Compact X-ray source at STF (Super Conducting Accelerator Test Facility)

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Abstract. KEK-STF is a super conducting linear accelerator test facility for developing accelerator technologies for the ILC (International Linear Collider). We are supported in developing advanced accelerator technologies using STF by Japanese Ministry (MEXT) for Compact high brightness X-ray source development. Since we are required to demonstrate the generation of high brightness X-ray based on inverse Compton scattering using super conducting linear accelerator and laser storage cavity technologies by October of next year (2012), the design has been fixed and the installation of accelerator components is under way. The necessary technology developments and the planned experiment are explained.

1. Introduction
Evolution of photon source, which is an X-ray source based on accelerator and laser technologies, indicates the necessity of a stronger and brighter photon beam according to following equation:

$$\text{Brightness} = \frac{\text{photons/ sec}}{(\text{mrad})^2 (\text{mm}^2 (\text{source} - \text{area})) (0.1\% \text{ spectrum} - \text{width})}.$$ (1.1)

The 10 µm size of photon source is considered, which means 1.0 mm mrad normalized emittance of the 40 MeV electron beam at the interaction point between electron and laser beams. Also, a 1 mrad angular spread collimation to achieve a 1% energy spread X-ray means small energy spread of the electron beam.

The main purpose of the test facility for the Quantum Beam Technology Program (QBTP) is to develop technologies for next generation compact high brightness X-ray sources using super conducting RF acceleration techniques. The characteristics of this facility are its compact size of less than 10 m total length, monochromatic energy spread less than 1%, higher flux of 100 times compared to compact normal conducting X-ray sources which can generate a flux of $10^{10}$ photons/sec/1% band width, high brightness corresponding to 2.5 generation photon factory which generates $10^{17}$ photons/sec mm$^2$ 0.1% bandwidth X-ray, and ultra-short pulse X-ray of about 40 fs using 30 fs TW laser pulse and inverse Compton scattering with 90 degrees crossing angle [1].

2. Purpose
There are many applications for this compact high brightness X-ray source, including genome structural analysis, evaluation of nano-material and precise fine X-ray imaging.
The impacts of compact high brightness X-ray are as follows:

1) The performance of a second-generation photon factory is obtainable within a 10 m laboratory.

2) Sub-ps eX-rays can be obtained in 10m laboratory, which makes research for fast dynamic phenomena possible. Chemical reactions in solvents, functions of proteins, the destruction by impulses and the phase transition induced by photons will all be researched using this X-ray source.

3) To solve energy and environmental problems it is necessary to detect isotopes in radioactive nuclear waste. If we can use 300 MeV ERL (energy recovery linac) or a small storage ring with a ring circumference of about 30 m, r -ray with a high brightness of 1 to 5 MeV can be generated to diagnose precise components of nuclear waste [2].

The purpose of this project is to demonstrate the feasibility of the above applications by developing advanced accelerator and laser technologies.

The test accelerator for QBTP is under construction at STF. The three dimensional layout for this test facility is shown in figure1. It will be completed by March of 2012. The beam operation will start from spring in 2012. However, since the design for the collision scheme for inverse Compton scattering was recently changed from a 10 degrees crossing angle to a head-on collision, the set-up of the laser system will be delayed by about three months. Yields of X-ray photons will be increased by factor of about 5 compared to the former collision schemes and the beam collision and the setup of the detector system for X-ray imaging will become easier.

**Figure 1.** Layout of QBTP Test Accelerator.

### 3. Status of basic technologies

Generation of an ultra low emittance electron beam by photo-cathode DC electron gun is under development. So, we decided to use an L-band photo-cathode RF gun for the 5 Hz 1ms pulse beam operation in 2012. We manufactured two sets of the L-band photo-cathode RF gun, one is the old type of DESY Flash and other is modified one of the water cooling channels [3-5].

A compact RF Source has been developed as the Distributed RF Source (DRFS) for ILC (International Linear Collider) application with synergy of ILC group. ILC Baseline RF unit consists of one modulator, 10 MW klystron, PDS (power distributed system), three cryo-modules that include 26 9-cell SC (Super Conducting) cavities. We at KEK proposed a DRFS scheme that consists of one small modulator, 800kW klystron and two 9-cell SC cavities. A compact RF source has to have high reliability for ILC. Four manufactured 9-cell super conducting cavities have been operated at the
highest accelerating gradient of 35 MV/m without the electron beam. We are assuming an accelerating
gradient of 30MV/m with the beam for next year’s operation.

We will use a 4 mirror optical cavity to accumulate the laser pulse and make the laser focus. Recently, we found a new method of fast switching for circularly polarized X-rays when three dimensional 4 mirror optical cavity is applied for the laser accumulation [6]. Also, we found a new laser storage scheme, so called ‘self-starting oscillator scheme’, and are developing a fiber laser system. A planar 4-mirror optical cavity will be made for QBTP test experiment because of its simplicity. The laser evolution is same in the tangential and sagittal plane of new planar 4 mirror optical cavity. Two laser pulses circulate with a spacing of 6.15ns in this ring optical cavity.

Figure 2. Layout of the inverse Compton scattering area for QBTP.

WFS (Wave Front Sensing) feedback will be used for the stabilization of this 4 mirror cavity. Figure 2 shows the area near the beam collision point for QBTP, which has a beam monitor screen, two sets of 20 degree bending magnets and a planar 4-mirror cavity system.

The laser system development for the laser oscillator and amplification is based on the fiber laser and LD (Laser Diode) burst amplifications. The injected laser power into the optical cavity will be about 1kW average power in 1ms pulse period. The 200W average power of the mode locked laser will be developed for the compact ERL project by the synergy with KEK-ERL group.

4. Perspective
We started the R&D for 30 MV/m 9-cell SC cavity from September 2008. Subsequently, the R&D for the stable operation of the SC cavity and the compact RF source system (DRFS) was started from October 2009. We established the technology on 30 MV/m 9-cell SC cavity by December of 2010 and the final fabrication for two 9-cell SC cavity system was ordered. Now, we have completed the final gradient test and two cavities have been installed into the cryo-module for the beam acceleration test at STF. We are aiming for the stable pulsed beam operation for the generation of high brightness X-ray at STF in 2012. Table 1 shows the comparison of the operation parameters for QBTP and ILC-STF
Phase2. After 5 Hz pulsed operation for the high brightness X-ray generation will be finished, the laser system including the optical cavity will move to the compact ERL facility in 2013 assuming the following the electron beam conditions will be achieved: beam energy: 35-65 MeV; average current: 10 mA; emittance: 1.0 \pi mm mrad.

| Operation Parameter for Quantum Beam | Operation Parameter for ILC-STF Phase2 |
|--------------------------------------|---------------------------------------|
| Pulse length                         | 1 ms                                  |
| Repetition rate                      | 0.9 ms                                |
| Bunch Spacing                        | 5 Hz                                  |
| Total charge/pulse                   | 6.15 ns (162.5MHz)                    |
| Number of bunch/pulse                | 369.27 ns (2.708MHz)                  |
| Bunch charge                         | 162500                                |
| Bunch charge                         | 2437                                  |
| Bunch charge/pulse                   | 62 pC                                 |
| Total charge/pulse                   | 3.2 nC                                |
| Beam current                         | 10,000 nC                             |
| Beam current                         | 7,798 nC                              |
| Beam current                         | 10 mA                                 |
| Beam current                         | 8.7 mA                                |
| Bunch length                         | 12 ps (Laser, FWHM)                   |
| Bunch length                         | 10 ps (Laser, FWHM)                   |
| Max. beam energy                     | 50 MeV                                |
| Max. beam energy                     | 21.5 MeV                              |
| Beam power                           | 2.5 kW (50 MeV beam)                  |
| Beam power                           | 0.8 kW (21.5 MeV beam)                |
| Beam power                           | Usually 2.0 kW (40MeV)                |

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