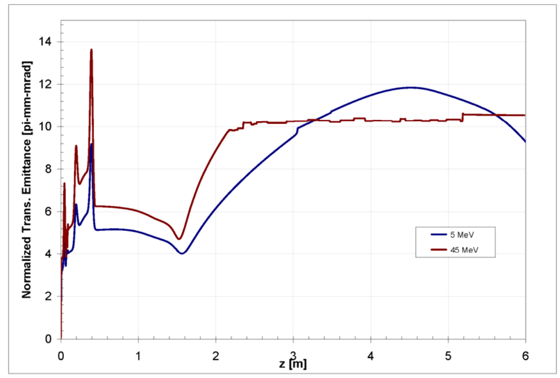

Figure 7: Emittance evolution from cathode position for high and low energy beams.

SUMMARY

The new RF gun cavity is under fabrication and expected to be ready for installation by July 2009. The high mode separation will be helpful in making gun stable against drifts due to thermal problems and make gun more stable. Emittance is expected to go down while the exit energy will be higher. With a new power delivery scheme, we expect to achieve 200 nC in 100 bunch with energy of 45 MeV with 7 pi-mm-mrad emittance in the vertical plane. By installing a linac replacement mechanism we will be able to operate the system in dual mode with 5 MeV energy and 2μC charge as low energy option.

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