FEASIBILITY STUDY OF A COMPACT SUPERCONDUCTING WAVELENGTH SHIFTER AT SRRC

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Abstract

In order to increase the critical photon energy of the synchrotron radiation from the SRRC storage ring, a compact 6 Tesla Superconducting Wave-Length Shifter (SWLS) has been designed and is under construction. In this device, a warm magnet gap of 20 mm and a 1.5 W Gifford-McMahon type cryo-cooler have been adopted to achieve a beam-dynamics-friendly and liquid-helium-free operation. Since there is no long straight section available in the storage ring for accommodating the SWLS, a feasibility study on the installation of this device between the two kickers located in the injection straight section has been carried out.

1 INTRODUCTION

The main purpose of the SWLS is to increase the characteristic energy of producing photon beams. The characteristic energy is proportional to the magnetic field strength of the wavelength shifter. Since the allowable length in this straight section for accommodating the wavelength shifter and its associated electron BPMs, flanges, and RF impedance tapers is 835 mm, the net length of the wavelength shifter including its cryogenic vacuum vessel is only 610 mm. The magnetic circuit design, field calculations, force analysis, cryostat design, and the heat load analysis of this compact three-pole SWLS were completed [1]. The dimension of magnetic circuit was modified a little bit in this paper.

Since the SWLS will locate near the down-stream between two kickers of the injection straight section. Therefore, the Bata function $\beta(s)= \beta_0+s^2/\beta_0$ in the location of the SWLS will be larger than that in the center of the straight section. The vertical gap should be larger than that in the middle of the straight section to increase the vertical acceptance. In our design, the vertical inside dimension of the electron beam pipe needs to be at least 20 mm because of beam dynamic aperture and the injection efficiency, the actual magnet gap was set at least 55 mm after taking into account the space for the thermal shielding and vacuum duck of the warm bore. Considering the limitations of the length and the large gap, we tried to design a center pole with a maximum peak field of 6.5 T (the nominal operation was set at 6 T in order to obtain a photon critical energy of 9 keV). This paper covers issues related to the magnet design, interface between the SWLS beam duct and taper vacuum tube, the RF impedance, and beam dynamics.

2 MAGNET DESIGN

The design of the cross section structure of the magnet main part including the superconducting coil and pole with yoke as well as the flux return of yoke is shown in Fig. 1. The calculation results of the roll-off on the central pole and the good field region of the integral field strength by the Radia Code [2] are shown in Fig. 2. The peak field strength of 6.0 T is obtained by exciting the current density of 137.5 A/mm^2 and 138.5 A/mm^2 on the central and side coil, respectively. The SWLS is a special liquid helium cryostat, which consists of the aluminum alloy Al 6063. A vacuum insulation is required between

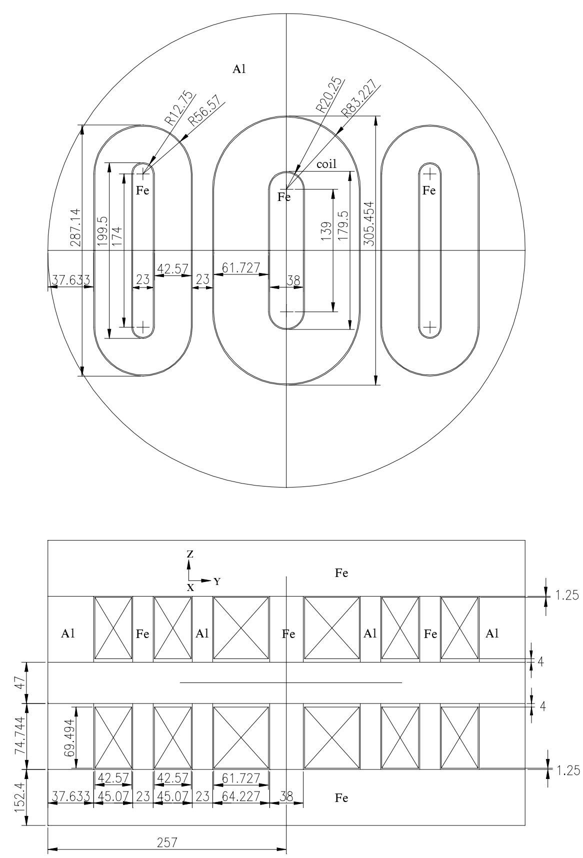

Figure 1: Top view and side view of the cross section structure of the magnet.

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helium vessel and an external aluminum alloy Al container. The SWLS is cooled by the two stages of a 1.5 W SUMITOMO cryocooler, with a water-cooled compressor. Because of a little vibration come from the cryocooler on the SWLS, therefore, a supporter with vibration damper was designed for supporting the cryo-cooler. However, 40 liters of liquid helium and 10 liters of liquid nitrogen are provided for emergency backup. Two transfer lines are supplied to transfer liquid into helium and nitrogen reservoir, respectively. A field strength 6.0 T caused a 1.5 GeV electron beam to make the maximum wiggle amplitudes of 8.5 mm and angular changes of ± 60 mrad. If consider the emitted photon from the two side poles, then due to the wiggle amplitudes, radiation in the forward direction has transversely separated source points.

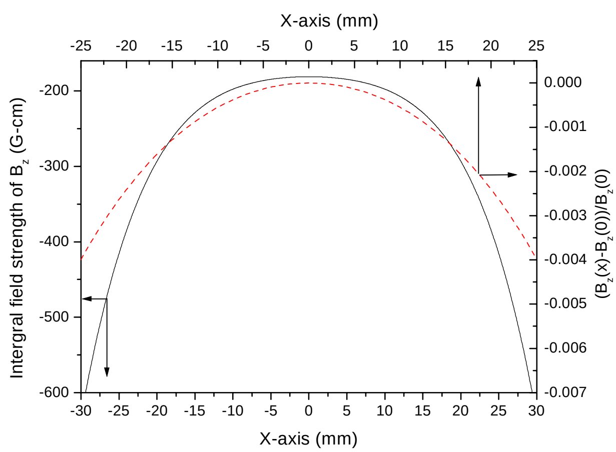

Figure 2: The roll-off on the central pole (dot line) and the integral field profile (solid line) along the transverse x-axis direction.

3 RADIATION POWER FEATURES

The wavelength shifter has three poles. However, only the central pole is useful for the users. The two end poles are just used to correct the first and second integral field strength to zero. The total power radiated by a 1.5 GeV/200mA beam in such a wavelength shifter is 2 kW. The power density distribution at the front end, which is 5 m away from the magnet, is calculated and the results are shown in Fig. 3. 90% power must be absorbed in the chamber and in the absorber of front end. Only about 10% of the wavelength shifter radiation contained in an angular range of 15 mrad is able to leave the exit chamber following the straight section.

Because of the radiation safety protection for the wavelength shifter magnet, an absorber on the RF taper at the upstream is necessary to absorb the radiation from the bending magnet. The bending radiation power density that will hit the main body of the SWLS (the SWLS is 8.1 m far away from bending magnet). Therefore, in the upstream of the RF taper need an absorber to prevent the radiation hitting the SWLS magnet. Meanwhile, the absorber on the RF taper is necessary at the downstream to protect the radiation hitting the ceramic bellow.

In addition, if 15 mrad extraction radiation is the requirement for 3 beam lines, the peak field strength will be changed by 800 G in the 15 mrad range. The critical energy variation will be in the range of (8.98±0.12) keV. Therefore, the reduced critical energy range is insignificant in the 15 mrad extraction radiation range. Meanwhile, for the enough space for the extracted beam line, the magnetic field will be in the negative parity like the field parity of the bending magnet to keep the electron beam offset to the positive transverse x-axis. Therefore, the radiation power hit on the outside vacuum chamber is larger than the inside vacuum chamber.

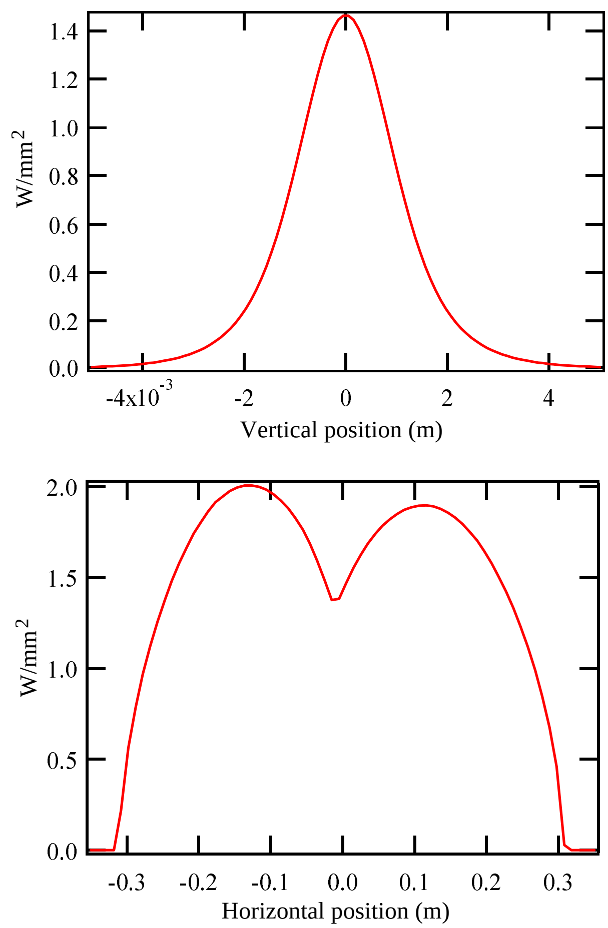

Figure 3: Power density distribution on transverse horizontal and vertical axis were calculated at the distance of 5 m from the magnet center.

4 THE TUNING SKILL

The linear effects included the closed orbit distortion, betatron tunes shift, increase energy losses per turn, emittance variation and the non-linear effect of the dynamic aperture reduction will be created after the SWLS installation. Therefore, the beam dynamic has been studied for the compensation of the chromaticity and the dynamic aperture reduction. Meanwhile, because the SWLS located between two kickers in the injection straight section, the tuning skill should be studied to keep the electron beam survived in the magnetic field ramping process. When the magnetic field ramping, the quadrupole magnet and four horizontal/vertical-combining correctors CV/CH are arranged near the SWLS were used to steer the electron orbit. The side coil supercomducting power supply was used to tune the first integral field strength and the corrector magnets were used to tune the second integral field strength.

5 THE VACUUM BEAM DUCT

In this magnet, the angular wiggle of ±60 mrad (at 6 Tesla) makes a total beam chamber with a width larger than 75 mm, which is necessary to protect the end of the magnet chamber from being hit by the radiation from upstream end pole. As the angular wiggle is very large, the absorber is necessary. The absorber is built in the RF impedance taper chamber, which includes the electron BPM, and is 0.5 m away from the magnetic field center. The beam duct with the RF impedance taper design is shown in Fig. 4. The parallel longitudinal axis between the taper vacuum chamber and SWLS main body after welding is kept within 0.38 mrad. The components on taper chamber include electron BPM, taper body, flanges, absorbers and cooling channels. The radiation photon beam is 8.5 mm offset with respect to the on-axis. Meanwhile, a 15 mrad photon flux is necessary for the three beam line requirement. Therefore, the absorber design has to take into account the photon beam offset. For cooling efficiency, all materials are suggested to adopt the extruded aluminum alloy Al 6063 except the electron BPM. Two pairs of BPM located at the top and bottom sides of the taper chamber. In order to minimize the complexity of alignment and e-beam welding, they are connected to the taper chamber via mini-flanges with helico flex to replace the gasket. The presence of two ceramic bellows between the SWLS in which the flexibility space between the two flanges is only 835±1 mm for accommodating the main body of the SWLS. Therefore, the precision installation and the adjustment of the SWLS in the tunnel become important.

6 THE BEAM DYNAMICS EFFECT

The focusing effect in the horizontal plane due to the transverse field variations whereas in the vertical plane the edge focusing effect will be significant. In order to keep the deflection angle and focussing strength identical to the sinusoidal function, we need to find the equivalent length and the bending radius. We used the hard edge model, the equivalent length and the bending angle, to simulate the SWLS impact on the bare lattice. For each pole of the SWLS is simulated by one hard edge magnet with proper magnetic field scaling. One full-strength pole (6T) is assumed to be modeled between two half-strength poles (4T). The multipole components for the SWLS, according to the specification, are placed at the center of the SWLS. The dynamic aperture on the horizontal axis is reduced by 20% when compared with the bare lattice in the horizontal direction. However, on the vertical axis, the dynamic aperture showed no significant change [3]. The dynamic aperture reduction on the horizontal axis is mainly due to the octupole field strength. The vertical tune shift and the distortions of the β_y function can be estimated by using perturbation method. The tune shift is inverse proportional to the square of beam energy and evaluated by MAD, using the hard edge model with the equivalent length and the bending radius to simulate the linear optics effect, is 0.05144 [3].

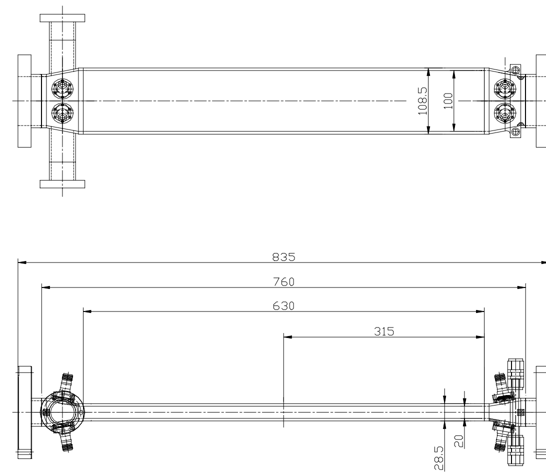

Figure 4: The front view and top view of the superconducting wavelength shifter chamber. The components include (1) flanges, (2) electron BPM, (3) taper body, (4) absorbers, and (5) cooling channels.

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