

VIBRATING WIRE AND FLIPPING COIL MAGNETIC MEASUREMENT OF A CESR-C 7-POLE WIGGLER MAGNET *

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Abstract

To increase radiation damping at 1.8GeV beam energy 12 super-conducting wiggler magnets will be installed in the Cornell Electron Storage Ring (CESR). The first 7-pole wiggler has been manufactured, tested and installed in the ring.

This paper describes the wiggler magnetic measurement using flipping coil and vibrating wire techniques. The field integrals along *straight* lines were measured with flipping coil, vibrating wire technique was used to measure both, straight line field integrals and field integrals along *wiggling* lines reproducing beam trajectories.

INTRODUCTION

Magnets with alternating magnetic fields (wigglers and undulators) are used in storage rings to increase radiation damping or as synchrotron radiation sources. Although radiation damping improves the beam stability, nonlinear beam dynamics effects caused by the wiggler's magnetic field may significantly compromise machine performance. Thus, the measurement of the magnetic field characteristics of wigglers and undulators is a subject of a great importance.

The methods traditionally used for wiggler magnetic measurements such as field integrating with long flipping coil, field mapping with a Hall probe or with a small searching coil provide information about field integrals along *straight* lines. However, because beam trajectory is *wiggling*, the particles passing the wiggler see a quite different field. So, it is particularly important to measure field integrals along lines representing the *wiggling* beam trajectory.

In the described magnetic measurement of a CESR-c 7-pole wiggler flipping coil [1] and a modified vibrating wire [2],[3] techniques were used. The latter was employed to measure magnetic field integrals along lines representing wiggling beam trajectory.

The vibrating wire technique uses a section of wire stretched through the testing region as a magnetic field probe. Lorentz forces between DC current flowing through the wire and the wiggler magnetic field cause the wire wiggling resembling the beam trajectory. Applying AC current with frequencies matching vibrating mode resonances and measuring amplitude and phase of the excited standing waves, one can obtain magnetic field characteristics along

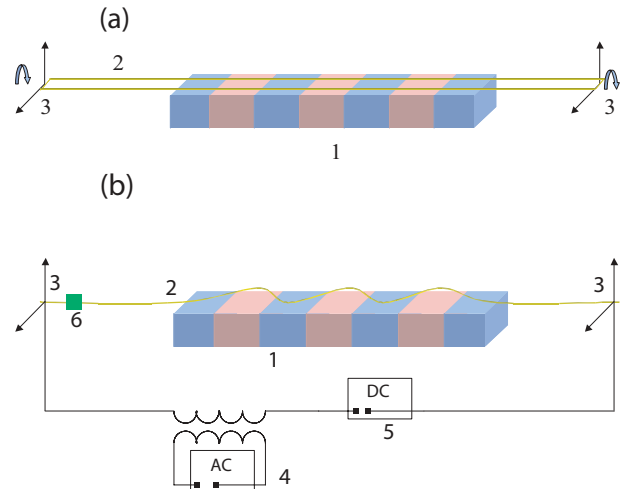


Figure 1: Schematic view of long flipping coil (a) and vibrating wire (b) measurement setup. Shown are: 1 - bottom half of tested 7-pole wiggler; 3 - stages for horizontal and vertical positioning of the coil or vibrating wire ends. On plot (a): 2 - 3/8in wide, 3m long coil consisting of 3 turns of 0.15mm copper wire. On plot (b): 2 - 4.648m section of 0.15mm copper wire; 4 - AC current generator; 5 - DC current power supply; 6 - horizontal and vertical wire motion sensors.

the wire, i.e., along the path reproducing the beam trajectory.

The paper describes the wiggler magnetic field measurement with flipping coil technique as well as with straight and "wiggling" vibrating wire and compares the results with model calculation. The "wiggling" vibrating wire measurement reveals all effects associated with the beam trajectory wiggling.

SETUP

A description of the tested 7-pole CESR-c wiggler is given in reference [4]. The measurements were done at several wiggler magnetic field levels between 1.7T and 2.1T.

The flipping coil measurement setup is schematically shown in Figure 1a. A 3/8in wide, ~ 3m long coil consisted of three turns of 0.15mm copper wire stretched through the wiggler. The coil ends were mounted on rotating stages providing the coil flipping. These stages, in turn, were mounted on moving stages for precise positioning in horizontal and vertical plane. The voltage induced in the

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coil was measured by digital integrating multi-meter "HP 3465".

The vibrating wire setup is depicted in Figure 1b. It consisted of 4.648m section of 0.15mm copper wire stretched through the wiggler with ends mounted on 2D movable stage assemblies. For wire motion sensing two "II" shaped opto-electronic LED-phototransistor assemblies H21A1 (Newark Electronics) were used. DC current power supply with 1A of maximum current was connected to the wire ends in series with a transformer. An AC current component in wire was excited by wave form generator "HP33120A" connected to the other transformer's input. A DAQCard-6024E and program based on "Lab-View" software provided all needed control and signal analysis.

FLIPPING COIL MEASUREMENT

Results of vertical and horizontal magnetic fields integral measurements as a function of horizontal coil position, $I_{y,x}(x)$, for various field levels are presented in Figure 2 and Table 1. The vertical field integral reveals a large quadratic component (normal sextupole) which depends on the wiggler field level. This dependence can be explained by well known specifics of symmetric (odd number of poles) magnetic structure. In this design, the central pole is compensated by two opposite polarity end poles. But because the magnetic field environment is different in the middle and at the ends, the compensation can be done only in a very limited range of field. The asymmetric structure with even number of poles is free of this problem. The horizontal field integral, Figure 2b, has skew quadrupole component significant for beam dynamics. It is practically constant for all fields. The origin of this component is not clear.

a_n, b_n $\frac{Gm}{cm^n}$	Wiggler field		
	1.7T	1.9T	2.1T
a_1	1.02	1.37	1.53
b_1	-0.24	-0.21	-0.19
b_2	0.18	-0.02	-0.28
b_3	0.007	0.007	0.004

Table 1: Shown are coefficients of polynomial the fit: $I_{y,x}(x) = \sum(b_n, a_n) \cdot x^n$.

VIBRATING WIRE MEASUREMENT

Theory

From formulas in [2] one can find that for the setup shown in Figure 1 the fundamental standing wave amplitude in horizontal and vertical plane, $A_{x,y}^1$, excited by AC current flowing through the wire with fundamental resonance frequency will be:

$$A_{x,y}^1 \propto I_0 \int_{-l_w/2}^{l_w/2} B_{y,x}(z) \cos(\pi z/L) dz \quad (1)$$

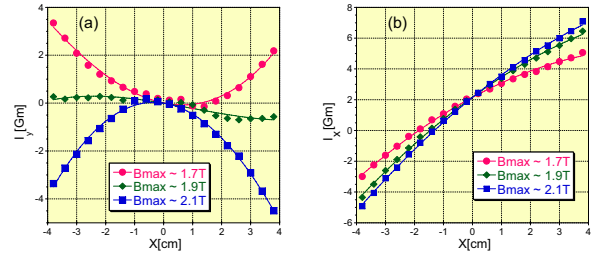


Figure 2: Vertical (a) and horizontal (b) field integrals measured with flipping coil as function of horizontal coil position.

Here I_0 is the AC current amplitude, indices x, y indicate the horizontal and vertical planes, l_w and L are for wiggler and wire lengths. If $L \gg l_w$, variation of $\cos(\pi z/L)$ can be neglected and expression (1) can be rewritten as:

$$A_{x,y}^1 \propto I_0 \int_{-l_w/2}^{l_w/2} B_{y,x}(z) dz = I_0 \cdot I_{y,x} \quad (2)$$

i.e., the standing wave amplitude is proportional to magnetic field integral multiplied by the driving AC current. Thus, the field integral can be obtained by measuring standing wave amplitude normalized by driving current, the integral sign can be determined from phase between driving AC current and the wire motion. For zero DC current (straight wire) it will be straight line integral similar to a flipping coil measurement, for non-zero DC current it will be an integral along the path imitating a beam trajectory.

"Straight" wire measurement ($I_{dc} = 0$)

The "straight" wire, $I_{dc} = 0$, measurement results at 2.1T wiggler field are given in Figure 3 in comparison with the flipping coil measurements. Shown are fundamental horizontal and vertical standing wave amplitudes (solid marks, left scale) with a sign given by the phase between driving current and the wire motion measured as a function of horizontal wire position. Flipping coil measurements (right scale) are indicated by open marks. There is a good agreement between these two data sets. Left and right scales comparison suggests that 1r.u. in vibrating wire measurements corresponds to $\sim 7.7Gm$ of field integral.

"Wiggling" wire measurement

The Lorentz forces between DC current flowing through the wire and wiggler magnetic field cause the wire wiggling which reproduces the beam trajectory. Optical measurement indicated that at 2.1T wiggler field, 0.5A of DC current flowing through the wire resulted in $\sim 3.7mm$ peak-to-peak wire wiggling which is similar to the beam trajectory wiggling at 1.8GeV beam energy.

Figure 4 presents the vertical field integral as a function of horizontal position measured with the "wiggling" wire in comparison with a) straight wire measurement and b)

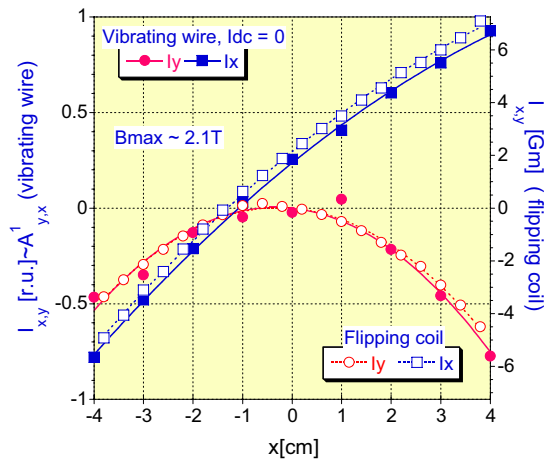


Figure 3: Vertical and horizontal field integrals measured with a straight vibrating wire, $I_{dc} = 0$, as a function of horizontal position (left scale) in comparison with flipping coil measurement (right scale) at 2.1T wiggler field.

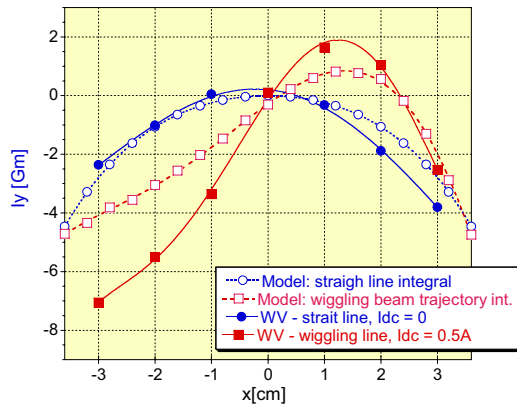


Figure 4: Vertical field integral as a function of horizontal position measured with a straight, $I_{dc} = 0$, and wiggling, $I_{dc} = 0.5A$, wire. Model calculation is indicated by open marks.

with the "wiggling" and straight field integrals calculated from the model. For the wire measurement the calibration obtained in the previous experiment was used. One can see that the measured effect of the path wiggling analogous to that calculated from the model, but has a bigger amplitude. This inconsistency could be due either to factors missing in the model or because of inaccuracy of the vibrating wire measurement calibration. Note that the variation between the straight and wiggling line vertical field integrals is mostly due to vertical field non-uniformity across the wiggler poles [5].

The beam vertical focusing effect in wigglers is another result of the trajectory wiggling. This effect can be seen from horizontal field integral measured with wiggling wire as a function of the wire vertical position, see Figure 5. While the straight wire data, $I_{dc} = 0$, indi-

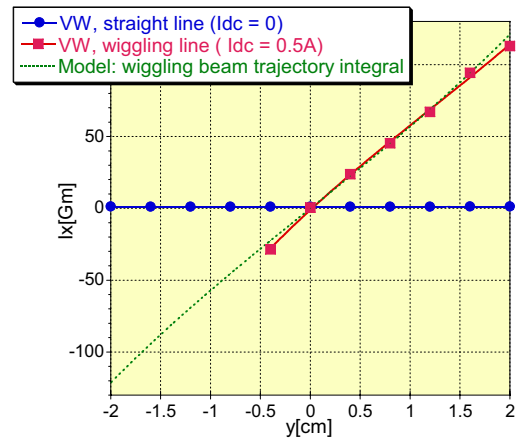


Figure 5: Horizontal field integral as a function of vertical position measured with a straight, $I_{dc} = 0$, and wiggling $I_{dc} = 0.5A$, wire. Dashed line shows a model calculation.

cated zero horizontal field integral for all y , integral measured with a wiggling wire, $I_{dc} = 0.5A$, has linear dependence $dI_x/dy(\text{measured}) \sim 62.3Gm/cm$ which is consisted with the model calculation $dI_x/dy(\text{model}) \sim 60.3Gm/cm$.

CONCLUSION

Two complementary magnetic measurement techniques were employed for CESRc super-conducting wiggler magnetic measurement. A long flipping coil technique was used to measure vertical and horizontal field integrals along straight lines, the relatively new vibrating wire technique was applied for field integral measurements along a path representing wiggling beam trajectory. The latter revealed all effects caused by the beam trajectory wiggling predicted by model.

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