AD-A256 236

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of inform... gathering and maintaining the data needed, and co... collection of information, including suggestions for... Davis Highway, Suite 1204, Arlington, VA 22202-430... or reviewing instructions, searching existing data sources... egarding this burden estimate or any other aspect of this... for Information Operations and Reports, 1215 Jefferson... Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	9-30-92	Annual Tech. 9/30/91 - 9/29/92

4. TITLE AND SUBTITLE
Compact Free Electron Laser for Medical Applications

5. FUNDING NUMBERS
N00014-90-J-4130
s400091scu01

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800 North Quincy Street
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Work by Prof. Bekefi and his collaborators is summarized here

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102

ANNUAL PROGRESS REPORT
Compact Free Electron Laser for Medical Applications
Grant# N00014-90-4130
September 30, 1992

The *raison d'etre* of the MIT microwiggler has been validated. Last year, we demonstrated that a highly tunable undulator can be constructed with an experimentally useful number of periods. This year, we successfully used the tuning capability to reduce the RMS spread in the peak amplitudes of the Microwiggler to 0.08%. This report describes the steps taken to attain this very high level of precision. In addition, it discusses our development of a new three-dimensional free-electron laser simulation for use in the design and subsequent data analysis of Microwiggler-based experiments.

Accomplishments (last 12 months):

The 70-period Microwiggler has been tuned (see Fig. 1). A 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). The resulting matrix equation is then numerically inverted to produce a list of resistor adjustments which to first order will produce a flat field amplitude profile. Some field error invariably will remain, however, due to non-linear saturation effects and measurement error in the matrix entries. The process is then repeated until the errors in the field profile are of the same magnitude as the errors inherent in the field measurement system. Experience has shown that this regimen converges very rapidly, with 3-4 iterations required to reduce field errors from 2.5% RMS (untuned) to 0.08% RMS (Fig. 2). Tuning, therefore, can be accomplished in 3-4 working days during most of which time the Microwiggler system runs unattended under computer control.

The tuning effort was necessarily preceded by important system integration milestones. A brief summary of the magnet work done this year is as follows:

- **Sustained and stable 4-kG operation at 1/4 Hz repetition rate.** This required that the custom-designed low-resistance 7 microhenry inductor of the pulsed power supply inductor be redesigned and rebuilt. A new charging power supply capable of 1 Hz operation was also integrated into the system to allow eventual increase of the shot repetition rate, if required.

- **Proof-of-principle initial tuning work.** Even though systematic errors were still present in the field measurement system at this point, a 0.25% RMS spread in the peak amplitudes was attained (this precision corresponded to the precision of the measurement system up to that point). In addition to attaining a level of precision in itself respectable, the validity of the tuning regimen was established.

o **Refinement of the field measurement system.** A new pickup probe translator was installed, the analog electronics were carefully shielded form noise produced by the pulsed power supply; a regimen was instituted to remove asymmetry in measurement of positive and negative field peaks, and a post-acquisition convolution algorithm was implemented to further smooth out noise in the field and current pulse signals. The result was a field measurement system capable of 0.05% precision in measurement of field peak amplitudes.

o **High-precision flat-profiled tuning work.** The RMS spread in the peaks amplitudes was reduced to 0.08% by applying the now-established tuning regimen using the newly-refined field measurement system. This precision level is the best in any sub-cm period wiggler we are aware of.

o **Entrance/exit taper tuning work.** We used a POISSON-based model to determine a zero-steering profile to be tuned into the Microwiggler. The virtual POISSON device was tuned using the same procedure as the physical magnet, except that instead of constant peak amplitude as an objective we used a zero-steering half-period-integral profile. The resulting POISSON field distribution was analyzed by a two-dimensional convolution to mimic our pickup-coil field sensor. The peak amplitudes of the convolved profile were then extracted to provide a "target" peak amplitude profile to be installed into the Microwiggler. That tuning effort in now in progress and near completion.

A new, fully three-dimensional non-linear fee-electron laser simulation has been made which permits study of a wide range of FEL phenomena, e.g., optical mode deformation and optical guiding, finite electron beam emittance and space charge effects, and wiggler field error and wiggler tapering effect (Figs. 3 and 4). The simulation includes a three-dimensional treatment of both the electron dynamics and the radiation field. Arbitrary electron beam energies can be modelled, and correct wave-particle coupling is obtained even when the wiggler and betatron oscillation amplitudes are not small compared to the transverse size of the optical mode.

Work Plan (next 12 months):

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

o **Implementing the computed zero-steering profile in the Microwiggler.** This will include ensuring that the field pulse at the ends of the magnet does not have temporal characteristics significantly different from the magnet body. Harmonic content will also be analyzed.

o **Designing a support for the Microwiggler's installation into the 50 MeV beamline.** The support must be mechanically stiff and not susceptible to vibration, and possess adequate adjustability for beamline alignment.

o **Installation of the Microwiggler into the beamline.** After supervision of the surveying and alignment operation, the field measurement system must be installed temporarily *in situ* and used to verify that the field has not been perturbed by the installation process. Proper triggering and current monitoring must be obtained in the potentially noisy experimental environment.

o **High-energy-beam emittance diagnostic and optical diagnostics development.** To be developed and installed in conjunction with Accelerator Test Facility personnel.

Upon completion of these tasks, we will perform 50 MeV electron beam propagation measurements: beam steering and deflection, emittance changes, etc. Optical diagnostics will be installed in parallel with these experiments, and will then be used to measure the spectrum of the spontaneous emission in the wiggler. The width of the spontaneous emission spectrum's central peak should be clearly resolvable, and will provide information about beam emittance and wiggler errors which can be compared to individually-made independent measurement of those quantities. This will be followed by FEL gain measurements once the Brookhaven facility is fully operational with multiple RF micropulses.

Theoretical and computation tasks include:

o Using our new 3-d FEL simulation to investigate the possible advantages of a microwiggler optical klystron using the high-quality beam expected on the ATF LINAC.

o Studying spontaneous emission in the presence of wiggler errors, steering errors, and finite beam emittance.

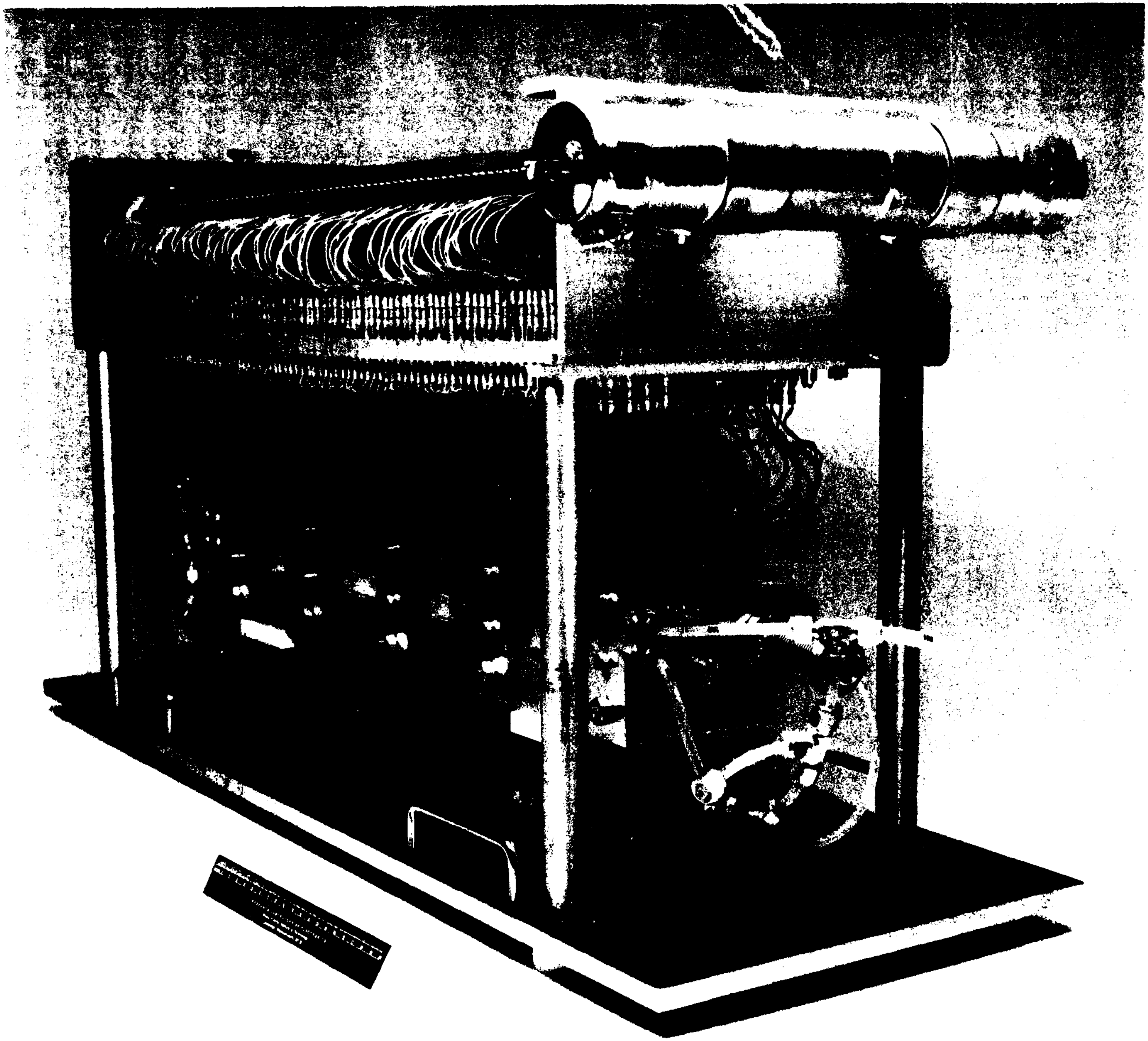

Figure 1

PEAK AMPLITUDE PROFILE

B_{mean} = 4 kG

RMS Spread in Peaks = 0.08%

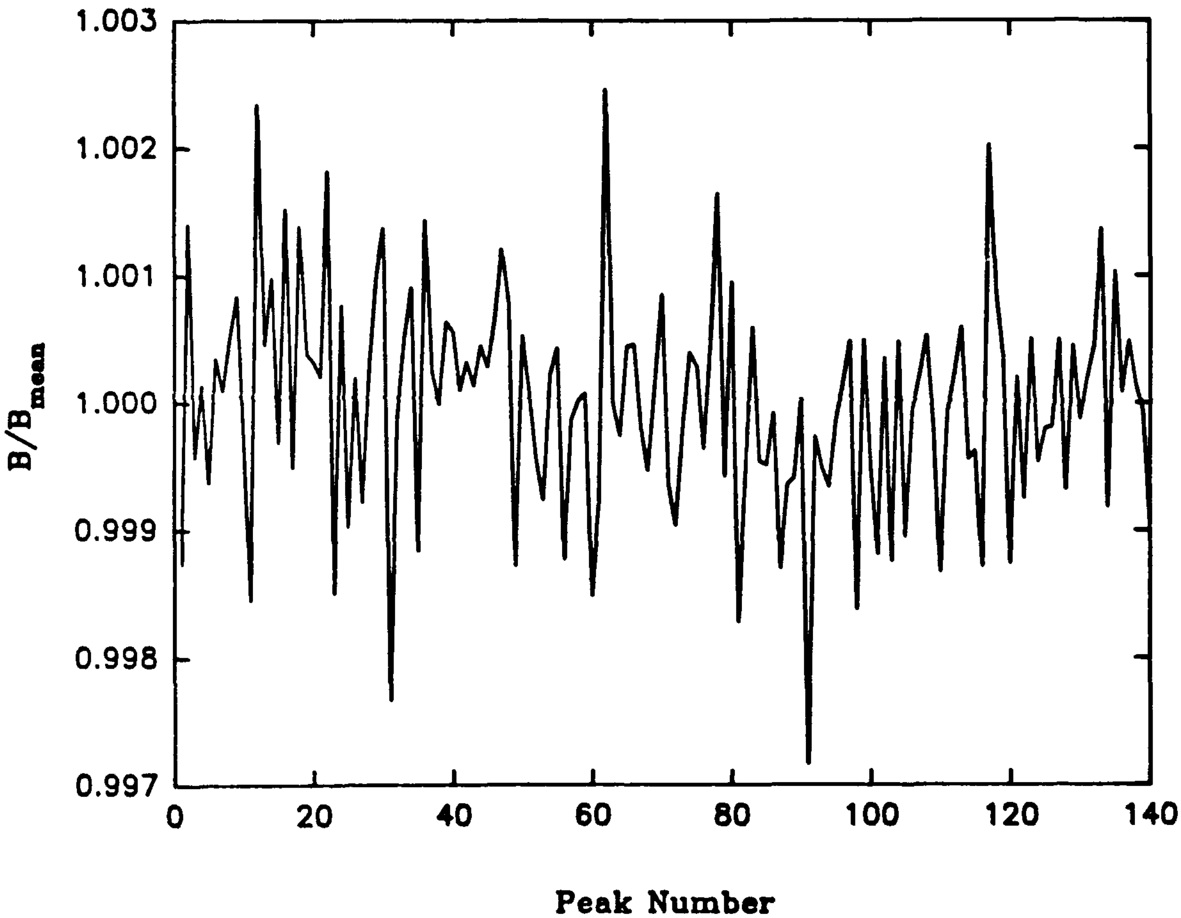

Figure 2

SPACE-CHARGE EFFECTS

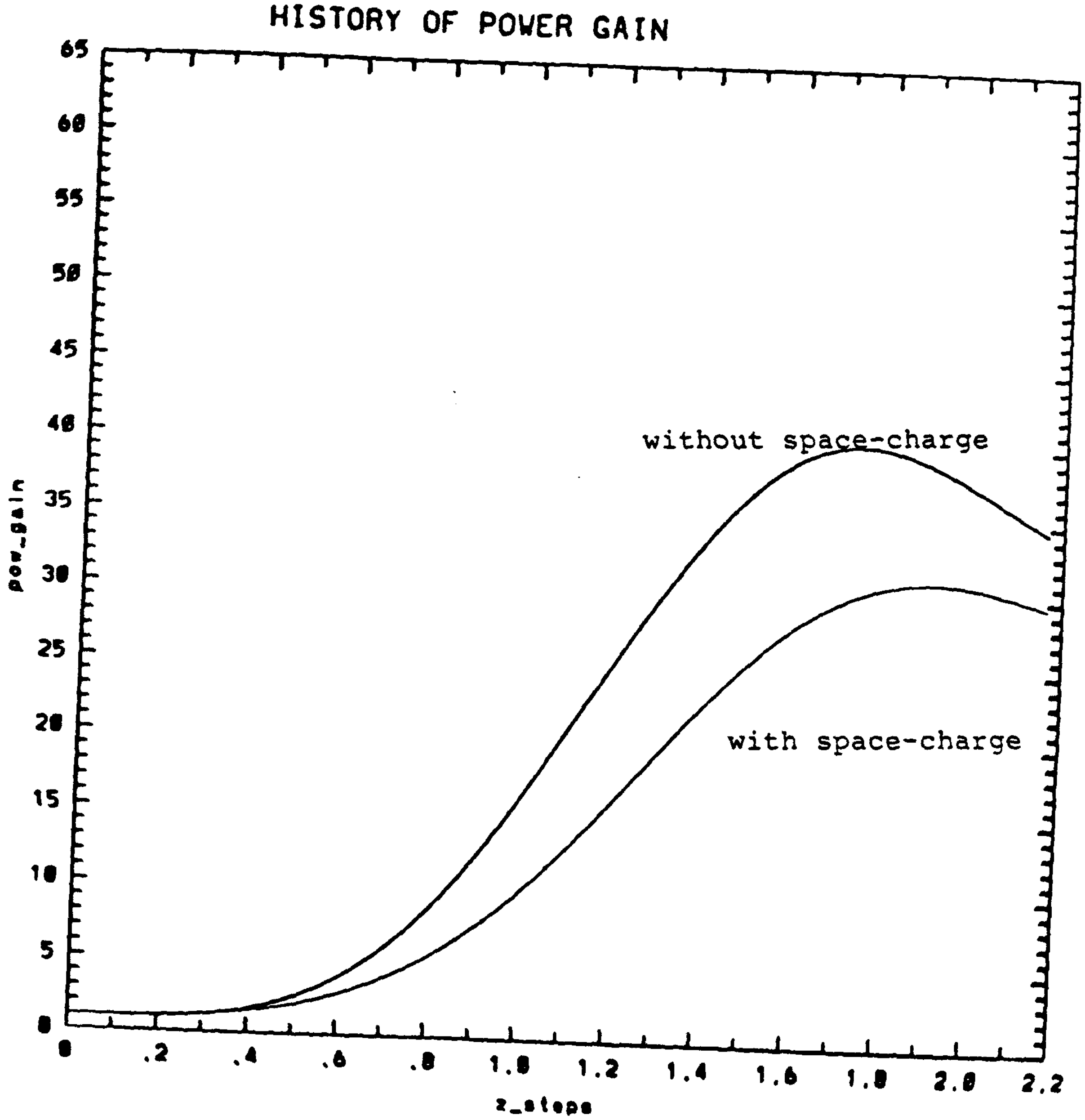

Fig. 2. Effect of space charge for an 8.8 mm microwiggler FEL, 2.2 m long operating at a wavelength of 40 microns.

Figure 3

DISTRIBUTION OF POWER INTO DIFFERENT AZIMUTHAL MODES

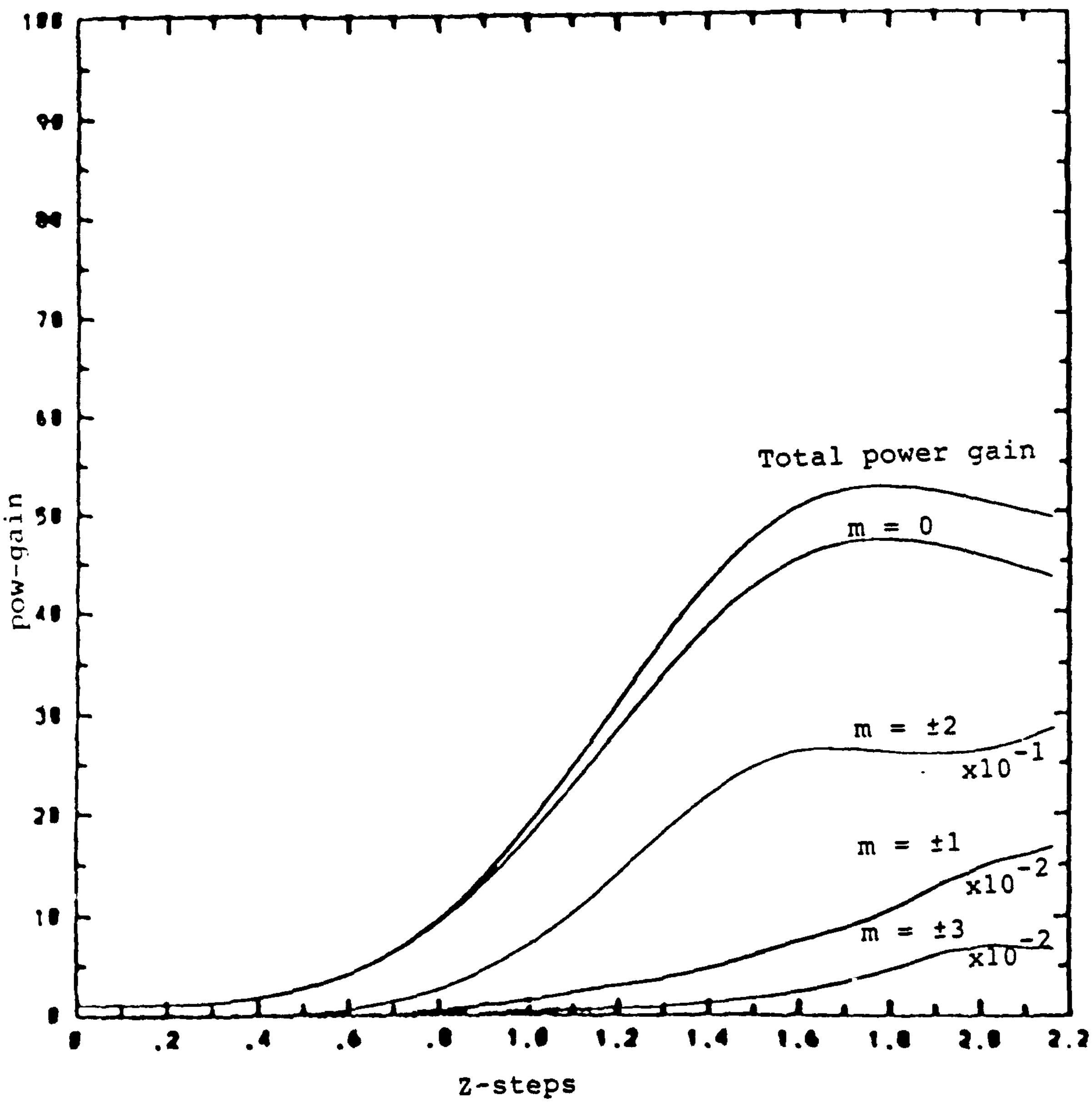

Fig. 3. Power distribution into azimuthal modes using the 3-d simulation code for an 8.8 mm microwiggler FEL 2.2 m long operating at a wavelength of 40 microns.

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