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FINAL REPORT

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PRINCIPAL INVESTIGATOR: Professor George Bekefi

INSTITUTION: Massachusetts Institute of Technology

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FINAL REPORT

Overview

We have designed, built, tested, and operated a 70-period electromagnet planar microwiggler for use in free electron lasers (FELs), constructed of current conductors wound on ferromagnetic cores. The device has an 8.8 mm period and a 4.2 mm gap and produces 0.5-msec magnetic field pulses of >4.0 kG at a rate of 1/2 Hz. The field of each half-period of the wiggler is independently adjustable; we have developed a novel tuning regimen and employed it to reduce the RMS spread in peak amplitudes of a uniform field profile to 0.12%, the best of any sub-cm period wiggler of which we are aware. In addition, the field at the ends of the wiggler have been tapered for reduced electron-beam steering and deflection.

The MIT Microwiggler is now operating at Brookhaven National Laboratory's Accelerator Test Facility (ATF). We have begun experiments to produce visible light from the ATF's 50 MeV electron beam, and observed incoherent emission of visible light at ~700 nm. This report describes the visible light experiments now in progress, as well as the recent efforts leading to the commencement of these experiments: we doubled the repetition rate of the Microwiggler system while preserving very high field precision and introducing wiggler entrance and exit tapering, and installed the Microwiggler on the ATF beamline.

Recent Accomplishments

The MIT Microwiggler (Fig. 1) has been installed in Beamline #3 of the ATF's Experimental Hall (see Figures 2 and 3) during the period of 16-18 August 1993. During that time the Microwiggler was surveyed into the ATF beamline, cabling for remote operation of the Microwiggler from outside the Experimental Hall was connected, correct operation of the Microwiggler was verified, and necessary vacuum connections were made between the Microwiggler and the beamline. From 18-20 August, we injected a 40 MeV electron beam into the Microwiggler and attempted to observe visible light emission. We made positive observation of electron propagation through the Microwiggler; however, our photomultiplier-tube-based detector system did not register a light signal. We hypothesized (and have since shown) that the light pulse signal was swamped by a hard-radiation pickup on the PMT that was observed to be correlated with the electrons' presence (but not the wiggler firing). We subsequently verified that our PMT has sufficient sensitivity to view as small a pulse as tens of visible photons; moreover, we removed the PMT from the plane of the electron beam so as to reduce X-ray pickup. These efforts, along with the use of lead glass to shield the PMT, reduced the effects of the x-ray background, and we observed visible light on 10 November 1993. Figure 4 shows a plot of PMT signals with and without the presence of a wiggler field in the interaction region; the wiggler results in a 30-fold increase in signal. We verified that the signal increase is due to visible emission (as opposed to increased x-ray emission due to e-beam steering by the wiggler into the drift tube walls) by blocking the optical path to the PMT with an optical neutral density filter: only the small x-ray pickup signal remained, even when the wiggler field was present.

Figure 4 also displays the results of two experiments in which we studied the variations in spontaneous emission as a function of the wiggler field strength. In one experiment,we varied the wiggler field strength by varying the injection time of the electron pulse with respect to the wiggler field shot. In the other, we held the injection time constant and varied the current delivered to the wiggler magnet. The results of the two experiments are very similar; both show a nearly linear variation with magnetic field strength, in contrast with the expected quadratic variation. This discrepancy is likely the result of off-axis, off-angle injection of the beam into the wiggler, resulting in partial blockage of the beam at higher wiggler fields. We intend in future runs to verify this hypothesis.

Our first light-generation experiments were preceded by recent intensive system development efforts:

o Sustained and stable 4-kG operation at 1/2 Hz repetition rate in the ATF Experimental Hall. This required that the pulsed power supply be rebuilt to permit more efficient cooling of the capacitor bank, as well as to accommodate space constraints in the Experimental Hall. Appropriate cabling for remote operation of the system had also to be installed. We also designed and constructed a support table for the Microwiggler's installation into the 50 MeV beamline. The support is mechanically stiff and not susceptible to vibration, and possesses adequate adjustability for wiggler-beam alignment.

o Further refinement of the field measurement system. We carried out tests to flush out systematic errors in our magnetic field $(\dot{B})$ pickup coil technology. We eliminated a false dipole from our measurements introduced during the Experimental Hall installation, as well as false contributions from spurious pickup from the pickup coil leads: we constructed new transverse and axial probes in which the pickup coils and leads are formed from a single piece of 32 AWG wire, with the leads wrapped into 700-µm-pitch twisted-pair configuration. Our field measurement system is now capable of producing 0.037%-precision measurement of the 140 field peaks' amplitudes-- in less than three hours.

o Microwiggler high-pulse-repetition-rate and end-taper retuning. The magnet has been retuned to operate at a pulse repetition rate of 0.5 Hz (a doubling of the previous repetition rate), with end-tapering for reduction of e-beam steering and deflection. (see Fig. 5). Our novel iterative tuning regimen was employed, which involves perturbing the tuning profile at selected points in order to produce an empirical Taylor expansion matrix relating the magnetic field profile (described as a 140-dimensional vector consisting of the peak amplitude of each half-period) to the tuning resistor profile (described as a 140-dimensional vector consisting of the length of the tuning resistor of each half-period). Tuning convergence was achieved in spite of the additional difficulty encountered in the installation of entrance/exit tapering: the first and last half-periods operate in the linear regime, while the remainder of the magnet is operates in the saturated regime. Thus, the tuning matrix had to be re-measured after some tapering had been installed, in order to model the differing saturation characteristics of the magnet ends and the magnet body. The precise adjustment of the POISSON-calculated taper (determined in FY 1992) could then be completed. The RMS spread in the peaks amplitudes was maintained at 0.12%: this precision level is the best in any sub-cm. period wiggler we are aware of.

o Wiggler-ends temporal phase-slip measurements. We carried out a study of the relative time dependence of the fields produced at the magnet ends vs. those produced in the body of the magnet. Figure 6 summarizes the results: the field at the ends of the magnet reach a peak roughly 20 μsec earlier than in the magnet body, resulting in an additional e-beam deflection error of 4.0 μm, a negligible amount.

Future Plans (next 12 months):

The focus of our next year's work will be to carry out beam propagation and visible-wavelength studies with the Microwiggler using the 50 MeV LINAC beam at Brookhaven's Accelerator Test Facility. Tasks include:

o High-energy-beam emittance diagnostic and optical diagnostics development. Initially, we will install optical transport systems to carry light from the experimental hall to an area outside the radiation shields where spectral analysis of the light will be performed. Later in the year, the resonant cavity for the visible free-electron laser (FEL) oscillator experiment will be installed, aligned, and tested. A computer-based experimental control system will also be constructed: some elements of the Microwiggler computer control system (A/D and oscilloscope interfaces, e.g.) can be immmediately adapted, while the spectrometer control interfaces must yet be implemented.

o Spontaneous emission studies. The small bore of the Microwiggler prohibits viewing of the electron beam position inside the magnet. We will characterize the spectral content of the spontaneous emission light with an overall goal of using the spontaneous emission as a steering diagnostic. Off-axis beam propagation should produce measureable increases in both spontaneous emission power and wavelength (due to the beam's passing through the stronger off-axis fields), so that wavelength and power minimization should correspond to optimized beam steering. Likewise, variations in beam emittance should produce observable changes in the spectral width of the spontaneous emission, and we intend to study such effects.

o FEL oscillator studies. Upon installation of the resonant cavity, we will attempt to produce FEL gain using the multiple-pulse capability of the ATF injector. An experimental signature of gain will be spectral narrowing of the emission as compared to spontaneous emission, as well as increased emission power.

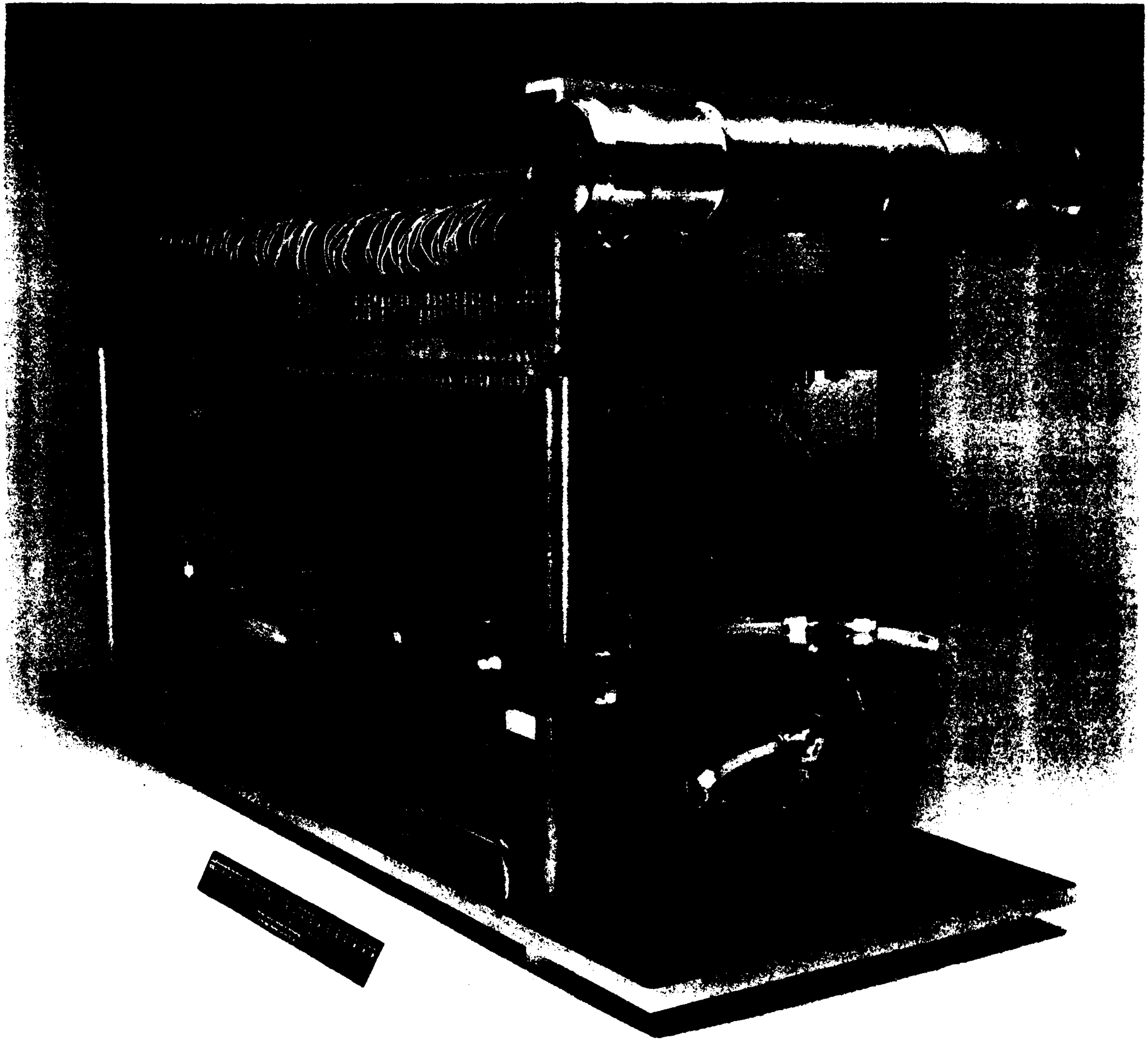


Figure 1: MIT Microwiggler

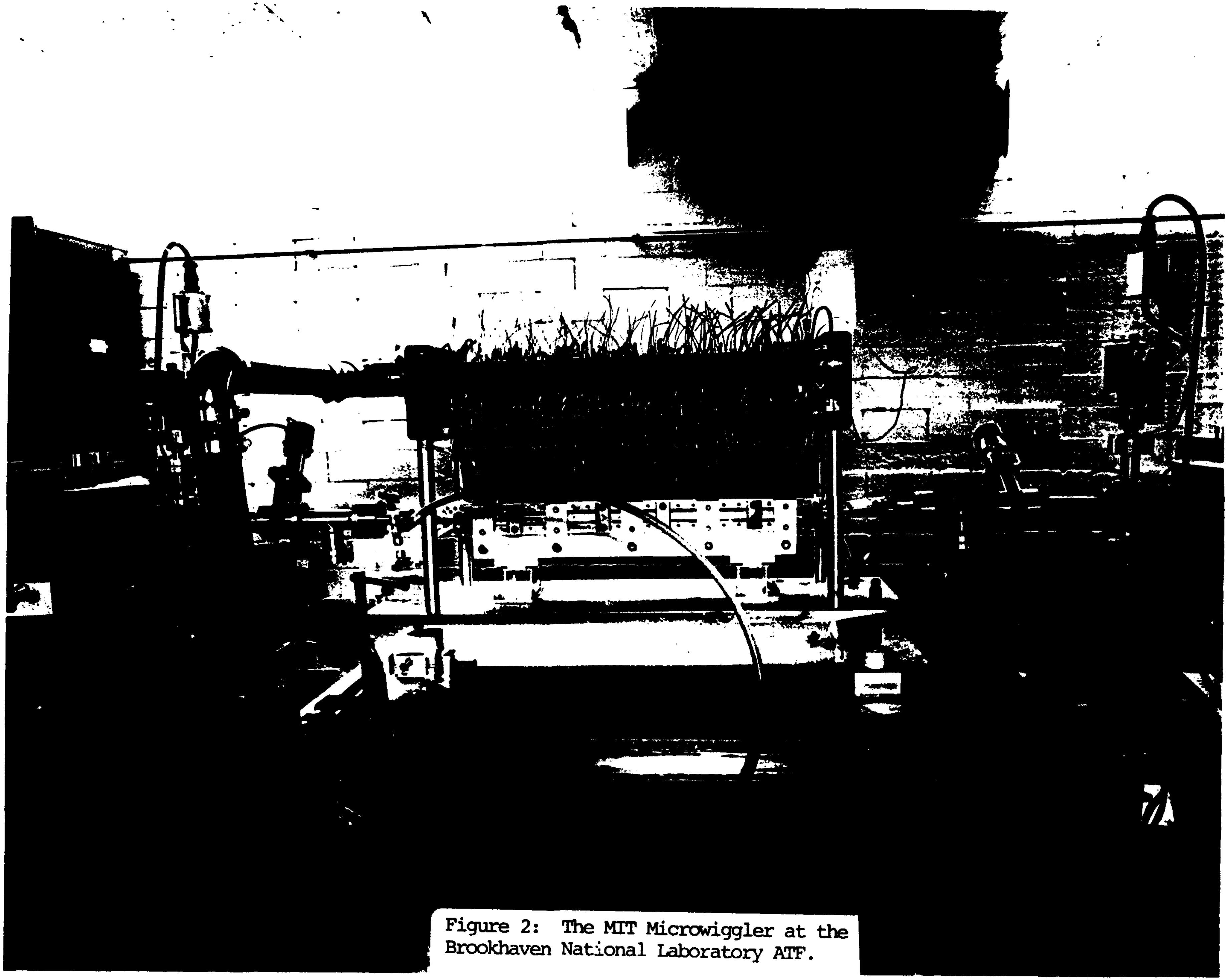
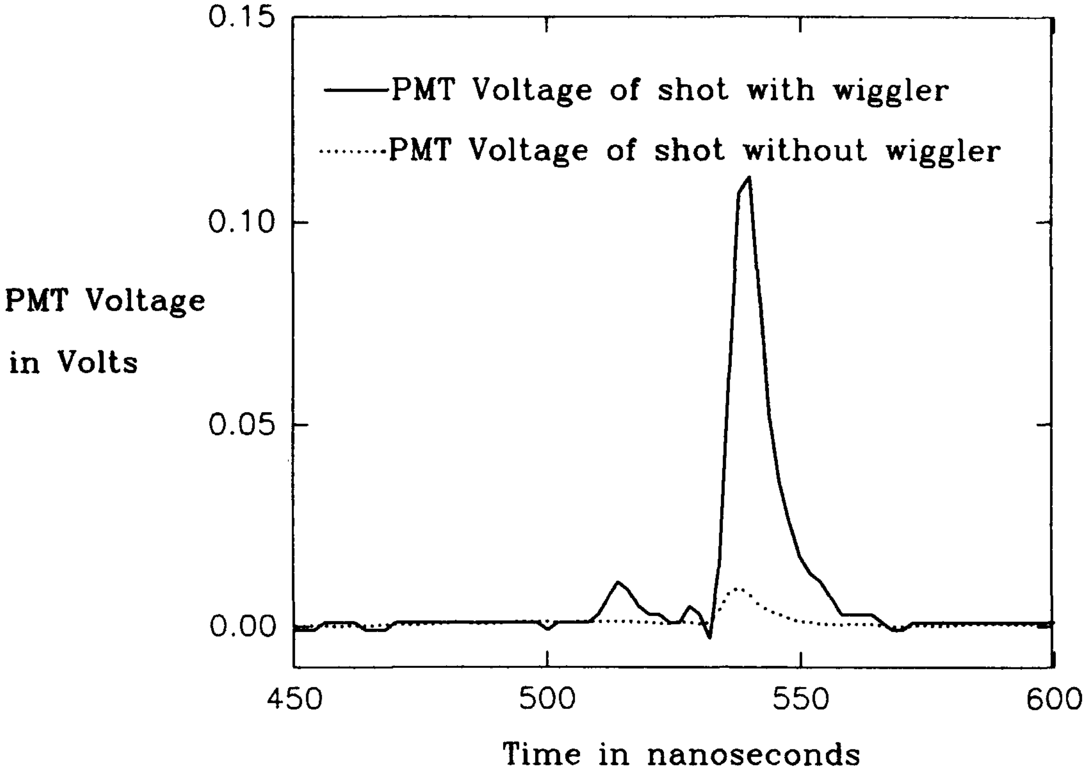


Figure 2: The MIT Microwiggler at the Brookhaven National Laboratory ATF.

Figure 3: A view of the Brookhaven National Laboratory ATF experimental hall.


Scope Trace of PMT voltage during shot

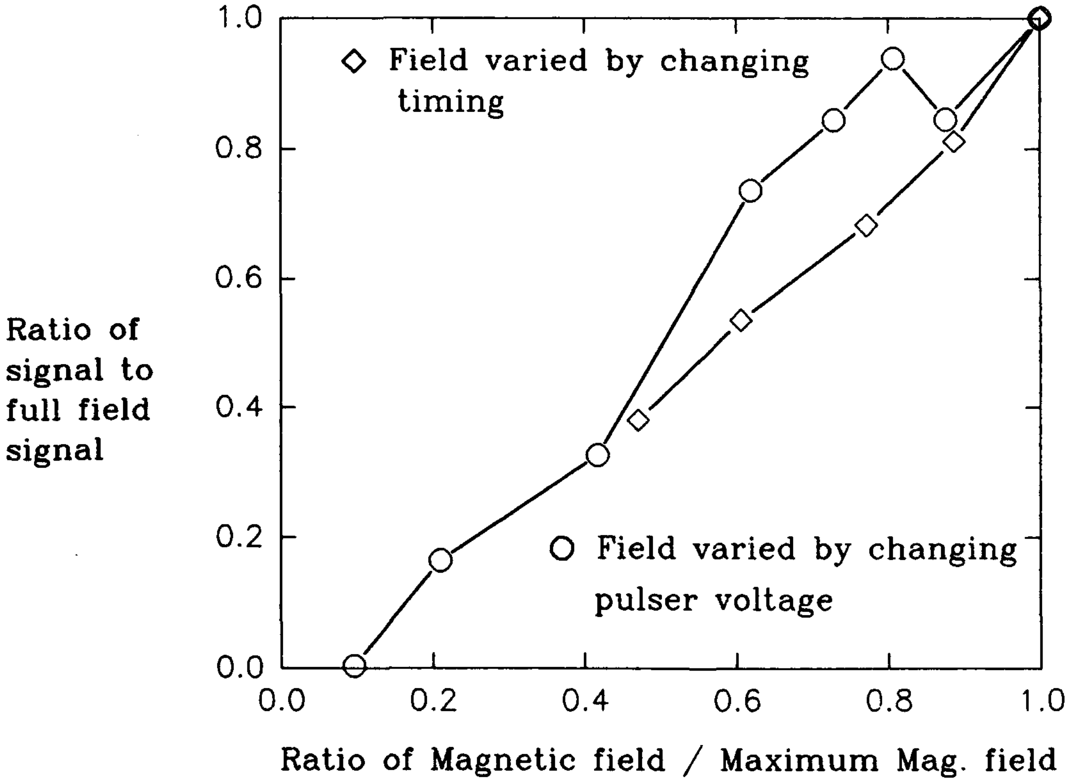

Signal amplitude with changing wiggler field

Figure 4: Spontaneous emission from the MIT Microwiggler.

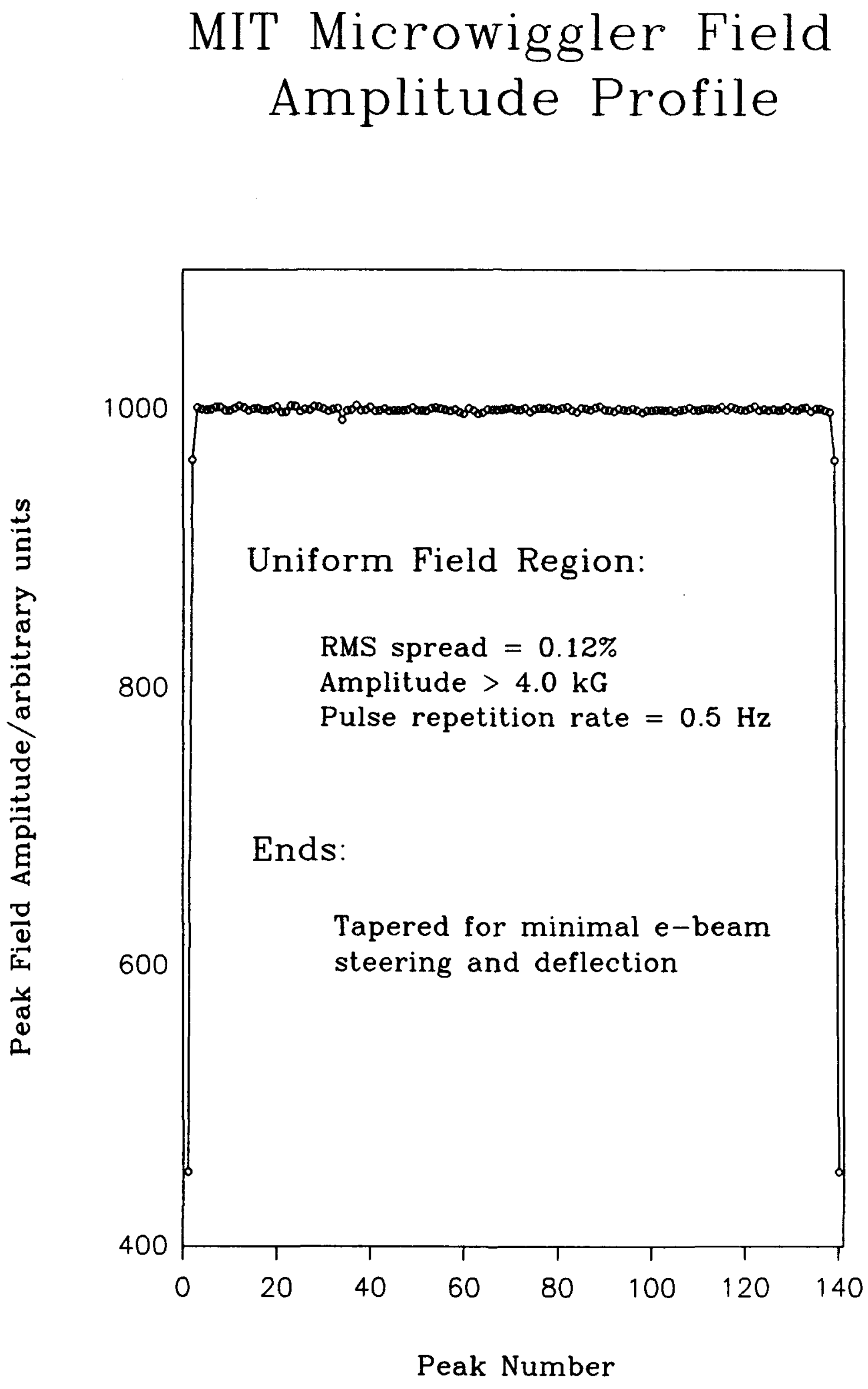
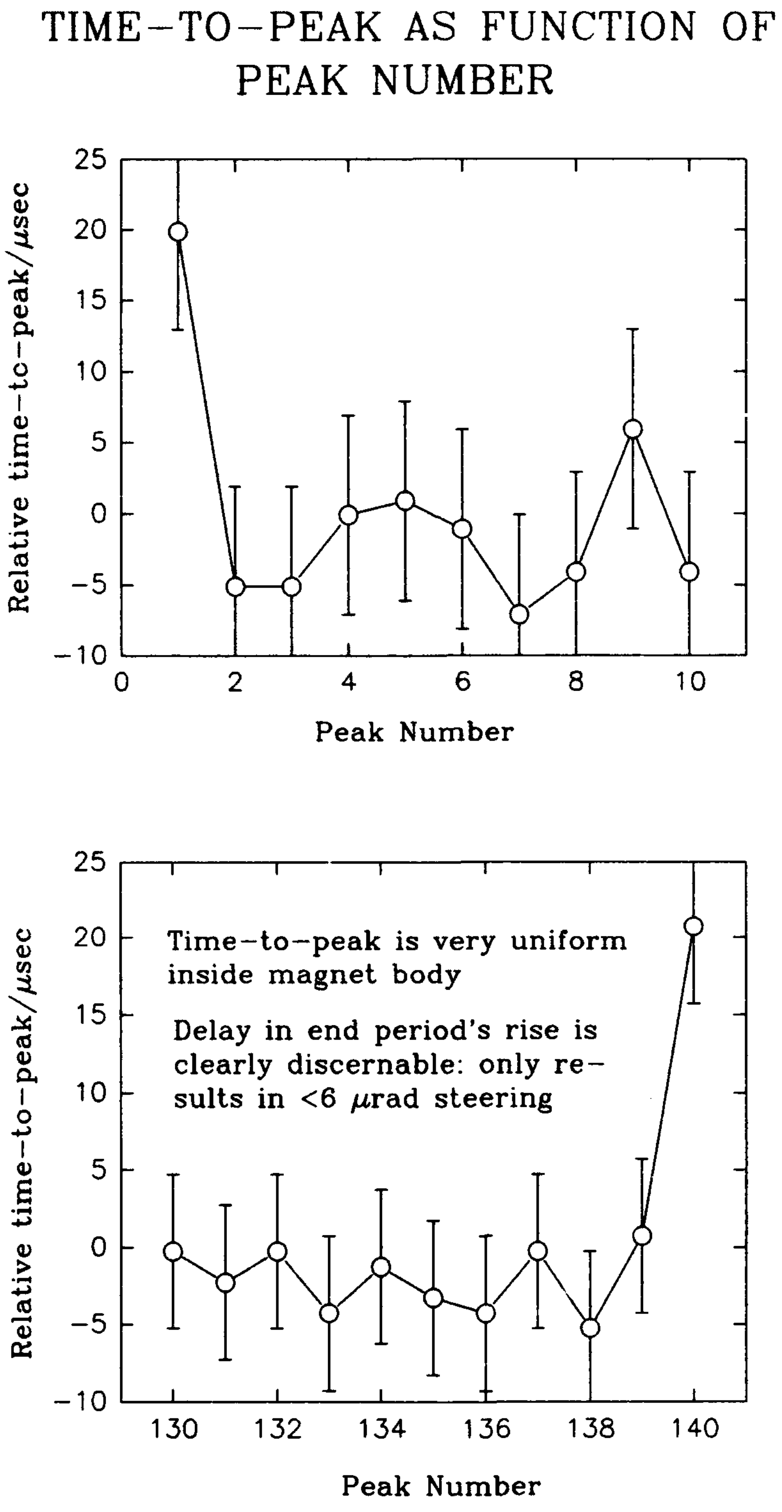


Figure 5: Field amplitude profile of MIT Microwiggler.



Time-to-peak is very uniform inside magnet body

Delay in end period's rise is clearly discernable: only results in <6 μrad steering

Figure 6: Temporal characteristics of the microwiggler.

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