IMPROVEMENT OF SC WIGGLER PERFORMANCE

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Abstract[1]

Described is a methodology of improvement for good field region in a SC 2.1 T CESR's wiggler as example. The method includes a tapering, shimming and pole face winding with active field distribution correction. This technology can be applied to any wiggler, however.

INTRODUCTION

Development of SC wigglers at Cornell LEPP was initiated by proposal considered to modernize the CESR for the low energy operation [1]. About 16 meters total of ~2.1 T wigglers will bring CESR-c to 10^{32} level in luminosity. With installation and testing the first wiggler in CESR, the job started more than 2 years ago [2, 3] came to its end. In first run luminosity $L \geq 10^{31}$ achieved at Ψ, gives assurance, that program can be accomplished.

Here the goal is to increase emittance in contrast to the goal clamed for the damping-ring in LC: as low emittance as possible.

It was shown in [3], that physical nature of appearance of octupole (and higher) type dependence of kick versus vertical displacement is in *wiggling with angle in the pole fringe* field.

The methods found might be interesting to others and now everyone can apply them to his own wiggler design.

OPTIMAL DIMENSIONS

Wiggler for CESR operation at 2 GeV was described in [2, 3]. All calculations carried with 3D code MERMAID. Period was chosen $\lambda_w = 40cm$. For $y_0 = 2cm$, $\lambda\!\!\!^{-}_w \cong 6.37cm$, the ratio of cubic term to linear one goes to be ~0.0164 or 1.6%. Quadrupole lenses typically designed with this ratio ~ ten times better, however.

The height was chosen equal to $\cong$ 14.5 cm. It is slightly below the saturation, but saved about one inch of steel, lowering field on ~5% only.

Loading curve is chosen so that designed current is ~half corresponding crossing with the wire property one. Technology is described in [5]. To prevent coil destruction initiated by quench, passive resistors attached to each coil was suggested [2] as simplest solution.

Wiggler acts in one direction mostly, providing vertical focusing. That is why it is difficult to keep orbit closed, as the wiggling amplitude is also changes with vertical position. Maximal field corresponds to the coil which width is twice the height. Finally the coil cross section was chosen with cross section $\cong 1'' \times 0.75''$ for simplicity of winding.

Evolution of temperature inside the coil defined by heat-skin layer depth, which for ~1cm thickness gives time constant τ ~100ms, mostly defined by parameters of epoxy.

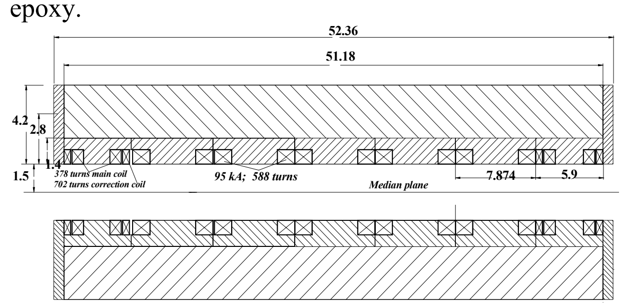

Figure 1: Dimensions of 40-*cm* period 7-pole wiggler #1. Wiggler #2 and all others have 660 turns of 0.8-mm OXFORD wire in main coil. A-turns remain the same.

TAPERING

Tapering, or variation in field strength along the wiggler, used when there is a desire to have zero (or any) average displacement of trajectory in a wiggler. Although it is likely evident, it was mentioned first in [6] however, that end poles with fields integrals ¼, -¾, +1 of regular one gives zero displacement of trajectory. If periods are the same these numbers reflect the field strengths at each pole.

This is not the only solution, however. Let us consider the series of odd numbers with reversing signs as

$$1, -3, +5, -7, +9, \ldots (-1)^k (2k-1),\ k=0,1,2,3,\ldots \qquad (1)$$

Let these numbers will represent now the nominators of fractions of the field integrals for each pole normalized to the maximal one in regular part of wiggler. So the next pole after *m,* supposed to be a main one, must have the value counted as (2*m*+1)+1, just one unit more, and opposite sign. Now one can obtain, that full integral over all wiggler will be

$$S(m) = 2\sum_{k=0}^{m}(-1)^k(2k+1) - (-1)^m(2m+2) \equiv 0.$$

One can also find that $\sum_{m=0}^{L} S(m) \equiv 0$. This means that the field first and second integrals over all wiggler are zero. For example series as +1/8, – 3/8 , +5/8, – 7/8, +1, [n(–1,+1)], – 7/8, +5/8, – 3/8, +1/8 , where fractions stand normalized to central pole integral, will also give zero angle and displacement. One can easily find the sequence of tapering for 6, 8, 10, 12, 14, 16,… , Fig. 2, and so on poles.

We called this ***adiabatic entrance***.

Once particle entered into wiggler with such tapering and began its oscillations following ~sinusoidal trajectory, there are two ways out. First is a symmetrical exit, when the sign of deflection in the last pole is the same as during

[1] Extended version is available at http://www.lns.cornell.edu/public/CBN/2003/CBN03-3/CBN03_3.pdf. Work supported by NSF.

entrance, and the second one is asymmetric one, when the kick is going in opposite direction. Obviously in first case the total number of poles is odd, in second case it is even.

One disadvantage associated with tapering is a necessity to have few different types of coils. However adiabatic entrance is useful for helical undulators having very short period for example, as exact managing the pole strength at the end is not an easy task.

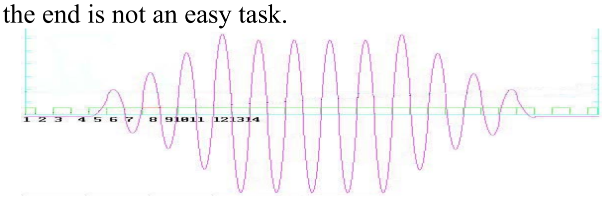

Figure 2: Trajectory of particle in a wiggler with tapering ~1/16, -3/16,+5/16, -7/16, +9/16, -11/16, +13/16, -15/16, +1. Doublet of quadrupoles envelops wiggler from each side. Same period.

Seven-pole wiggler was made with tapering ½, -1. This gives displacement $\Delta \cong \lambda_w K/\gamma$ what is amplitude of wiggling but this, first, supposed to reduce the coil types to two only and to have maximal period for reduction of nonlinearities. For eight-pole wiggler tapering is ¼, ¾, 1. Knowing the fields and having tracking code in hand one can investigate properties of wiggler model *dynamically by tracking*. For tracking special code was used [4]. This code used the field map obtained from MERMAID. Kicks, obtained by particles running across aperture with different x – coordinate remain in $\pm 50\mu$rad for all fields and *not correlated* with integrals along straight lines.

SHIMMING

To reduce nonlinear effects the pole top field must be as flat as possible. The old fashion way as shimming is also working here, despite the iron is deeply saturated.

Poles having length 20 cm, 15cm and 10 cm were developed during these years, Fig. 3. The 10 cm poles successfully used in 3-pole model [5] and are in use in 8-pole one. Width of the deeps was chosen as a half of all pole width and with simplest shape.

POLE FACE WINDINGS

Next step in flattering is active correction. So if one puts a coil on the pole surface it will generate the dipole, sextupole... field with the same symmetry. So as adjusting main current can neutralize the dipole field change, this coil can be considered as a source of sextupole. Lowering at the center is an ideal place for positioning this correction coil.

For winding the SC wire with 0.017” diameter was used. This dimension includes Capton tape wrapping and Bonadll impregnation. After winding form with coil was heated ~200°C and after cool down a solid coil obtained. The coil having 100 turns will require the feeding current of 400/100=4 A only. Poles with coils wounded and cured on the pole attached to the steel plate (Fig.1) enveloped by stainless steel cover.

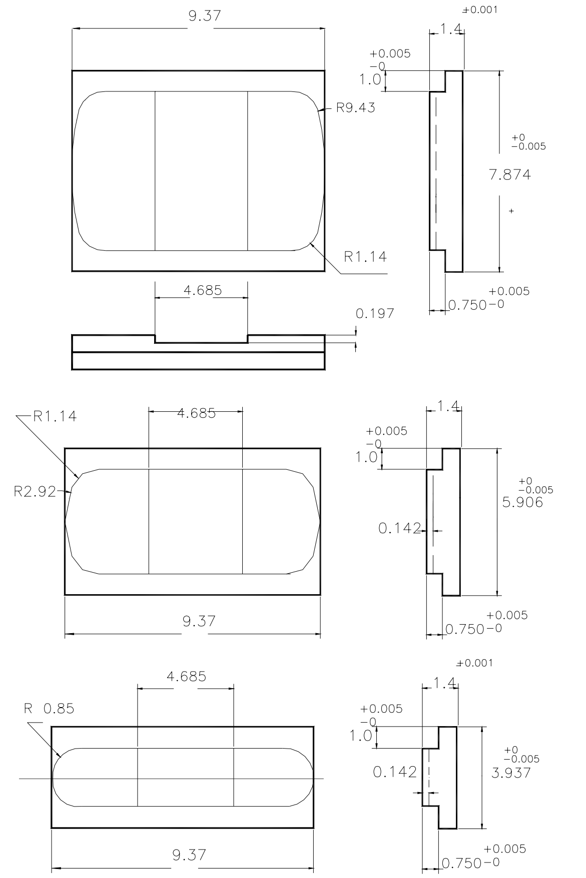

Figure 3: 20 cm, 15 and 10 cm poles developed for wigglers.

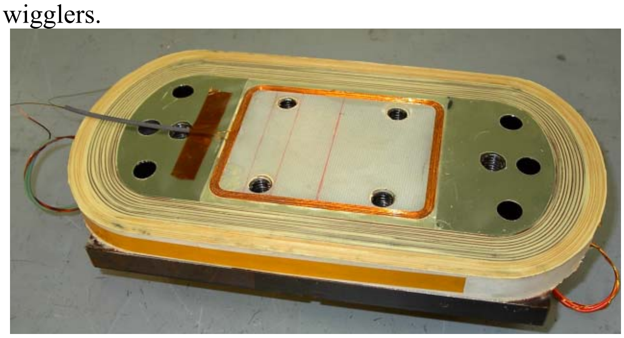

Figure 4: Pole with trim coil inserted into the lowering in groove made in G10 insertion.

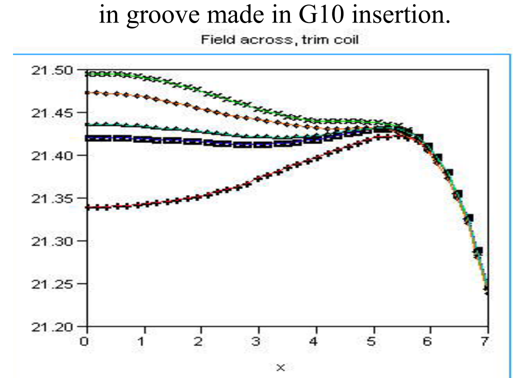

Figure 5: Field across the pole as a function of current in trim coil.I=0(up);0.1;0,4;0.5;1 kA Main feeding current is 95 kA/pole. Material of the pole is annealed Steel 1010.

MEASUREMENTS

To the moment six wigglers total were measured so far. Two of theses have seven-pole structure, four others eight-pole ones. Measurements were carried with Hall probe device F.W.Bell 6010 series. The difference in readings at the same points are less that 5G during the time of measurements. The readings stay within $\leq 1.25 \cdot 10^{-3}$ for all measurements.

Number of longitudinal points is 1060, going through 1/16″. Signal acquired at every point becomes written to the file (having 1060 data rows). Each of these files marked in association with transverse position of Hall probe in cartridge, direction of motion of the cartridge, data, when taken. Slots in cartridge have transverse period 0.625 cm, so mostly deflected from center ones running at $\pm$ 3.75 off central line.

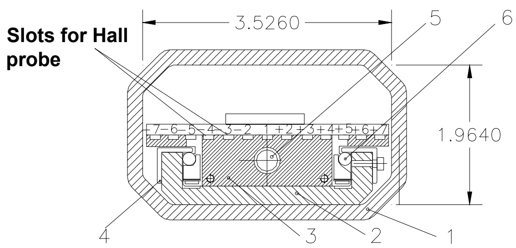

Figure 6: Hall probe cartridge assembly cross-section. 1 is the warm copper vacuum chamber with dimensions in inches, 2 is aluminum rail, 3 is a cartrige with slots for Hall probe, 4 is holding profile, 5 is a shaft with 1/16" thread, 6 represent alignment fixtures. Slots are numbered as they appear in the file descriptor.

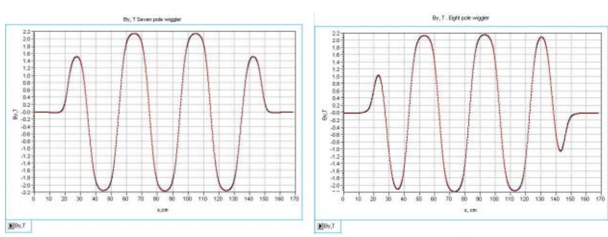

Figure 7: Measured longitudinal distribution for seven and eight pole wigglers.

According to formulas [3] the eight-pole wiggler generates 7.68/6.3 $\cong$ 1.22 times more strong integrated cubic vertical nonlinearity than a seven-pole one. The difference between calculated and measured values can be estimated as 50G *in absolute value*. Measurements conclude with a series of files with measured data along lines defined by position of Hall probe in a cartridge.

CONCLUSIONS

MERMAID demonstrated excellent possibilities for optimization and wiggler design.

Tapering in a wiggler allows having zero displacement of trajectory. It might be vital for wigglers with even number of poles, as trajectory sweeps only ~half of transverse coordinate swept without tapering. This king of procedure can be recommended for TESLA damping ring, as one can see from publications, that they use even number of poles without proper tapering.

We represented here for the first time the possible tapering laws for zero displacement of orbit in a wiggler.

Flatness of the poles need to be kept as plane as possible. This can be done either with profiling iron, either with active pole face winding.

Measurements with long coils can be considered as indicative only, as they are not related directly to dynamic properties of the wiggler. Mapping with Hall probe can be considered acceptable within accuracy ~10^{-3}. With special probes having microchip with calibration, this can be lowered in half. Such probes are available on the market now.

Implementation of *trim coils* integrated with end poles of wiggler is extremely useful for fine-tuning.

Nonlinearities in a wiggler strictly correlated with period, reversibly proportional to its square and proportionally to the square of magnetic field.

In CESR wigglers the width of poles, 24 cm were made maximal possible and was defined by the diameter of Dewar, available at that moment.

Pole face windings can be recommended for widening dynamic diapason.

Steel properties for room temperature deliver rather good approximation for such ones at liquid Helium temperature.

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