EXPERIMENTAL RESULTS OF RF GUN AND GENERATION OF MULTI BUNCH BEAM

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Abstract

At Laser Undulator Compact Source (LUCX) at KEK, we designed and made a new RF Gun with high mode separation of 8.6 MHz and high Q value as compared to earlier guns. This paper presents fabrication details, low power measurements and tuning procedures followed in making the gun cavity. We also discuss in detail, experimentation done using this gun and show the measurement results. Currently we produce 100 bunch per train but we plan to go for 300 or more bunch per train operation. This will make possible to have higher charge available for laser-beam collisions to generate high flux soft X-rays by Inverse Compton Scattering at our setup.

INTRODUCTION

At KEK we have designed and developed a 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 with up to 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 0.7 % 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 1×10^4 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 [1].

Changes were 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 [2]. The mode separation between operating π mode and the zero mode is increased from 3.5 MHz in the old gun to 8.6 MHz in the new gun. We measured various parameters of the new RF gun. We found that the energy spread of the new gun with larger mode separation is more stable for phase variations as compared to old gun. This makes the new gun stable over phase variations. We also worked out a new scheme, as proposed earlier, to make long bunch trains with higher charge per train [3]. We replaced the linac in our setup with a drift tube and achieved 5 MeV beam with 160 nC total charge in 300 bunches with peak to peak energy difference less than 0.9%. The further long train generation was limited due to limitations of the Pockels Cell. The old Pockels cell showed ringing in the waveforms for more than 300 bunch mode. Recently, we purchased a new cell and due to this modification, 8000 bunches per train will be possible using the mode separated RF gun in near future. The high mode separation RF gun is needed for long pulse width RF power necessary to generate long bunch trains. The increased stability of gun for temperature and for energy spread variations makes it possible to have long operation shifts with higher rep rate. Encouraged by the results we are making 3.5 Cell RF gun to get 10 to 12 MeV beam energy with 5000 bunches per train and 0.5nC per bunch charge for various applications including medical applications.

DESIGN AND TESTING OF RF GUN

We planned to increase the mode separation to 8.6 MHz while increasing the Q and Shunt Impedance of our new RF gun. We proposed a new internal profile for the gun cavity. Accordingly we made the design drawings and initiated the fabrication of the gun structure. To be able to have better control on mode separation and field balance, we kept the starting frequency of cells very high and measured the separation and field balance. After simulating the cells as per machine shop settings, we planned a few micron cut on the diameter of each cell and the cut was taken at KEK machine shop. Then we measured the parameters again and repeated the process of simulations and further cut on diameter. In this iterative process, we gradually approach the final π and zero mode with desired field balance between half cell and full cell fields. After 08 cuts, the desired frequency and field balance was achieved and the structure was brazed. Further tuning was needed to keep field balance

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to unity and this was done using the tuners provided in each cavity. Fig 1 shows the completed RF gun and Table 1 shows the comparison of predicted parameters to achieved parameters. Fig 2 shows the measured and simulated field balance of the RF gun. This shows, we have achieved a good control over RF gun fabrication and we can tune the gun as desired. The completed RF Gun was then installed at our facility and RF processing was done for 150 hrs with 2 μs pulse width and 10 MW power. The cathode was then coated with Cesium - Telluride and the gun was again subjected to conditioning for 100 hrs. The quantum efficiency, 30 days after coating, was found to be around 0.5% and the dark currents were substantially low. At this point, the beam was turned on and beam quality measurement was done.

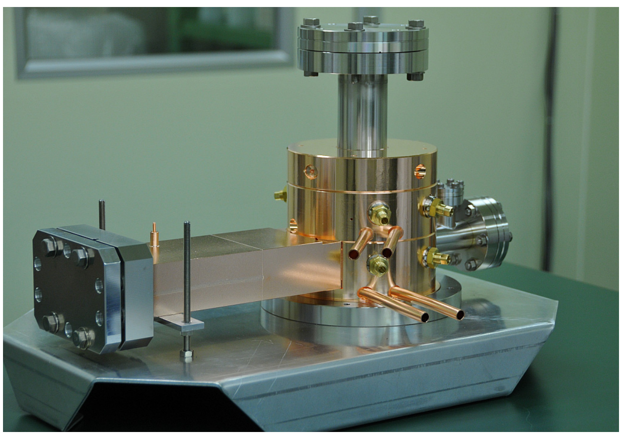

Fig 1: RF photo cathode gun structure before brazing.

Table 1: Measurement results for RF gun

	Simulation	Measured	Old Gun Measured	unit
Frequency	2855.64	2855.61	2855.74	MHz
Mode Separation	8.67	8.63	3.52	MHz
Field Balance	1.0	0.98	1.3	
Q	18000	15000	7900	

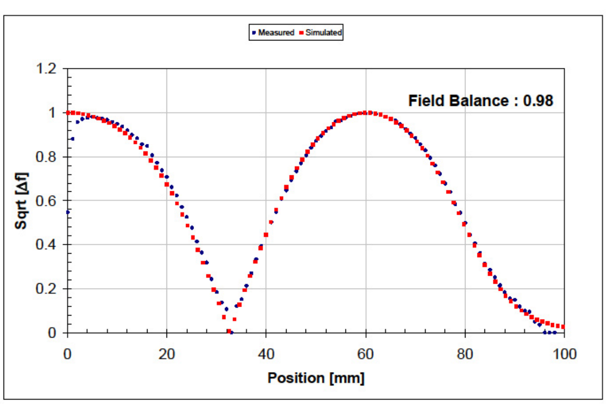

Fig 2: Measured field balance using bead pull method.

BEAM PARAMETER MEASUREMENTS

The RF gun was thoroughly tested to find the actual operation parameters at which minimum emittance can be achieved. In our setup we use a laser system with 7W average power at 1064 nm wavelength. The oscillator is mode locked to produce 2.8 ns pulses from which the desired number of pulses per train is selected using the Pockels cell. We use two single pass amplifiers to enhance the pulse power and then two BBO crystals to convert the wavelength to 266 nm. We select 100 pulses per train for 45 MeV operation and 300 pulses per train for 5 MeV operation. The limitation of bunches per train for 45 MeV operation comes because of heavy beam loading in the linac. Where as the RF gun, can sustain very long bunch trains. The selected laser pulse train is incident on the cathode to produce the electron bunch. A very high gradient of 120 MV/m was made at the cathode position to compensate for the degradation in emittance due to space charge effect. A focusing solenoid is introduced at the exit of RF gun for emittance compensation due to exit kick. A 3 meter long constant gradient travelling wave linac tube accelerates the beam to 45 MeV and we use a quadrupole doublet after the linac to measure the emittance using the quad scan method.

Using the quad scan method, we found that the normalized x emittance is 4.22 ± 0.23 π-mm-mrad while the normalized y emittance is 1.89 ± 0.0023 π-mm-mrad. The energy and energy spread is measured by passing the beam through the bending magnet on to a screen. A beam position monitor and current transformer are also placed in beam line after the bend. Fig 3 shows the variation of energy spread as a function of injection phase for a beam with 1.6 nC charge. For comparison, measurement results for the old gun with less mode separation are also shown. The operating conditions and bunch parameters are same for both the measurements. It is clearly seen that, the new gun is much more stable over injection phase.

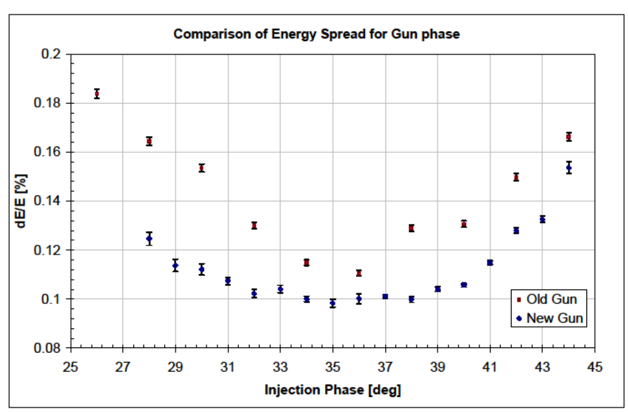

Fig 3: Energy spread as function of injection phase.

MULTI BUNCH BEAM GENERATION

We have already demonstrated multi bunch beam at 45 MeV with 100 bunches per train and 0.5 nC per bunch charge [4]. We use ΔT method of beam loading compensation. In this method the injection time of beam is changed in order to get the least possible peak to peak energy difference in the bunch train. The travelling wave linac is used to accelerate the 100 bunches to 45 MeV and we observe heavy beam loading. We successfully compensated the loading to achieve 0.7% peak to peak energy difference with the new gun. Generation of further long bunch train leads to more beam loading and it was found by simulations that for further long trains some of the bunches may hit the linac walls, thus damaging the system. However it is possible to use the standing wave RF gun to generate long bunch trains. Hence we proposed and replaced linac by drift tube [3]. To make use of same diagnostics, we simulated the performance of beam from the cathode of gun to the dump at 8 meter distance using ASTRA [5]. After careful tuning and many trials we succeeded in transporting bunches from gun to dump with no loss. Fig 4 shows the ASTRA simulation till collision chamber while fig 5 shows the orbit of the beam from the gun (before BPM 1) to the dump (after BPM 7). The emittance diagnostic is near BPM 5 in the figure.

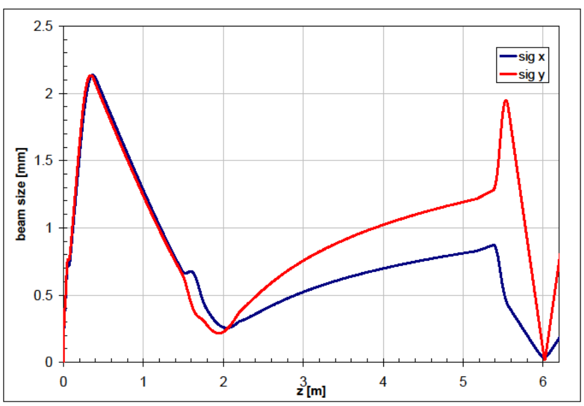

Fig 4: ASTRA simulation for 5 MeV beam size from cathode to interaction region. BPM 5 is at 6.0 m from cathode.

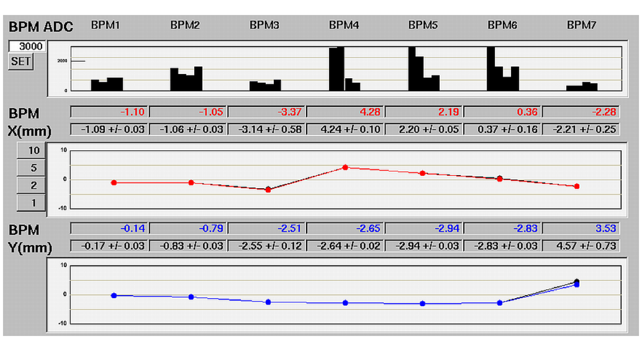

Fig 5: Tuned orbit for LUCX setup with no linac. The cathode is before BPM 1 on left end of figure and the dump is after BPM 7 on the right end. The emittance measurement doublet is before BPM 5 in the figure.

After establishing the fine tuning, we launched a multi bunch beam in the orbit and carefully adjusted the injection timing to get 300 bunches with 0.55 nC per bunch charge. Fig 6 shows the experimental result. It shows clearly that we achieved less than 0.9% peak to peak energy difference for the 300 bunch-train. Table 2 summarizes the parameters for this important result.

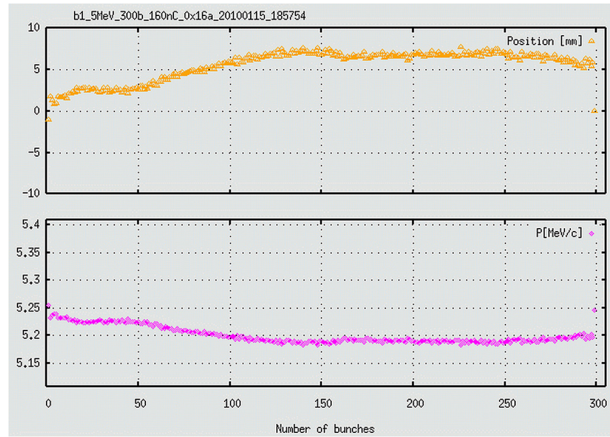

Fig 6: The 300 Bunches with 160nC charge. The plot shows the energy (y-axis) as a function of bunch number (x-axis) in the lower part and the position as a function of bunch number in the upper part.

Table 2: Measurement Results for Multi Bunch Beam

Number of bunches	**100**	**100**	**300**
Energy [MeV]	45	5.3	5.25
Charge per bunch [nC]	0.5	0.5	0.55
Peak to peak energy difference [%]	0.7	0.3	0.9

CONCLUSIONS

We successfully designed and made 8.6 MHz mode separated RF gun and installed it in our setup. The variation in energy spread over injection phase was found to be much less as compared to the old gun. The high shunt impedance makes it possible to generate 6 MeV beam at the gun exit. We used the gun to generate 300 bunches with 160 nC total charge with peak to peak energy difference less than 0.9%. This important result has boosted our confidence in producing long bunch trains and we will be able to produce 5000 bunches per train in recent future.

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