

STATUS AND FUTURE PLAN OF THE ACCELERATOR FOR LASER UNDULATOR COMPACT X-RAY SOURCE (LUCX)*

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Abstract

We have developed a compact X-ray source via inverse Compton scattering between an electron beam and a laser pulse stacked in an optical super-cavity at Laser Undulator Compact X-ray (LUCX) accelerator in KEK. The accelerator consists of a photo-cathode RF-gun and an S-band accelerating tube and now produces the multi-bunch electron beam with 100 bunches, 0.5nC bunch charge and 40MeV beam energy.

It is planned to upgrade the RF-gun and the RF system of the accelerator and the super-cavity in order to increase the X-ray yield. The new RF-gun with high mode separation and high Q value and a new klystron for the gun will be installed to provide good compensation with a high-intensity multi-bunch electron beam. A new optical super-cavity consisting of 4 mirrors is also being developed to enhance the stacking power in the cavity and to reduce the laser size at the focal point. The first targets are to produce a multi-bunch electron beam with 3000 bunches, 0.5nC bunch charge and 5MeV beam energy in low energy mode and with 100 bunches, 2nC and 40 MeV in high energy mode to generate X-rays by inverse Compton scattering. In this paper, the status and future plan of the accelerator will be reported.

INTRODUCTION

X-rays have various fields of application, such as medical application, biological science, material science etc. Recently, the research and development of X-ray source based on Compton scattering is done by various laboratories and universities [1][2]. For high brightness X-ray sources, synchrotron radiation with an undulator insertion device in an electron beam ring with energy as high as GeV order, are most commonly used. However the device is generally huge and expensive. On the other hand, the X-ray source based on Compton scattering is compact and inexpensive because the energy of an electron beam can be lower than the GeV order synchrotron ring, for producing X-ray with same energy.

We have constructed the small accelerator at KEK in order to develop the compact x-ray source based on inverse Compton scattering using the optical super-cavity. The project is called Laser Undulator Compact X-ray source (LUCX). The LUCX is used for production of a multi-bunch electron beam, development of an optical super-cavity and for understanding of X-ray generation by

collision of an electron and a laser pulse.

The project has developed through several stages. At first, the electron source using photo cathode RF-gun has been developed. In 2005, we succeeded in the generation of a high intensity multi-bunch beam with 100bunches, 2.2nC/bunch and 5MeV beam energy [3]. Subsequently it has been used to demonstrate the generation the hard X-ray generation using the super-cavity. An S-band accelerating tube was added to produce the multi-bunch electron beam with 100 bunches, 0.5nC bunch charge and 40MeV beam energy as shown in Fig. 1. An optical super-cavity has also been installed in this beam line. The cavity is Fabry Perot resonator and consists of two mirrors with the curvature of 210.5mm and the reflectivity of 99.6%. Because the length of cavity is equal to half of the pulse duration of the injected laser pulses, the pulses are stacked on the laser pulse in the cavity. This allows to make the laser pulse with a high peak power. The pulse energy in the cavity is 110 μ J/pulse. By colliding the laser pulse with the electron beam, the X-ray production has been succeeded in 2008. The number of x-rays produced is 10^4 photons/train. Good agreement was also confirmed between the observed and the expected number of X-rays [4].

It cannot be said that the intensity of X-ray is sufficient for practical applications. Therefore, in the future, the upgrade of the accelerator and the super-cavity has been planned to increase the number of X-rays and to overcome some of the problems which we observed in this X-ray generation experiment. In this paper, we explain the upgrade plan.

UPGRADE PLAN

Our final target is the generation of soft X-ray with a flux of 10^7 photons/train. To achieve the target, various devices in acceleration section and the optical super-cavity will be upgraded.

By upgrade of the accelerator section, we aim to increase the total intensity and quality of electron beam and to reduce the dark current from the RF-gun. In future RF-system, a new klystron which can produce a long RF pulse of 24 μ s will be introduced for creating the very long multi-bunch beam with 8000 bunches. The RF systems of the RF-gun and the accelerator will be separate as shown in Fig.2. The new klystron with long pulse width will drive the RF-gun. The existing klystron feeds the RF power into the accelerating tube. This will make it possible to compensate for the beam loading effect by

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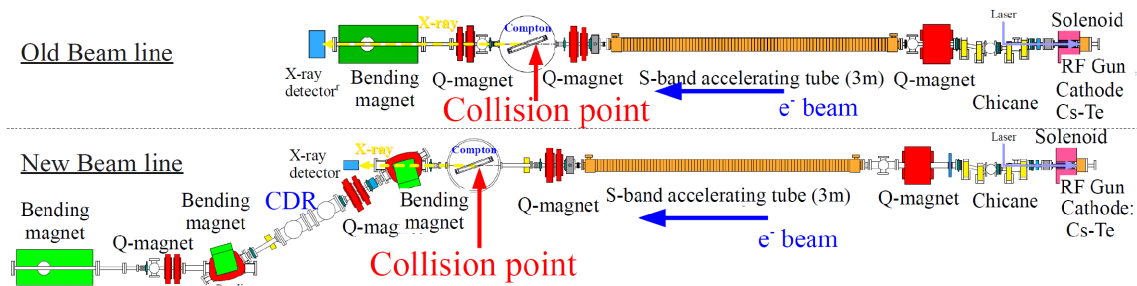


Figure 1: These are the old and new beam line of LUCX accelerator. The new beam line has been constructed in this March.

both the gun and the accelerator. The beam loading effect, which is important issue in accelerating the multi-bunch beam, is compensated by accelerating the beam during transient state when RF is filled in cavity. Since the proper timing to compensate the effect is different for the gun and the accelerating tube, the timing can be independently selected in future rf-system. This is an added advantage in the new scheme.

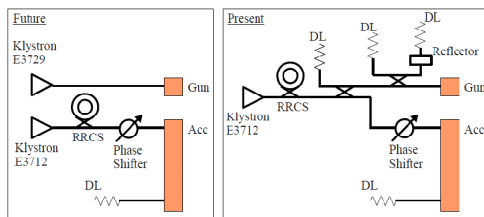


Figure 2: These are new and old RF-system.

Another upgrade is the installation of the new RF-gun[5] which has high mode separation of 8.62 MHz and high Q value of 14342. The new gun is 1.6cell which is same as the existing gun (BNL-Gun-IV). However, the geometry of the cavity is different. It consists of the smooth curved surface as shown in Fig. 3. Furthermore, the gun has no laser injection port, no tuner hole and no Helicoflex seal, that is, the end plate is brazed. Tuners are modified so that they distort the shape of the cavity by pushing the surface for tuning the resonant frequency and the field balance.

By using the new gun, the improvement of the emittance and the reduction of the dark current are expected. Because the Q-value is 1.8 times higher than the existing one and therefore accelerating field is also higher, the space charge effect to worsen the beam emittance will be reduced. Large mode separation improves the stability over phase variations. RF emittance is low for the laser ports are removed. The dark current creates the noise in the detection of X-rays. The noise accounts for about 50% of the total. Therefore improvement of the S/N ratio will be expected in the X-ray measurements.

In the optical super-cavity section, a new super-cavity which consists of four mirrors is being developed to increase the stored power and to reduce the size at focal point. The cavity is a confocal resonator which has larger clearance on the transverse alignment of the mirrors than the concentric resonator. This helps to achieve a high

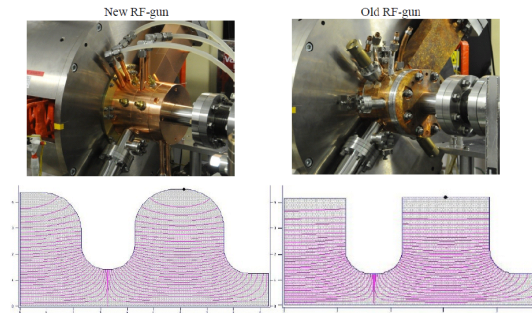


Figure 3: The photograph and geometry of the new and old RF-gun.

storage power and a small laser size. A detailed explanation of the cavity can be found in [6].

The new beam line is shown in Fig.1. The downstream part from the collision point (CP) of the electron beam and the laser pulse is mainly changed. The multi-bunch electron beam generated by the RF-gun is accelerated up to 50MeV by the 3m S-band accelerating tube and is collided with the laser pulse in the cavity. In the low energy mode, the accelerating tube is removed. The generated x-ray is separated from the electron beam by the first bending magnet with the bending angle of 30degree. The X-ray is extracted through the Beryllium window from vacuum to air. The beam is bended again by the second bending magnet and is dumped to the ground by the final 90deg bending magnet. The first bending magnet is put close to the collision point because soft X-rays have big angular spread. The beam dump is also moved further away because secondary particles generated at the dump serve as the noise in the detection of X-ray. The monitors of the beam position, current and profile are put at many necessary places of the beam line.

Moreover, we also have plans to develop microwave and soft X-ray sources based on coherent diffraction radiation (CDR) and Thomson scattering in this accelerator [7]. The device will be installed between the 30deg bending magnets as shown in Fig 1.

OPERATION TEST OF THE NEW GUN

The new gun was installed in the old beam line in order to estimate the performance.

The dark current in the new gun has dropped to about half compared with the old gun. The removal of

Helicoflex seal, the holes of tuners and the ports of a laser light is thus confirmed to be effective.

Figure 4 is the result of the search of optimum solenoid field. The emittance was measured at various solenoid fields for each gun. The minimum horizontal and vertical emittance in the new gun are respectively 3.8π and 1.5π mm mrad at 0.4nC/bunch. These value are about half of the old one values. It is considered that the emittance growth by the space charge effect is reduced by the higher accelerating field because the new gun has high Q value. The solenoid field at minimum emittance is stronger in the new gun since the beam energy becomes higher.

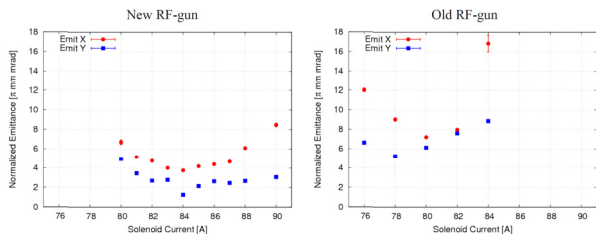


Figure 4: The results of measured emittance at various solenoid field in the new and old rf-gun.

In multi-bunch beam generation over 100 bunches, the accelerating tube was removed because the beam loading effect was heavy in the linac. The result is shown in Fig. 5. We have successfully generated the 300 bunches beam with 5 MeV and 140nC total charge. The energy difference in the bunch train was within 1%.

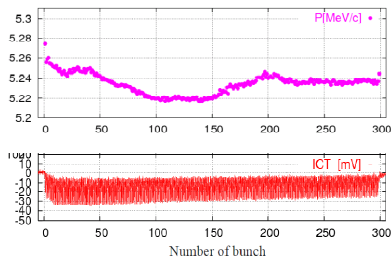


Figure 5: The energy and current of each bunch in 300 bunches beam generation.

BEAM OPERATION AND X-RAY GENERATION

We plan to operate the LUCX in two modes of operation with high energy mode and low energy mode.

In low energy mode, the aim is to produce long multi-bunch beams and to generate soft X-rays. The beam is not accelerated because there is not a sufficiently strong rf source to accelerate this beam in a normal conducting accelerator. Therefore the accelerating tube will be replaced by the beam diagnostic devices. The final target is to create the multi bunch electron beam with 8000 bunches, 0.5nC bunch charge and 5MeV beam energy and to generate the soft X-ray with the beam. The expected number of the X-rays is 1.8×10^7 photons/train.

The parameters of an electron beam and a laser pulse are shown in Table 1 and Table 2. The first target is the production of 3000 bunches beam.

In high energy mode, the achievement of a multi-bunch beam with 100 bunches, 2.0nC/bunch bunch charge and 50MeV beam energy is the final goal. The X-rays will be used to develop the X-ray detectors.

Table 1: Parameters for the electron beam in future plan

Energy	5MeV	50MeV
Intensity	0.5nC/bunch	2nC/bunch
Num. of Bunch	8000 bunches	100 bunches
Bunch spacing	2.8 ns	2.8 ns
Bunch length (FWHM)	10 ps	10 ps
Repetition Rate	12.5 train/sec	12.5train/sec
(σ_x, σ_y) at C.P.	200 μ m, 60 μ m	80 μ m, 40 μ m

Table 2: Parameters for the laser pulse in future plan

Wave length	1064nm
Intensity	10mJ/pulse
Pulse width	7ps
Beam size(σ_x, σ_y)	8 μ m, 8 μ m

SUMMARY AND SCHEDULE

The LUCX accelerator is being upgraded now. The new RF-gun has been installed. The estimation of the performance is on-going. The construction of the new beam line was finished in March 2010. The commissioning has been started. The RF-system will be upgraded in recent future. The first target is the generation of a multi-bunch beam with 3000 bunches, 5MeV beam energy and 0.5nC/bunch (Total 1500nC). The generation of soft x-ray will also be tried.

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