Superferric Wigglers for CESR-C

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About 20 m of 2 T wigglers will be needed to provide adequate damping for low energy operation of CESR. The wigglers will be seven-pole superferric devices, with a 78 mm gap and packaged in 1.33 m lengths. The period must be at least 40 cm, to provide sufficient vertical dynamic aperture. A short three pole model wiggler has been built, and a full scale seven pole prototype will be fabricated and tested this fall.

1. Introduction

A proposal [1] is being developed to operate CESR in the range of 1.5-2.1 GeV beam energy, in order to study charm and QCD physics. The natural damping at this energy is quite weak compared to that at 5.2 GeV, and the equilibrium emittance is too small for collider operation. To provide additional damping and to increase the emittance, superferric wigglers have been proposed to be placed into the CESR lattice.

2. Requirements on Wiggler Field and Length

The transverse damping rate τ_x^{-1}, rms horizontal equilibrium emittance ε_x, and rms relative energy spread σ_E, for a wiggler-dominated machine, are given by the following relations:

$$\tau_x^{-1} \propto L_w B_w^2, \tag{1}$$
$$\varepsilon_x \propto B_w \mathcal{H}_w, \tag{2}$$
$$\sigma_E \propto \sqrt{B_w}, \tag{3}$$

in which B_w is the wiggler peak field, L_w is the wiggler length, and $\mathcal{H}_w$ is related to the lattice functions at the wigglers. To maximize the damping rate for a given wiggler length, one would like a high magnetic field. However, for operation on pretzel orbits, aperture restrictions in CESR limit the rms relative energy spread to $\leq 8 \times 10^{-4}$. From Eq. (3), this implies that B_w must not exceed 2.1 T at 1.9 GeV. With this field, a wiggler length of about 20 m gives a transverse damping time at 1.9 GeV of about 50 ms, roughly twice that of normal CESR operation at 5.2 GeV. The 20 m length will be realized by building 14 identical wiggler modules, each 1.33 m in length (slot length 1.7 m). Free space in two short straights will be used; in addition, several CESR dipoles will be reworked to make additional space. This will allow 7 wigglers to be placed on each side of the IR.

3. Requirements on Wiggler Aperture and Period

The magnet gap must be sufficient to accommodate the (warm copper) CESR vacuum chamber. This requires a gap of about 78 mm. The horizontal width of the magnet must be sufficient to provide good field quality over the aperture explored by the pretzel orbits (about 2 cm). This requires a horizontal pole width of about 24 cm.

The choice of wiggler period is dominated by the need to minimize the effects of the wigglers on the machine's dynamic aperture. In a Cartesian coordinate system, with the z axis along the

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beam, and the y axis vertical, the magnetic fields of an ideal wiggler (i.e., infinite in the x and z directions) of period $\lambda = \frac{2\pi}{k}$ are given by

$$\begin{aligned} B_y(y,z) &= \sum_{n\,odd} B_n \cos nkz \cosh nky, \\ B_z(y,z) &= -\sum_{n\,odd} B_n \sin nkz \sinh nky, \end{aligned} \tag{4}$$

in which B_n are harmonic coefficients. In the paraxial approximation, the solution to the x equation of motion for a particle of momentum p and charge e leads to the following solution for the x angle:

$$x' \approx -\sum_{n\,odd} \frac{eB_n}{nkp} \sin nkz \cosh nky. \tag{5}$$

This describes the "wiggle" motion of the particle. The y equation of motion, in the paraxial approximation, is

$$y'' = \frac{-ex'}{p}\left(-B_z + y'B_y\right). \tag{6}$$

Substituting Equation (4) and Equation (5) into Equation (6) gives

$$y'' = \frac{e^2}{2kp^2} \sum_{n\ odd} \frac{B_n^2}{n} \cosh nky \sinh nky \approx \left(\frac{e}{p}\right)^2 \left[\frac{y}{2} \sum_{n\ odd} B_n^2 + \frac{y^3}{3} k^2 \sum_{n\ odd} B_n^2 n^2 + \ldots\right] \tag{7}$$

The linear term in y, analogous to the vertical edge focusing in a conventional dipole magnet, causes a tune shift of about -0.1 per wiggler. The cubic nonlinearity, which is quadratic in k, causes a tune spread with amplitude. This has serious consequences for the vertical dynamic aperture. To mitigate this effect, the period has been λ has been chosen to be 40 cm. Increasing λ further makes it difficult to obtain good field quality in the horizontal direction, and makes the radiation masking problem more difficult.

4. Wiggler design

4.1. Cold mass

The 40 cm period, together with the 2.1 T required field and the 7.8 cm gap, dictate the choice of superferric magnet technology. To begin the technology development, a short three-pole wiggler model with a 20 cm period has been built. The model is designed to achieve 2.1 T at about 150 A, with an 80% operating margin. The 600 turn coil for this device has dimensions of about 2 cm by 2 cm and uses formvar-coated 0.6 mm diameter round superconducting strand. The coils are wound with wet epoxy around the iron pole and cured in air. After fabrication, the coils are assembled with the yokes onto stainless steel plates, extending the full length of the magnet, to form the top and bottom halves of the cold mass. One of the fabricated coils is shown in Figure 1, and the completed three-pole model cold mass (without the He vessel) is shown in Figure 2.

For quench protection, individual coils within the wiggler will be isolated using shunt diodes or resistors within the cryostat. Isolated coils can fully absorb their own energy without damage. Each wiggler will also be bypassed by an external dump resistor, to be switched in upon quench detection. This will remove roughly half of the stored energy from the cryostat.

The three-pole model will be quench tested and field mapped during the months of August and September, 2001. Subsequently, a seven pole full-scale prototype wiggler will be built and tested. It will use 0.8 mm diameter Fe-rich Oxford strand, with $I_c > 800$ A at 4 T and 4.2 K. The end poles will have trim coils for orbit adjustment.

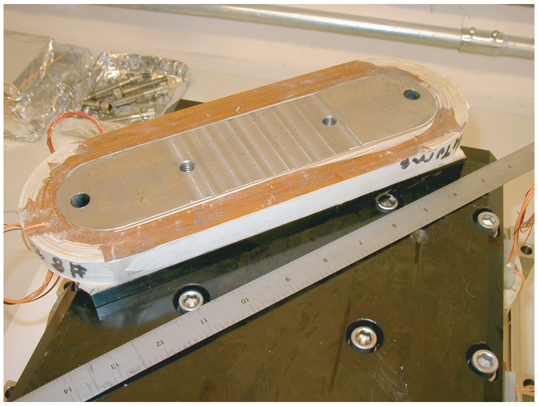

Figure 1: Coil fabricated for the three-pole model

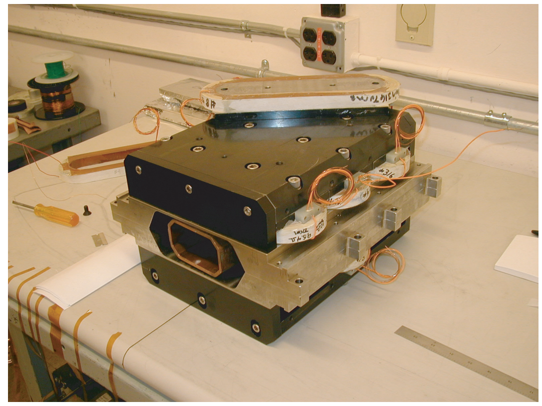

Figure 2: Complete three-pole model cold mass

4.2. Cryostat

All wiggler modules will have identical cryostats. The cold mass will be supported in the cryostat using 8 carbon-fiber straps. The power leads will use commercial high temperature superconductor to minimize the heat leak. The estimated total refrigeration power required for all 14 wigglers (at 4 K) is less than 100 W. Figure 3 shows a two dimensional layout of the cryostat, and Figure 4 shows a three-dimensional model of the cryostat in the tunnel.

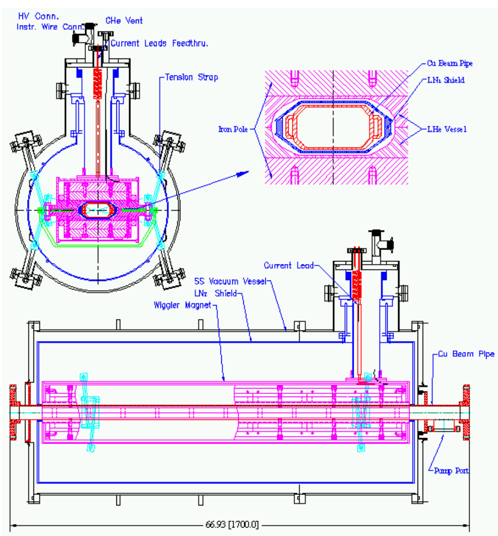

Figure 3: Two dimensional layout of the prototype wiggler cryostat

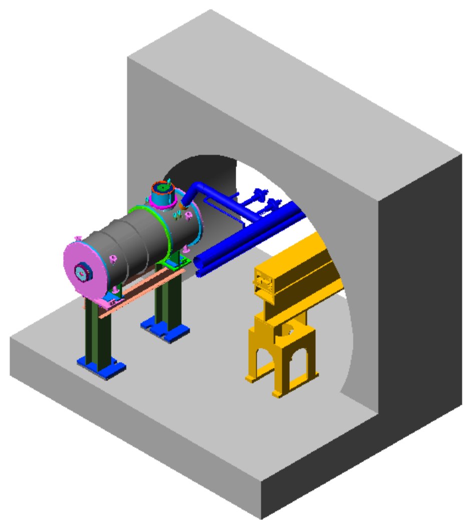

Figure 4: Three dimensional model of the 1.7 m long cryostat in the tunnel

5. Cryogen Distribution

Cryogens will be supplied from the CESR central refrigerators (capacity 1800 W) through 100 m long new transfer lines in the tunnel. (See Figure 4). The new transfer lines will tee off from the satellite valve boxes at the existing superconducting rf (SRF) cavities. They will be assembled in 5 m units, and will carry 1.5 g/s of LHe in operation.

The expected total operational load on the central refrigerators will be the existing SRF cavities (700 W), the new IR quadrupoles (200 W), and the wigglers (100 W). Additional SRF cavities may be added at a later date.

6. Wiggler Radiation

Each wiggler will radiate about 3 kW of power forward and backward, with a maximum horizontal angle of about 22 mrad. The critical energy is about 5 keV. Most of this radiation will hit the water-cooled outer wall of the dipole chambers. However, because of the large opening angle, some of the radiation may hit the uncooled inner wall of the dipole chambers. Estimates of the resulting thermal stresses indicate they are tolerable in most cases. Water-cooled masks at wiggler cluster ends may be needed in some cases.

References

[1] D. Rice *et al.*, in *Proceedings of the 2001 Particle Accelerator Conference* (2001), p. 315.