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MIT Microwiggler for Free Electron Laser Applications**

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ABSTRACT

A microwiggler-based FEL permits operation at shorter wavelengths with a reduction in the size and cost of the device. The MIT microwiggler is a pulsed ferromagnetic-core electromagnet with 70 periods of 8.8 mm each which generates an on-axis peak magnetic field of 4.2 kG. The pulse repetition rate is 0.5 Hz with FWHM 0.5 msec. The microwiggler is characterized by extensive tunability. We employed a novel tuning regimen through which the rms spread in peak amplitudes was reduced to 0.08%, the lowest ever achieved in a sub-cm period magnetic field. The microwiggler is a serviceable scientific apparatus: spontaneous emission has been observed for wavelengths of 700-800 nm using a 40 MeV beam from the Accerator Test Facility LINAC at BNL.*

INTRODUCTION

In order for the Free Electron Laser to become a practical radiation source at short wavelengths, it is necessary to reduce the size and cost of the device. Reduction in the period of the wiggler from the typical 3-10 cm to below 1 cm permits operation of FELs at shorter wavelengths for a given beam energy.

High field precision in short-period wigglers is difficult to achieve. Mechanical tolerances and other coil-to-coil variations become sufficiently large on the scale of the wiggler period that they translate easily into field errors of harmful amplitude. The severity of the problem compounds with wiggler length, and curtails the FEL efficiency through deleterious increases in electron beam walk-off and energy spread. Various microwiggler designs have been investigated to address these technical challenges. (Table 1) [1-8] We have employed a novel approach to reducing wiggler field errors in which extensive tunability is controlled through a rigorous tuning procedure. The high performance of the microwiggler makes it well-suited for the development of a linac-based FEL in the visible and UV wavelengths.

Table 1. Comparison of some short-period wigglers.

GROUP	TECHNOLOGY AND STATUS	N_w	λ_w,mm / G,mm	B_w kG	PEAK RMS ERROR	POLE INT. ERROR
Stoner *et al.*, MIT	Pulsed ferrocore electromagnet; operational	70	8.8/ 4.2	4.2	0.08%	0.14%
Huang *et al.*, Stanford	Staggered ferrocore array in solenoid; test	50	10.0/ 2.0	10.8	1.2%	Not reported
Warren and Fortgang LANL	Permanent magnet; operational	73	13.6/ 1.5	6.5	0.3%	Not reported
Tecimer and Elias CREOL	Hybrid, test	62	8/ Not reported	1.0	0.2%	0.6%
Ben-Zvi *et al.*, BNL	Superconducting ferrocore electromagnet; test	20	8.8/ 4.4	>5.5	0.29%	0.36%

Table 2. MIT Microwiggler parameters.

PARAMETER	VALUE
on-axis magnetic field, B_w	4.2 kG
wiggler period, λ_w	8.8 mm
wiggler parameter, a_w	0.34
wiggler gap, G	4.2 mm
number of periods, N_w	70
rms spread in peak amplitudes, $(\delta B/B)_{RMS}$	0.08%
rms spread in pole integrals, $(\delta I/I)_{RMS}$	0.14%
repetition rate	0.5 Hz

MICROWIGGLER FIELD CHARACTERISTICS

Table 2 summarizes the microwiggler parameters. Wiggler design, construction and tuning algorithm are

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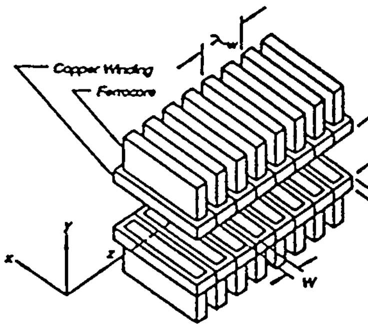

Figure 1. Schematic of the wiggler geometry

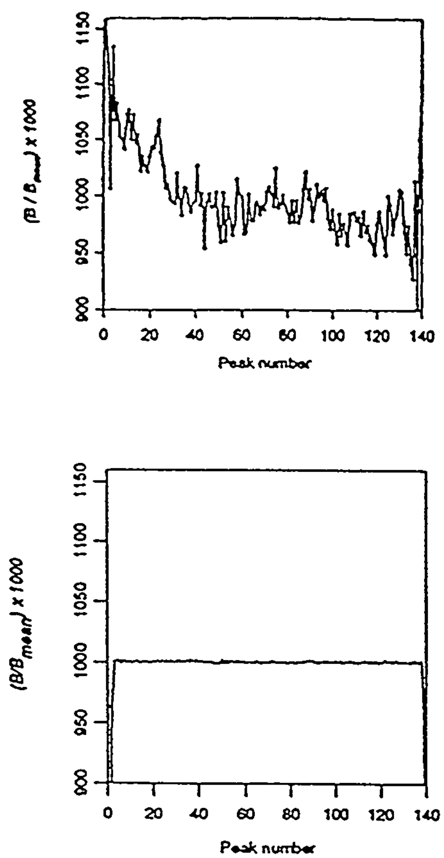

Figure 2. Peak amplitude profile: untuned profile (rms spread 4%) and tuned profile (0.08%).

detailed in our previous work. [9] The measurements of field characteristics described here are for the full 70 periods (excluding tapered end effects) and for a repetition rate of 0.5 Hz.

Each half period in the wiggler is created by a pair of magnets connected electrically in parallel, which are mounted on either side of a stainless steel bore in a precisely formed Aluminum matrix. (Figure 1) Current flows independently to each pair of magnets and is controlled by an variable series resistance.

In order to completely characterize the microwiggler field characteristics, a comprehensive battery of field measurements was performed.

The measurement system

An automated control system monitors the field profile, in which a B-dot loop is pulled through the bore and recorded. Peak amplitudes and peak axial positions are extracted from curve fits to the data. The control system includes feedback to maintain the wiggler total current at a constant level. Complete field scans are repeated from 5-15 times and averaged, so that a single field profile contains the information of over 10,000 field amplitude data points.

Results of tuning

The untuned field profile was dominated by the effects of small inhomogeneities in the wiggler construction and had an rms spread of 4%. (Figure 2) From a consecutive sequence of field profile measurements, tuning iterations reduced the spread in peak amplitudes to 0.08% or better, an improvement of nearly two orders of magnitude. This is an outstanding level of uniformity for a sub-cm period wiggler, and illustrates the power of our tuning algorithm in controlling the field.

Cross-gap field symmetry

Field profile measurements are taken along the axis of the wiggler bore. In order to determine how well the axis of the bore coincides with the wiggler axis, cross-gap field symmetry was measured. The distance between the center of the wiggler bore and the magnetic field center was determined with an axially-oriented B-dot loop positioned at the maxima of the axial magnetic field (nulls of the transverse field.) The voltage on the axial B-dot loop is zero for perfect cross-gap symmetry and is linearly proportional to small displacements. The results determined a spread in the magnetic center displacements of at most 17 μm.

The coils and bore are mounted securely in a precisely formed aluminum matrix. Coil heights relative to the face of this matrix were measured and it was determined that they secure the position of the bore to within 10 μm in the transverse direction. The mechanical measurements are in agreement with the magnetic center measurements, and confirm the straightness of the bore.

Harmonic content of field profile

A high level of purity in the wiggler field harmonic spectrum was measured and provides an independent confirmation of the peak amplitude uniformity. Furthermore, it is important that the design of the wiggler gap dimension, which must be small for large field amplitudes, not result in field harmonics, since the high frequency harmonic emissions can damage optical coatings during lasing. Measurements show that the third

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harmonic is down by more than five orders of magnitude from the fundamental, the fifth harmonic is just above the noise level, and the other harmonics are not measurable. [10]

Estimate of spread in pole integrals

The rms spread in pole integrals is an important figure of merit for wigger field uniformity and can be estimated from a precise measurement of the peak amplitudes and positions. Evaluation of errors in the measured amplitude profile, including contributions from stray pick-up, leads to an rms spread in peak amplitudes of 0.08% along the center of the wiggler bore. Contributions to the spread in peak amplitudes due to differing temporal coil response were measured and shown to be negligable. [11] The peak position error spread is currently 10.4 um. As the peak position and peak amplitude spreads are uncorrelated, they add in quadrature, giving an estimated spread in pole integrals of 0.14%.

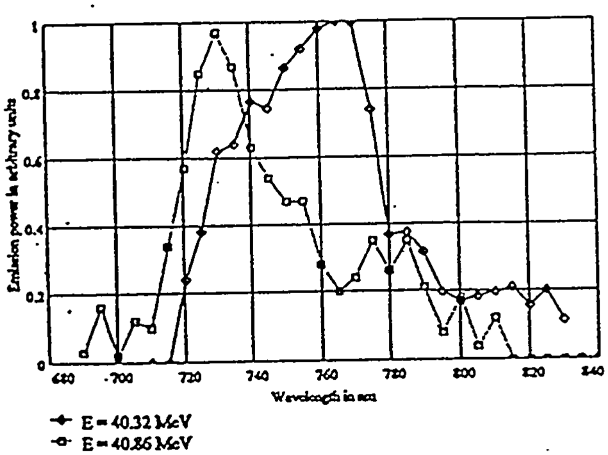

Figure 3. Spontaneous emission spectra for beam energies of 40.32 MeV and 40.86 MeV.

SPONTANEOUS EMISSION MEASUREMENTS

To date, the MIT Microwiggler has been used in measurements of spontaneous emission at the wavelengths of 700-800 nm. (Figure 3). These measurements were taken using a 40 MeV beam produced by the ATF LINAC at BNL. We observed the expected redshift in peak wavelength accompanying a decrease in beam energy. The emissions feature a shoulder at the red wavelengths. An evaluation of possible broadening mechanisms (beam energy spread, off-axis electron propagation and off-axis emission) shows that off-axis emission can easily account for the observed assymetry. Thus, the first steps in extracting information about the electron beam characteristics from the wiggler emissions have been possible.

We are currently working in collaboration with researchers at the Accelerator Test Facility at BNL to lase at 538 nm.

DISCUSSION:

The high precision field profile of the MIT Microwiggler will permit the generation of coherent radiation at wavelengths ranging from the visible to ultraviolet. With our typical observations of an rms spread of 0.08% in peak amplitudes and 0.14% in pole integrals, the microwiggler currently provides the world's most uniform periodic field for any sub-cm period wiggler. Such negligable field errors will permit extraction of information about characteristics of the electron beam from the wiggler emissions.

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[10] *Ibid.*

[11] *Ibid.*