A COMPACT SOFT X-RAY SOURCE BASED ON THOMSON SCATTERING OF COHERENT DIFFRACTION RADIATION

A. Aryshev*, A. Araki, M. Fukuda, J. Urakawa
KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
P. Karataev
John Adams Institute at Royal Holloway, Egham, Surrey, TW20 0EX, UK
G. Naumenko
Nuclear Physics Institute at Tomsk Polytechnic University, Tomsk, 634050, Russia
A. Potylitsyn, L. Sukhikh, D. Verigin
Tomsk Polytechnic University, Tomsk, 634050, Russia
K. Sakaue
Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo, 169-8555, Japan

Abstract

High-brightness and reliable sources in the VUV and the soft X-ray region may be used for numerous applications in such areas as medicine, biology, biochemistry, material science, etc. For that purposes many 3rd generation light sources based on large synchrotron radiation facilities have been built around the world. Moreover, 4th generation light sources based on X-ray free electron lasers are being built in a few world's leading laboratories. However, those installations are very expensive and the access to wider community is very limited. We propose a new approach to produce the intense beams of X-rays in the range of ≤ 500 eV based on compact electron accelerator. The state-of-the-art soft X-ray generation is based on inverse Compton scattering of laser photons. Such method usually requires a dedicated high power laser system, which makes the experiment complicated. We propose a new method for generating soft X-rays. An ultimate goal of the project is to create a compact soft X-ray source based on Thomson scattering of Coherent Diffraction Radiation (CDR) using a small accelerator machine.

INTRODUCTION

CDR is generated when a charged particle moves in the vicinity of an obstacle. The radiation is coherent when its wavelength is comparable to or longer than the bunch length. The CDR waves will be generated by a multi-bunch beam and accumulated in an opened resonator formed by two mirrors. Every subsequent bunch will experience Thomson scattering and the X-ray photons will be detected downstream by a photon detector.

In our recent report [1] we have demonstrated the status of the project on development of a novel soft X-ray source based on inverse Thomson scattering of Coherent Diffraction Radiation (CDR). We have represented the first CDR measurements at the multibunch beam of LUCX facility and demonstrated the performance of the fast millimeter wavelength detection system based on the Schottky Barrier Diode (SBD) detector. The experimental data demonstrates the feasibility of the LUCX facility for building an intense THz radiation source which can later be used for generating soft X-rays. In this report we shall represent the current status of the project and discuss the design of the microwave resonator in details.

LUCX UPGRADE

Recently the LUCX facility experienced a major upgrade. A new klystron producing a long RF pulse of 24 μs will be installed to create a long multi-bunch beam with 8000 bunches. The new RF gun with high mode separation and high Q value [2] is already installed to produce an exceptional quality multi-bunch electron beam.

Nowadays two LUCX operation modes are planned. One is the low energy (5 MeV) with maximum of 8000 bunches. The other one is the high-energy mode (43 MeV) with a maximum of 100 bunches [3]. The main LUCX beam parameters are summarized in Table1.

Table 1: Main LUCX beam parameters

Energy	5MeV	43MeV
Intensity	0.5nC/bunch	2nC/bunch
Number of bunches	8000	100
Bunch spacing, ns	2.8	2.8
Bunch length, ps	10	10
Repetition rate, train/s	12.5	12.5
Normalized emittance(πmm mrad)	0.5	2

Both modes are very attractive for our study since the large number of produced bunches in the first mode or higher energy electrons in the second mode will result in increase of the stored radiation power in the microwave open resonator.

*alar@post.kek.jp

Figure 1 represents schematic diagram of the upgraded LUCX beam line. The multi-bunch electron beam generated by the RF gun is accelerated up to 43MeV by the 3-m S-band accelerating structure (in the low-energy mode, the accelerating tube will be removed). After that electron beam is deflected by the first bending magnet, it passes through the CDR open resonator made of two aluminium mirrors on fused silica substrate with 1 mm penetration holes in the centres. Afterwards the beam is bent again and dumped to the ground by the final 90 degree bending magnet.

Small fraction of microwave radiation power will be extracted through the discontinuity in aluminium layer of the upstream target and detected by the SBD detector capable of resolving the CDR photons produced by each bunch in the train in order to monitor power build-up (typical oscilloscope trace of the SBD detector and corresponding trace of the Inductive Current Transformer (ICT) is shown at the Figure 2).

Two large aperture fused silica vacuum windows were introduced to transmit a fraction of stored microwave power out of the cavity in upstream direction and to extract scattered UV/visible photons in downstream direction. Also both view-ports will be used for alignment procedure. To align the targets with respect to electron beam a colorimeter gamma detector will be placed downstream of the PMT based detector of the scattered photons (see Fig.1 subframe).

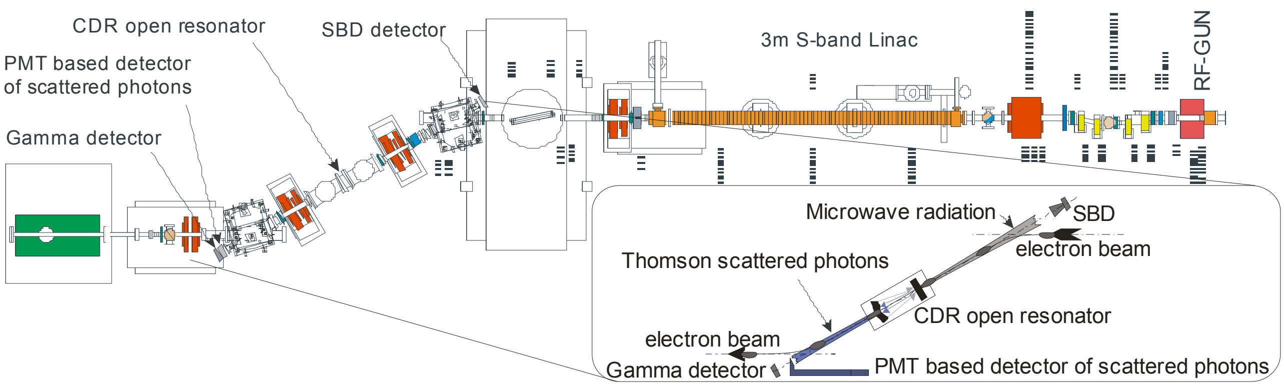

Fig. 1: LUCX schematic layout and general experimental setup.

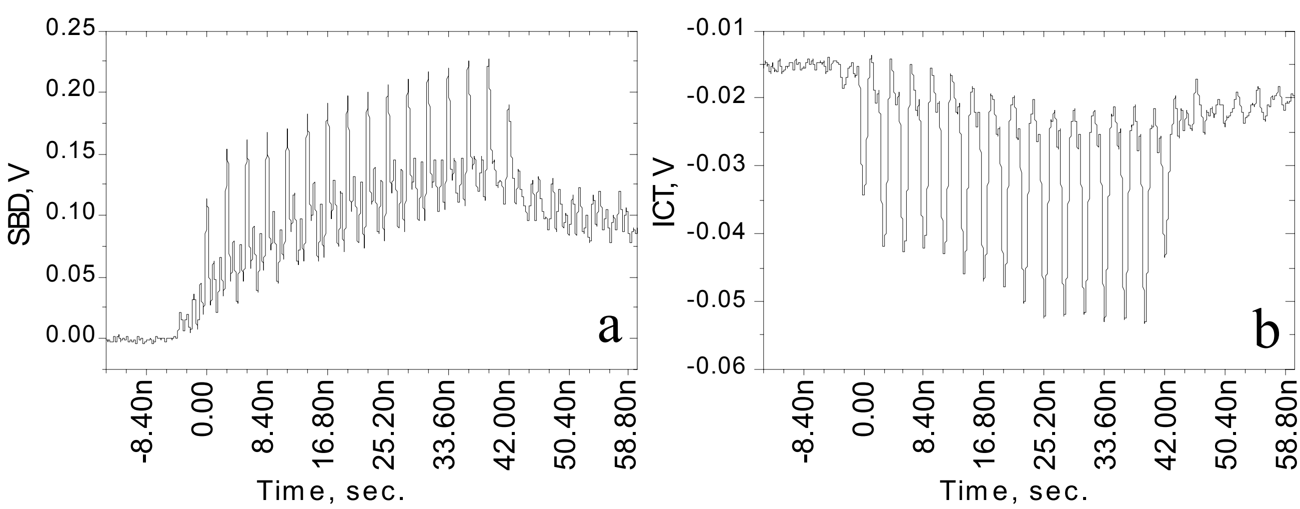

Fig. 2: Typical oscilloscope traces of (a) SBD and (b) ICT for the multi-bunch LUCX operation.

MICROWAVE RESONATOR DESIGN

To tune the resonator two mirrors on a beam line will be mounted on multi-axes (XYZ, and rotation in X-Z plane[#]) vacuum manipulation systems. Which will be installed into 6-way crosses separated by a custom made nipple to keep correct (420 mm) distance between the centres of the mirrors (Fig. 3).

The in-vacuum mirror mounts are designed to accept 100 mm diameter and minimum 3 mm thickness mirrors and has two manual adjusters: angular (±5° in Y-Z plane) and linear (±1.5 mm in Y-Z plane), see Fig.4. Adjusters are made in order to align the aluminium surface of the mirrors with respect to the rotation axis of the manipulator.

[#]accelerator coordinate system is used

The resonator should have a good quality factor and one should be able to change its axis orientation in order to align the system and tune the Thomson scattering process. We are considering a step-by-step approach to achieving our goal. The first step is to have two CDR targets (concave and flat) with slits for the electron beam, forming a microwave cavity of a half length of the bunch-by-bunch spacing. In this case the radiation from preceding bunch will interact with radiation generated by the subsequent bunch because the travel distance of the radiation will be equal to the bunch spacing. However, the interaction point will be close to the upstream target in this case. The lower energy of the electron beam (γ= 84; $1/\gamma$ = 12mrad) is, the larger the intrinsic angular divergence of the scattered photons. Therefore, a significant portion of the scattered photons will be cleared by the downstream mirror. Nevertheless, it is much easier to tune the cavity and demonstrate the microwave power storage.

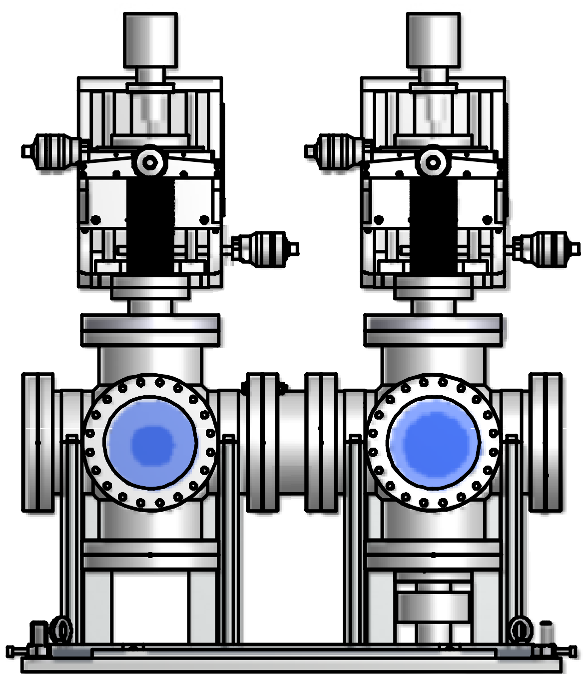

Fig. 3: General view of the microwave cavity with two manipulators

FUTURE PLANS AND CONCLUSION

The second step is to add a third mirror. Two mirrors will be used to generate CDR photons (flat and concave) and the third one will be a movable concave mirror attached to the side of the vacuum chamber. The total length of this cavity will be equal to the bunch spacing and CDR photons produced by the odd bunches will be scattered by the even ones. Since the collision point is very close to the 2^{nd} flat CDR target one can expect low losses in UV and soft X-ray due to target aperture cut and lower collision angle.

The first step realization is scheduled for June-July this year. The hardware has already been ordered and expected to be delivered in June.

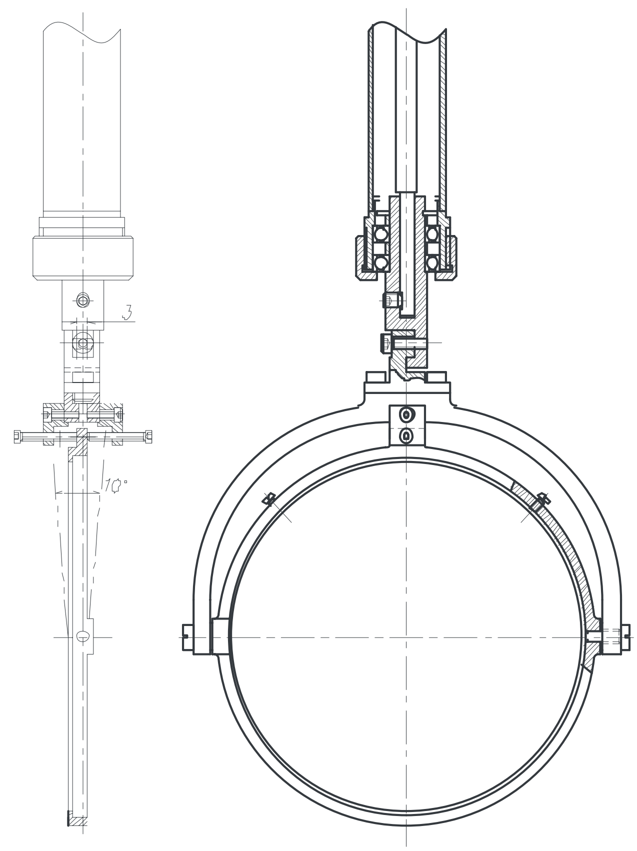

Fig. 4: General design of the vacuum mirror mount

ACKNOWLEGEMENTS

The work was carried out with the partial support from the "Grant-in-Aid for Creative Scientific Research of JSPS (KAKENHI 17GS0210)" project and Quantum Beam Technology Program of the Ministry of Education, Science, Sports, Culture and Technology of Japan (MEXT) and grant No. 1.81.2006 of the Ministry of Education and Science of Russian Federation.

REFERENCES

[1] A. Aryshev, A. Araki, M. Fukuda, P. Karataev, et. al. "Development of microwave and soft X-ray sources based on coherent radiation and Thomson scattering", RREPS-09 proceedings, to be published in "Journal of Physics: Conference Series".

[2] A. Deshpande, et al., NIMA, 600 (2009) 361-366.

[3] M. Fukuda et al., NIMA. to be published "Upgrade of the accelerator for the Laser Undulator Compact X-ray source (LUCX)".