Title:**DEVELOPMENT OF A PULSED MICROWIGGLER
SYSTEM**

LA-UR--92-2805

DE92 040376

Author(s):**Roger W. Warren and Clifford M. Fortgang****Submitted to:****14th International Free Electron Laser Conference
Kobe, Japan
August 24-28, 1992**

MAILED

Received at OSTI
SEP 03 1992**DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Los Alamos
 NATIONAL LABORATORY

DEVELOPMENT OF A PULSED-MICROWIGGLER SYSTEM*

**Roger W. Warren and Clifford M. Fortgang
Los Alamos National Laboratory
Mail Stop H825
Los Alamos New Mexico 87545
Phone: 505/667-1988
Fax: 505/667-0919**

ABSTRACT

Pulsed microwigglers can develop unusually high magnetic fields with short periods. They find potential applications in compact systems that use low energy accelerators that can generate very bright electron beams, and in systems that lase on high harmonics of the fundamental frequency. In the past, many of the unique properties of pulsed wigglers have been addressed. In this paper, we will concentrate on our solutions to the practical problems that must be solved to make such a device work. Among other topics, we will discuss the following: achieving adequate precision in fabrication; controlling quadrupole fields; "trimming" the field after fabrication; providing structural support, cooling, and vacuum; and coupling to the pulsed power supply. Completed microwigglers of our design will be installed in an FEL this summer to lase on the fundamental in the red part of the spectrum and on the third harmonic in the ultraviolet.

I. INTRODUCTION

Pulsed-electromagnetic wigglers can be designed to generate fields of much higher strength and shorter periods than permanent magnet or superconducting wigglers. Various groups are developing this type of wiggler, which often is designed to use many turns of thin copper wire or tape wound on ferromagnetic cores [1-4]. We have built a microwiggler [5] that, instead of wire and ferromagnetic materials, uses two coaxial tubular conductors [6]. These conductors are specially slotted and pierced to generate the desired field and to use available space efficiently. A pulsed- microwiggler system incorporating this microwiggler will be used with the Los Alamos accelerator, APEX, to generate light in the visible and ultraviolet regions of the spectrum. [7]

Because of its unique design characteristics, this pulsed-microwiggler system requires considerable effort—both theoretical [8] and experimental—to understand the details of the fields generated by slots of different depths and shapes and to develop appropriate fabrication techniques. In this paper, we discuss the design of the system's various parts, the problems we experienced in building it, and our solutions to these problems.

*Work supported by Los Alamos National Laboratory Institutional Supporting Research, under the auspices of the United States Department of Energy and the DOE Office of Basic Energy Sciences, Division of Advanced Energy Projects.

II. DESIGN CHOICES

The heating of the wiggler's tubes places a limit on the magnitude and length of its current pulse, on its repetition rate, and on the tubes' dimensions (i.e., diameter, wall thickness, and slot period). For our prototype, we chose a conservative design that can achieve a high field (3 Tesla) for $\sim 100 \mu\text{s}$ with a much shorter period (5 mm) than previously achieved. We made no effort to provide the excellent cooling that is needed to achieve high-pulse repetition rates.

Figure 1 shows a simplified diagram of the wiggler's main components, including the concentric tubes that are cut and pierced so that the current flowing down the tubes produces the desired field on axis. Table 1 lists some of the system's critical parameters. Using a slotted tube with a small inner diameter reduces the current requirement and the temperature reached but is of concern because the optical and electron beams must pass through its bore and because of vacuum pumping problems, wakefield effects, etc. Therefore, we built tubes with two different diameters (Table 1). We performed beam tests on these two types of tubes and on smaller tubes; we experienced no serious problems.

Table 1

WIGGLER

overall length	47 cm
length of wiggler tubes	30 cm
period	0.5 cm
number of periods	51
slot shape	curved "T"
inner diameter	3/32 or 1/16 in (2.4 or 1.6 mm)
outer diameter	1/8 in (3.2 mm)
current for $K_{pk}=1$	30 or 24 kA
resistance	6 or 3 m Ω

TRANSFORMER

V-Sec rating	0.01
turns ratio	4 or 5 stepdown

PFN

pulse length	100 μs
max. current	20 kA
impedance	0.1 Ω

A current of 30 to 40 kA is needed to generate the desired peak K value (about 1.5). This current, the length of the current pulse ($\sim 100 \mu\text{s}$), and the resistance of the wiggler tubes ($\sim 5 \text{ m}\Omega$) determine the current, charge, and energy needed from the pulse-forming network and the size of the impedance-matching transformer. This transformer

is our system's primary component in terms of size and weight. Figure 2 shows a partially assembled wiggler system under test.

III. THE WIGGLER TUBES

Conventional permanent magnet wigglers are composed of many separate magnets that must be assembled. Besides being tedious, this assembly process is also difficult if the magnets used are small. This process, however, also offers significant advantages because of the random nature of the accumulation of field errors and the possibility of reducing these errors by replacing or interchanging offending magnets. A permanent magnet microwiggler has been built by Paulson at UCSB that avoids the difficulty of assembling the magnets by using a series of magnetic poles cut into large opposing blocks of magnet [9]. He finds, however, that this technique produces large field errors because of minor magnetization errors in the large blocks that in turn cause correlated field errors in the individual poles. These correlated errors are difficult to correct and individual poles cannot be replaced.

Our copper tubes have similar problems with correlated errors. Commercial extruded or drawn copper tubes have nonuniform walls. Usually one side of the tube is about 5% thicker than the other. Current flowing through such a tube, whether the tube is slotted or not, concentrates where the wall is thick and produces a transverse field inside the tube that seriously bends an electron beam. As a result we made our own tubes by plating copper on a mandrel composed of a smaller aluminum tube and then removing the mandrel by passing an alkaline solvent through it. Although such plated tubes are currently 50-100 times more uniform than extruded ones, they still produce significant field errors. Therefore, we continue to work to develop more effective tubes.

Unless the depth of the slots is exactly right for the tube's diameter, wall thickness, period, and slot shape, our wiggler generates severe defocusing quadrupole fields. We know the approximate correct depth of the slots [8]; we find the exact value empirically, by cutting different depths and measuring the resulting quadrupole field strength. This technique is also used to determine the depth of the first and last slot to avoid large deflections of the electron beam at the entrance and exit of the wiggler,

The outer tube is pierced with a series of small tapped holes (Fig. 1). These holes allow centering of the inner tube in the outer tube and "trimming," (minor adjustments) of its field. Centering is done by adjusting nylon screws threaded into the tapped holes and bearing on the inner tube. The adjustment must be done with great precision, while observing the field strength as a function of time. After centering the inner tube, we trim the field by enlarging the size of selected holes to alter the current distribution in the outer tube. This process alters the combined field on axis. The fields that need to be corrected are nonperiodic in nature; that is, they are relatively constant down the length of the wiggler. The pattern of holes is such that fields of various complexities can be canceled, including dipole, quadrupole, sextupole, and octupole fields. If not corrected, all of these field components are large enough to severely distort the electron beam. The pulsed wire field measuring technique is used to determine the corrections needed [10]. Its speed, convenience, and high spatial resolution of <0.1 mm are essential during their tedious procedure.

The space between the wiggler tubes is filled with an epoxy or inorganic cement to strengthen their structure and help to cool them. Next, we attach four water cooling tubes to the outer surface of the tube structure with epoxy or inorganic cement. Most of the heat is generated in the inner tube. This heat flows to the cooling tubes through the outer tube and two layers of cement. This cooling technique is inefficient and must be improved if we are eventually to achieve a high pulse repetition rate. The heating during one current pulse occurs so fast, however, that the cooling technique used has no effect on the wiggler's temperature rise during a macropulse.

Electrical contact to the inner and outer tubes is provided by standard brass Swagelok connectors [11]. Currents of up to 50 kA have been used with these connectors without any problems. Furthermore, their demountable feature (and the design of the system) allows the inner and outer tubes to be easily replaced as a unit.

V. SUBSYSTEMS

Current supply

The source of the current pulses is a conventional $0.1\ \Omega$ PFN containing twenty 25- μF capacitors; it is switched with an ignitron. No special care has been taken to reduce an initial overshoot or to optimize the flatness of the current pulse. The PFN is connected through a coaxial cable to a stepdown transformer mounted coaxially with the wiggler. The single-turn secondary of the transformer is composed of the tight-fitting transformer case and the inner and outer wiggler tubes. A transformer of this kind was needed to couple the PFN to the low-impedance wiggler load, to provide a low series inductance, and to provide a short, symmetrical current path to the wiggler.

Trim Coils

The four water cooling tubes are also used to supply uniform field corrections down the length of the wiggler. A current of up to 200 A can be passed through three of the tubes and returned through the fourth tube. This arrangement generates independent x and y dipole fields and a quadrupole field of a special orientation. Together they can cancel any residual dipole or quadrupole fields generated by bad tubes or slots of the wrong depth. These currents are pulsed on for $\sim 100\ \mu\text{s}$ and are generated by electronic circuits connected to three pulse transformers that, like the main transformer, are biased and mounted close to the cooling tubes to reduce inductance. The current pulses can be tailored. For example, the quadrupole strength can be increased during the $100\ \mu\text{s}$ current pulse to compensate for heating effects near the slots. These uniform correction fields, together with the localized field trimming, provide a flexible, if complex, control over field errors. We hope to eventually find a supply of more uniform tubes so that we can eliminate or simplify this complex system.

Wiggler support and vacuum tubes

The wiggler tubes are surrounded by a third metal tube. This cylinder supports the tubes at their free ends (the opposite end from the current connectors) and contains windows through which field trimming of the outer tube is conducted. This cylinder also

contains a heavy stainless steel shield to protect the wiggler from an errant electron beam.

Around the support tube is a fourth vacuum tube. We used various materials to build the wiggler, including rubber O-rings, fiberglass insulators, and epoxy cements. Tests show that the vacuum attained ($\sim 10^{-5}$) is low enough so that it has no effect on the electron beam.

Other systems

Fully assembled, the microwiggler system weighs about 50 pounds. We have mounted it so as to provide four degrees of motion: two translations perpendicular to the beamline and two rotations with axes perpendicular to the beamline, all achieved by adjustments of micrometer screws. The wiggler is electrically isolated from the beamline. Extensive electrical diagnostics allow us to monitor all of the electrical signals provided to the wiggler. Screens can be inserted into the beamline very close to the wiggler to provide views of the position and shape of the electron beam.

V. PRELIMINARY PERFORMANCE

We built two prototypes. One was tested at currents up to 35 kA. Lasing was tried with it, but was not achieved [7]. We experienced two problems. First, because the tubes were imperfect we had to enlarge the holes in the outer tube extensively to correct a dipole field error. This elimination of the dipole field was successful and was done in such a way as to keep the quadrupole fields low. Unfortunately, the correction introduced sextupole and octupole fields that seriously deformed the electron beam. Second, the gas pressure in the wiggler tube was seriously increased by the combined effects of outgassing from the epoxy used to construct the prototype and by a discharge in this gas caused by the longitudinal electric field normally present on the axis of the wiggler.

We are working to correct these problems in the second prototype by using new trimming techniques to eliminate the sextupole and octupole fields and by using inorganic adhesives instead of epoxies. In future studies, we will test a thin metal liner tube that will be placed inside the wiggler tube. This liner is expected to simultaneously eliminate the longitudinal electric field, provide a cleaner environment for the electron beam, and eliminate wakefields.

VI. CONCLUSIONS

Pulsed microwigglers promise significant advances in FEL technology. In particular, they could be used in conjunction with inexpensive, compact accelerators to generate short wavelength radiation. The technology is new, however, and further research is needed to make it work. We have progressed to the point where we are now trying to lase with prototypes that have fields and periods well beyond those produced by conventional techniques. We have encountered problems but expect to achieve lasing in the near future. Further developments in fabrication techniques should simplify our designs and extend their performance to achieve fields of higher strength and shorter periods.

VII. ACKNOWLEDGMENTS

We wish to thank Sherman Armstrong, Kerry Prewett, and Stephen Guillet for their painstaking work, constructing and cutting slots in the wiggler tubes.

VIII. REFERENCES

- [1] S. C. Chen, G. Bekefi, S. Dicecca, and R. Temkin, "Tunable microwigglers for free electron lasers," Nucl. Instrum. Methods, A285, 290 (1989) .
- [2] A.Sneh and E. Jerby, "Coaxially fed folded foil electromagnetic wiggler", Nucl. Instr. and Methods., A285, 294 (1989).
- [3] C. Zhou and M. Wang, "An experimental study of a shielded pulsed electromagnet wiggler concept," Nucl. Instrum. Methods, A296 555 (1990).
- [4] H. P. Freund, H. Bluem, and R. H. Jackson, "Nonlinear theory and design of a harmonic ubitron/free electron laser," Nucl. Instrum. Methods, A285,169 (1989).
- [5] R.W.Warren, D. W. Feldman, and D. Preston, "High Field Pulsed Microwigglers," Nucl. Instrum. Methods, A296, 558 (1990) R. W. Warren, "Progress with the slotted-tube pulsed microwiggler", Nucl. Instrum. Methods, A318,789 (1992).
- [6] R. L. Gluckstern, "Slotted cylindrical shell for use as a compact wiggler", Phys. Rev. A3889 (1991).
- [7] R. W. Warren, P. G. O'Shea, S. C. Bender, B. E. Carlsten, J. W. Early, D. W. Feldman, C. M. Fortgang, J. C. Goldstein, M. J. Schmitt, W. E. Stein, M. D. Wilke, T. J. Zaugg, B. E. Newnam, and R. L. Sheffield, "Lasir.g with a Microwiggler on the Los Alamos APEX FEL," submitted to this conference.
- [8] Brian E. Newnam, Roger W. Warren, John C. Goldstein, Mark J. Schmitt, Steven C. Bender, Bruce E. Carlsten, Donald W. Feldman, and Patrick G. O'Shea, "The Los Alamos POP Project: FEL oscillator experiments in the ultraviolet and beyond," Nucl. Instrum. Methods, A318, 197 (1992).
- [9] K. P. Paulson, "Micro-undulator research at UCSB," Nucl. Instrum. Methods, A296, 624 (1990).
- [10] R. Warren and D. W. Preston, "Field measurements in pulsed microwigglers," Nucl. Instrum. Methods, A318, 818(1992).
- [11] Crawford Fitting Co., 29500 Solon Rd., Solon, Ohio 44139.

FIGURE CAPTIONS

- 1. Simplified drawing of the two concentric wiggler tubes.
- 2. Wiggler system being tested.

fig 2