PROPOSAL OF 6 GEV ENERGY RECOVERY LINAC HYBRID MACHINE

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Abstract

6 GeV energy recovery linac (ERL) is proposed as a hybrid machine of a high intensity gamma-ray for the international linear collider (ILC) polarized positron source and a high brilliance hard X-ray light source for photon science. It is feasible because ERL based on continuous wave (CW) superconducting (SC) linac enables us to deliver simultaneously short electron bunches and an extremely low emittance beam at high repetition rate.

The intense gamma-ray is generated by the inverse Compton scattering (ICS), in which coherent synchrotron radiation (CSR) from short bunches stacked in an optical cavity instead of the external laser. In addition, the CW SC linac accelerates the 5 GeV electron beam for the conventional positron source and other 5 GeV polarized electron beam and positron beam for the ILC damping ring. On the other hand, the hard X-ray undulator light source can be installed in the additional recirculation loop of 1~2 km. This proceedings shows the schematic layout, photon output parameters, and the beam optics in the linac, in which the multi energy electron beams are accelerated/decelerated.

INTRODUCTION

KEK has some future plans such as ILC for the high energy physics and ERL for the photon science. To construct, fabricate and operate the 30 km long SC linac, a few GeV class ERL can be a good test machine because the superconducting accelerating cavity is the common key component for the both projects. Therefore the collaboration is built in KEK even in the different operation mode; 1ms pulse and CW operation.

On the other hand, one of the technical development issue of ILC is the polarized positron source produced by the polarized 10 MeV gamma-ray. The baseline is the undulator scheme with 150 GeV electron beam. The most serious problem is the heat load of the target because the high energy beam is provided only by 1 ms pulse duration with 5 Hz. Therefore, some other schemes are proposed [1]. One is a conventional electron driven positron source. It is considered to be feasible in the present technology, however, the positron is unpolarized. Another one is based on the laser Compton scattering for the gamma-ray generation, in which the electron energy is a few GeV. Storage ring and ERL are candidate for the electron accelerator. In this scheme, the polarization is good, however, the intensity of gamma-ray isn't enough in the present technology. Both schemes can provide the positron with quasi-CW or long pulse duration to reduce the heat load.

We proposed another scheme based on the CW SC cavity in this presentation. It works as both schemes, the conventional positron source and the polarized gamma-ray source by ICS. The polarized electron beam can be also accelerated for the damping ring because both damping ring are located at the same tunnel as shown in Fig. 1. Furthermore, the CW SC can provide for the extremely low emittance electron beam for the high brilliance hard X-ray by adding another recirculation loop for the insertion devices.

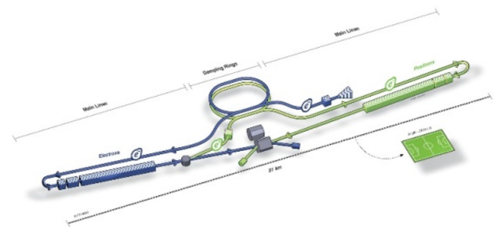

Figure 1: Schematic figure of layout of ILC.

POSITRON SOURCES BASED ON CW SUPERCONDUCTING CAVITY

Inverse Compton Scattering by CSR for Gamma-ray Source

CSR is expected to be the strong light source at the wavelength much shorter than the bunch length. Therefore, we proposed ICS induced by CSR instead of the external laser for the intense gamma-ray source [2-3]. The basic concept is that the following electron beam collides with the CSR reflected by the mirror. If the longitudinal jitter is much smaller than the CSR wavelength, the electron bunch train interact the electrical field of CSR in the optical cavity. We call it "coherent stacking". The mechanics is similar to the excitation of the free electron laser (FEL). However there are some differences. The energy exchange is proportional to the first order of the electrical field because the bunch length and the jitter is much smaller than the wavelength. Then the induced energy spread is expected to be smaller than the amount of the energy exchange. To increase the intensity of CSR, the high finesse optical cavity is utilized as the same manner as the external laser scheme. ERL is powerful tool for this purpose because it can provides the short electron bunch with the high repetition rate and no effect

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of the degradation of the electron quality due to ICS leave in the following collision.

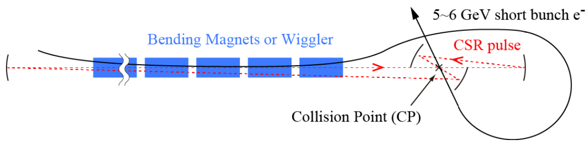

Figure 2: Schematic figure of the optical cavity for CSR-ICS.

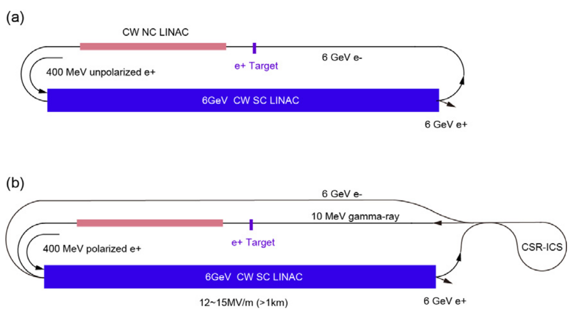

Figure 3: Rough sketches of (a) conventional positron source and (b) polarized positron source at CSR-ICS scheme.

Figure 2 shows the schematic figure of the optical cavity and the electron orbit. After the short electron bunches exchange the energy, they come back into the optical cavity to collide with the CSR pulse. In this scheme, the positron number is expected to achieve 10^8 particle per pulse with quasi-CW pulse at 3 MHz. It satisfies the requirement of ILC specification with the hundred stacking at the damping ring. The electron charge is 3 nC/bunch, therefore, the average electron current is limited under 10 mA by the HOM heat load of the SC cavity.

Two Schemes of the Positron Source

The rough sketches of the two positron source schemes are shown in Fig. 3. The conventional positron source scheme also utilizes 5-6 GeV electron beam as well as CSR-ICS scheme [4]. The acceleration field of CW SC cavity (~15 MV/m) is almost the half of those of the pulse SC cavity (~30 MV/m) and the normal conducting cavity (~25 MV/m). Although the length CW SC linac is doubled, the same linac is also utilized for acceleration of the positron injecting to the 5-6 GeV damping ring. Before accelerating the positron beam in the SC CW linac, it is accelerated up to 400 MeV by the CW normal conducting cavity, in which the acceleration field is very low. The peak current is less than 1 mA. It can be upgraded for polarized positron source as shown in Fig. 3 (b) by adding the extra loops. The scheme of Fig. 3 (a) is operated without energy recovery while Fig. 3 (b) needs the energy recovery.

HIGH BRILLIANCE HARD X-RAY LIGHT SOURCE BASED ON ERL

The average electron current is limited by HOM-BBU threshold and HOM heat load of the SC cavity [5]. At CSR-ICS scheme, the beam current is less than 10 mA although the heat load is larger than a hundred watt. On the other hand, the heat load of 10 mA for the X-ray light source is a few watt because the electron charge is less than 10 pC/bunch at 1.3 GHz. That is why it is possible to simultaneously provide the additional electron beam for x-ray source. Figure 4 shows the example of the brilliance spectra of 30 m long undulators. The undulator radiation with reasonable undulator period at the first order covers 10 keV because the electron energy is 6.5 GeV. The normalized transverse emittance and the energy spread is 0.1 mm-mad and 5e-5 at the electron in this case. The natural emittance of 8 nm-rad satisfies the diffraction limit at 10 keV. The extremely high brilliance of 10^{23} phs/s/mr^2/mm^2/b.w. 0.1% is achieved with the helical undulator. In the case of the linear undulator, the brilliance at higher order keeps as the same level of the first order thanks to the low energy spread.

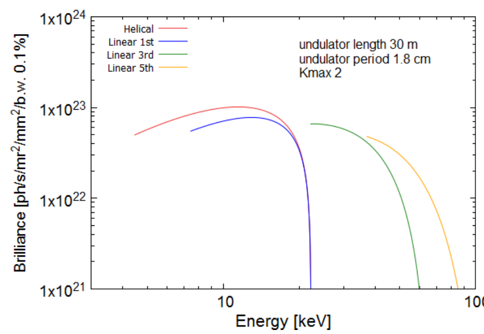

Figure 4: Example of the brilliance spectra calculated by SPECTRA [6]. Betatron function is 5 m, in which 30 m long undulator composes of six 5 m undulators.

PROPOSAL OF 6 GEV ERL

Lattice Layout

Both polarized positron source with CSR-ICS and the high brilliance X-ray are based on 6 GeV ERL. The former is off crest acceleration because a bunch compression is necessary for the intense CSR. On the other hand, the latter is on crest acceleration to minimize the energy spread. The maximum electron energy after the full acceleration is different, 5.7 GeV and 6.5 GeV even in almost the same injection energy, 10 ~ 20 MeV. Therefore the two electron orbit can be separated by a DC bending magnets.

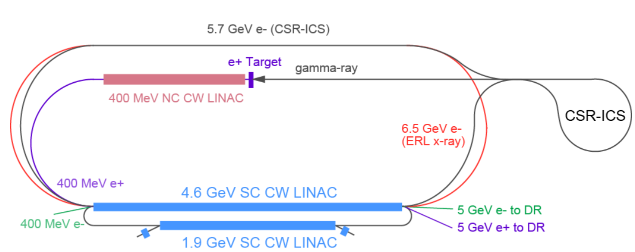

Figure 5: Schematic figure of 6 GeV ERL for hybrid operation.

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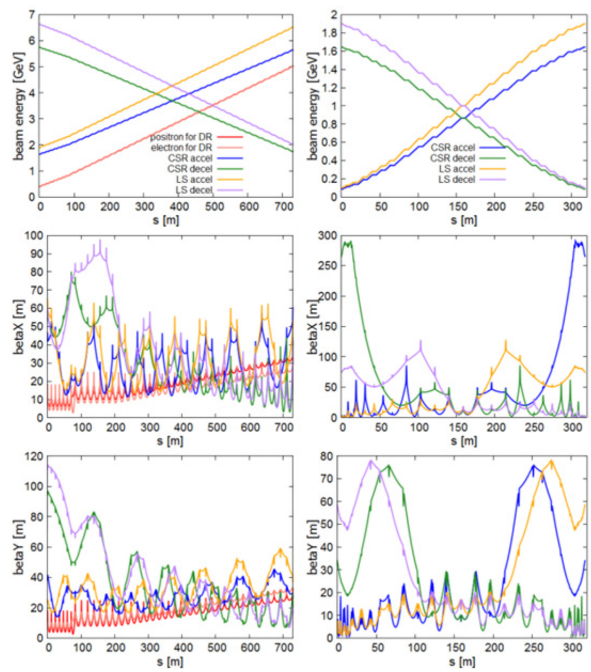

Figure 6: Beam energy and betatron function of multi beam in 4.6 GeV linac (left) and 1.9 GeV linac (right). They are simulated with SAD [7].

There are two reasons to choose the Matryoshka type as shown in Fig. 5. One is to reduce the site area of the recirculation loops. Another reason is to suppress the rms transverse beam size of the positron beam at the large normalized emittance close to 0.01 mrad. The focus strength should be optimized for the positron beam otherwise the rms size becomes larger than the aperture of the SC cavity. Therefore the electron beam at the lower energy from 10 MeV to a few GeV transports another linac. This is why the 6 GeV ERL composes of the two linacs of 4.6 GeV and 1.9 GeV. The 4.6 GeV linac accelerates the polarized electron beam as well as the positron.

The recirculation loops share the tunnel with the dumping ring, in which the circumference is 3.2 km and the shape is a race track type. The total length of the two arc section for the insertion devices is approximately 1 km. The lattice layout of the recirculation loop is based on the triple banding magnet with the two triplets [5]. It is similar to the 3 GeV ERL design except the bending radius. It is approximately 80 m to keep the low emittance from increasing by the quantum excitation at 6.5 GeV. It is possible to share the transport line of the both 6.5 GeV and 5.7 GeV beam in the long straight section, in which no insertion device is installed.

Linear Optics in the SC Linac

The 4.6 GeV SC linac also accelerate the polarized positron and electron beam for the damping ring. Therefore the six beams with different beam energy transport in the 4.6 GeV linac and the four beams transport in the 1.9 GeV linac. Basically the betatron function is optimized for the minimum energy beam because the quadrupole strength is in inverse proportional the beam energy. Each beam energy and betatron function is shown in Fig. 6.

In the 4.6 GeV linac, the betatron function is optimized to reduce the rms beam size of the positron beam as described in the previous section. To supress the betatron function at the energy region lower than 800 MeV (s < 80 m), the triplets are inserted every four cavities. On the other hand, the triplets are inserted every right cavities in the downstream. The betatron function gradually increases from s = 200 m, otherwise the other two deceleration electron beams are out of control. The maximum rms beam size of the positron beam in the SC cavity is approximately 10 mm.

The lattice is more complicated in the 1.9 GeV linac. The triplets is inserted every cavity at the first four cavities and is inserted every four cavity at the following 16 cavities. The following triplets are inserted every eight cavity and the triplets at the end of the 1.9 GeV linac is symmetrically located. Some triplets is in cryostats. Thanks to this layout, the betatron function can be supressed down to 1 m at the cavity in the low energy region. It might help to increase the threshold current of ERL and reduce the rms beam size after CSR-ICS.

CONCLUSION

We proposed the 6 GeV ERL as the hybrid machine which provides the positron source, the polarized electron and positron driver for the damping ring and the hard X-ray light source. The scheme of CSR-ICS is expected to provide the quasi-CW polarized positron beam without huge heat load of the target. The conventional positron source is feasible as a backup system. Furthermore the insertion devices can be installed in the additional recirculation loop. The brilliance achieves up to 10^{23} phs/s/mr^2/mm^2/b.w. 0.1% at 10 keV.

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