LA-UR -91-3237

LA-UR--91-3237 --30

DE92 002460

TITLE: FIELD MEASUREMENTS IN PULSED MICROWIGGLERS

AUTHOR(S): R. W. Warren, D. W. Preston, AT-7

SUBMITTED TO: Free Electron Laser Conf.,
Santa Fe, NM
Aug. 25-30, 1991

FIELD MEASUREMENTS IN PULSED MICROWIGGLERS*

Roger Warren
Los Alamos National Laboratory

and

Daryl W. Preston
California State University, Hayward

ABSTRACT

A pulsed microwiggler can provide a large field, greater than 5 T, with a short period, less than 2 mm. It is essential to find a way to measure the field produced in the small bore, with accuracy as well as with high resolution in all three coordinates and the time domain. Conventional field-measuring probes are too large and have poor temporal resolution, but the pulsed-wire technique is well suited to these demands. Los Alamos researchers have made recent improvements to this technique.

I. INTRODUCTION

The pulsed-wire technique [1, 2] is quite different from competing magnetic field-measuring techniques, and it has particular advantages and disadvantages that can be important in some circumstances. A thin wire is stretched between two supports in the region where the field is to be measured and a current pulse is passed through the wire. A force equal to the product of the wire's current and the field perpendicular to the wire is exerted on the wire. The force generates a deflection of the wire that progresses to both ends of the wire as a wave. A sensor at one end

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

detects the wave's amplitude and time dependence. This amplitude signature is analyzed for the field magnitude and orientation along the wire.

The pulsed-wire technique has special advantages:

1. One measurement gives the field all along the wire rapidly and conveniently.
2. Both field components perpendicular to the wire can be measured simultaneously.
3. If a short current pulse is used, the measurement corresponds to the field at one instant of time.
4. The field probe is the thin wire; it can fit into spaces much smaller than those for a typical probe. The signal generated on the wire is propagated down the wire to a convenient spot where there is room for the sensor.
5. Depending on the length of the current pulse, the amplitude measurement gives directly either the first or the second integral of the magnetic field. If the field is to deflect electron or ion beams, the integrals are particularly useful. The first integral, for example, determines the angular deflection of the beam; the second, the amplitude of its transverse deflection. Using more common field-measuring techniques, we have to determine these important quantities by measuring the field and then integrating these results numerically, a tedious method fraught with errors.

The major disadvantages of the pulsed-wire technique are related to the sag in the wire, distortions in the signature caused by the stiffness of the wire, and the occurrence of spurious signals that are not understood.

The purposes of this paper are threefold: to describe advances we have made in the hardware, toward simplification and increased sensitivity for use with microwigglers; to identify and clarify the sources of some of the spurious signals; and to describe some situations in which we have found the pulsed-wire technique especially valuable.

II. HARDWARE ADVANCES

Figure 1 shows a photograph of a recently improved sensor of the wire's motion. Included are two (for x and y motions) red solid-state lasers [3] illuminating two high-speed, solid-state photodetectors [4]. The detectors are powered by a 15-V power supply and are connected to 500-ohm loads. The (approximately single mode) lasers are tightly focused on one edge of the wire, providing a spot with a diameter of ~1 mil (25 μm). The detectors have a rapid response (much faster than 1 μs) and provide a sensitivity of about 1 V/mil of wire motion.

The electronic noise level of this circuit is such that a wire motion of about 1 μm (typical of a normal signal) produces a signal-to-noise ratio of ~100. The signal-to-noise ratio, including noise caused by vibrations of the equipment, is normally ~10 times worse. Increasing the signal strength, for example, by driving the wire harder with a higher current or a longer pulse would improve this ratio. We are limited, however, by heating of the wire and by various nonlinear effects that occur with large wire deflections, such as those described below. There is a real need to reduce vibrations of the wire by using an isolation system of some sort on the anchors at both ends. At present, we reduce the effect of random vibrations by signal-averaging techniques.

At one time, we used to use copper wire 4 mils in diameter [1]. We now routinely use tungsten wire 1 mil in diameter and are testing even thinner wires. A 1-mil tungsten wire is amazingly strong. It can be seen under good lighting and manipulated with relative ease. Such a small diameter is necessary to minimize problems with wire stiffness [2], especially if wigglers with short periods are to be measured. Such thin wires produce weak electrical signals, so the enhanced sensitivity and low noise previously described are necessary. To mount the wire, we carefully unroll it from a spool, thread it through the eye of a long needle, thread the needle through the position sensor and the wiggler, position the wire over a roller bearing (to equalize tension), and then clamp the needle with its wire to a weight that provides tension (~50 gm for a 1-mil tungsten wire). The other end of the wire is clamped by a simple wingnut.

III. NEW UNDERSTANDING

The signal that is received by the position sensor has at least four spurious components. The first, caused by the finite stiffness of the wire, has been recognized before [2]. Stiffness causes the signal moving along the wire to be distorted because of the higher velocity of its short-period components. We (and others [5]) have recently identified three other less important distortions: weak signals that arrive at the sensor after the main signal, weak signals that arrive before the main signal, and signals that are distorted by a rotation of the polarization of the wire's displacement.

The weak signal that arrives after the main signal differs in detail if the wire is replaced by another of the same kind, but it is reproducible with a given wire. We find that it is caused by reflections of the signal at slight imperfections, dirt, or kinks in the wire. We can reduce the reflection to less than 1% of the main signal by mounting the wire so as to avoid kinks and, sometimes, by cleaning it. The other two distortions are not reproducible, we find they are induced by random vibrations of the wire that grow in strength at the expense of the main signal. The details of this growth are complicated. A second kind of wire motion, a longitudinal stretching mode, is involved. A longitudinal vibration can proceed down the wire almost independently of the transverse vibration, with a velocity that is ~20 times higher than that of the transverse vibration [6]. The longitudinal vibration is weakly coupled to the transverse vibrations because the transverse deflections also stretch the wire. The coupling of these two kinds of vibrations, as well as the higher velocity of the longitudinal wave, can explain both the early spurious signal and that with rotated polarization.

To illustrate the kind of coupling we invoke, consider a simple vibrating system. A mass, m, is suspended in the center of a wire of length, l, with tension, t_0. The mass and wire are set vibrating in the x-direction with a large amplitude, x_0, and a frequency, w. They are also set vibrating in the y-direction with the same frequency, a much smaller amplitude, y_0, and a different phase, theta. Because of the x-motion, the wire's tension, t, oscillates as $t=t_0(1+a*x_0^2*\sin [2 wt])$, where the constant, a, depends on the properties of the wire. The time-dependent force exerted on the mass in the x-direction by the wire's tension is $f_x=4*t*x_0*\sin(wt)/l$, and in the y-direction, $f_y=4*t*y_0*\sin(wt+theta)/l$. These forces can feed energy into the corresponding motions. The rates of energy transfer into the transverse modes can be calculated from these forces times the corresponding velocities. In the x-direction, this power averages to zero. If theta is not zero, the power flow in the y-direction is not zero, but peaks at the value $a*x_0^2*y_0^2*t_0*w/l$ for theta $= 45°$. One can show that the energy of the y-directed vibration increases exponentially with time at the expense of the x-directed vibration until they are roughly equal. The time constant for this growth is proportional to the period of oscillation divided by $a*x_0^2$. To keep this growth rate low (i.e., the time constant for energy transfer long), x_0 should be small and the wire should be very long or "rubbery," (i.e., it should have stretched a long distance to establish its tension).

The mechanism invoked above for the rotation of polarization with a single mass has been extended to cover a standing wave on a wire, with similar results. The calculated rate of transfer from one polarization to the other agrees with the observed phenomena. This process of energy transfer from one transverse mode to another through the action of the longitudinal mode is, we believe, responsible for the remaining two kinds of spurious signals. In one case, the energy transfer is from one polarization of transverse oscillation to the longitudinal motion and then to the opposite polarization, all at the same position on the wire. This transfer produces a localized rotation of polarization. In the other case, the energy transfer is also to the longitudinal mode. But this mode propagates down the wire before it is transferred back to a transverse mode. Because of the high velocity of the longitudinal mode, the final transverse mode can be detected well ahead of the main signal. In either case, the amplitude of the spurious signal grows exponentially with time, starting from random vibrations. We can control the growth by keeping the wire's main displacement, x_0, fairly small and by reducing the "noise" on the wire that starts the growth. By using these strategies, we have kept the early spurious signal smaller than 1% of the main one, and we have reduced polarization rotation to a negligible amount. These spurious signals can be more serious in other situations, for example, when long wigglers are examined. It is, therefore, important to recognize them when they occur and to understand their origins.

We have investigated the ultimate consequence of spurious signals in the following way: we have measured the field in a wiggler and have corrected the field errors by adding small correcting magnets at appropriate places [7] until the errors were very small. We then flipped the wiggler end to end and remeasured the field. The spurious signals were different, but the field errors observed were still small, needing no further correction.

IV. SPECIAL USES

We have used the pulsed-wire technique in three special cases: to align solenoid and quadrupole magnets used in accelerator beamlines to focus and guide the beam, to rapidly measure and eliminate steering and focusing errors in conventional permanent magnet wigglers, and to measure similar errors in pulsed electromagnetic microwigglers.

The major advantages of the pulsed-wire system used to align beamlines are the speed with which results can be obtained and the convenience of using this technique with systems that are already completely assembled. In practice, we often thread the wire through a complex, confined system, which includes the magnets to be measured, as well as beam pipes, valves, pumps, position detectors, etc. The measurements often show the presence of unexpected fields contributed by these auxiliary devices. The precision achieved has been high [8] (i.e., components can be aligned to a tolerance of a few mils).

We have built and measured the field errors in six permanent magnet wigglers. Fig. 2 shows a typical measurement made on a conventional 1-m-long wiggler with a long current pulse [1], showing the trajectory an electron will experience in the wiggler. Clearly shown are large unwanted bends in the trajectory. We have developed techniques [7] that allow us to identify the magnet that is the source of the error, to understand what is wrong with this magnet, and then to eliminate the error by gluing a small correcting magnet on the offending magnet, in the right place and with the right orientation.

We have measured the fields in three different, pulsed electromagnetic wigglers, with periods as short as 3 mm. Figure 3 shows a typical measurement made with this technique on a wiggler with a 6-mm period [9]. Two traces are shown (i.e., with and without current supplied to the wiggler). On the right side of each trace is the signal generated by a permanent magnet array of known strength, used to calibrate the sensitivity of the sensors. Weak noise signals can also be seen. They are dominated by vibrational noise, but also contain contributions from the spurious signals discussed above. This noise is normally reduced by signal averaging. The electromagnetic wiggler was supplied with a 20 kA current pulse 100 μs long to generate a peak magnetic field on axis of about 2.5 T. The current used in the wire to measure this field was pulsed on for only 3 µs. The timing of this short pulse was varied to measure the fields strength at various times during the 100-µs field pulse. It was easy to observe variations in strength caused by the inductance of the wiggler, the time it took for the field to penetrate the wigglers slots, and the heating that took place during the 100-µs pulse.

V. CONCLUSIONS

We have made major improvements in the hardware of the pulsed-wire technique that have increased its sensitivity and reduced noise by about a factor of 100. Further improvements should isolate the wire from vibrations that are coupled in from the environment. We understand more clearly the source of several kinds of spurious signals. We know how to reduce those signals to levels that are inconsequential to us. We believe that the signals do not generally cause errors in interpretation; that is, they do not identify a field error that is not really there or miss one that is there. We have exercised the pulsed-wire technique in several different applications and find it to be flexible, fast, and convenient. Its use with pulsed microwigglers is, we believe, a special case. We have found that our microwiggler work could not have proceeded without this technique. No other field measuring technique could have provided the capability to fit into a very small space, the ability to measure the field at a particular time on a microsecond time scale, and the speed and flexibility to allow many measurements to be made during the adjustment of the wiggler.

REFERENCES

1. R. W. Warren and C. J. Elliott, "A New System for Wiggler Fabrication and Testing," in Undulator Magnets for Synchrotron Radiation and Free Electron

Lasers, eds. R.Bonifacio, L.Fonda, and C. Pelligrini World Science Publishing Co., (1988) p. 28.

2. R. W. Warren, "Limitations on the Use of the Pulsed-Wire Field Measuring Technique," Nucl. Instr. and Meth. A272 (1988) 257.
3. Available from Lasermax Inc., 207 Tremont St., Rochester, NY, 14608.
4. Model OP9135L available from Optek Technology, Inc., 1215 West Crosby Rd., Carrollton, Texas 75006.
5. O. Shahal, B. V. Elkonin, and J. S. Sokolowski, "Dispersion Interference in the Pulsed-Wire Measurement Method," Nucl. Instr. and Meth. A296, (1990) 588; O. Shahal and R. Rohatgi, "Pulsed Wire Magnetic Field Measurements on a 4.3 m Long Wiggler," Nucl. Instr. and Meth. A285 (1989) 299.
6. Acoustic Properties of Solids, in American Institute of Physics Handbook, 2nd Ed., Ch.3f, pg.88.
7. D. Preston, "Wiggler Field Measurements and Corrections Using the Pulsed Wire Technique," in these proceedings.
8. C. Fortgang, L. Dauelsberg, C. Geisk, D. Liska, and R. Shafer, "Pulsed Taut-Wire Alignment of Multiple Permanent Magnet Quadrupoles," in Proceedings of the 1990 LINAC Conference LA-12004-C, Los Alamos National Laboratory report (1990) 426.
9. R. W. Warren, "Progress With the Slotted-Tube Pulsed Microwiggler'" in these proceedings.

FIGURE CAPTIONS

1. Photo of an x- and y-position sensor.
2. Typical field (double integral) measurement illustrating electron trajectory.
3. Typical field (integral) measurement in a pulsed microwiggler.

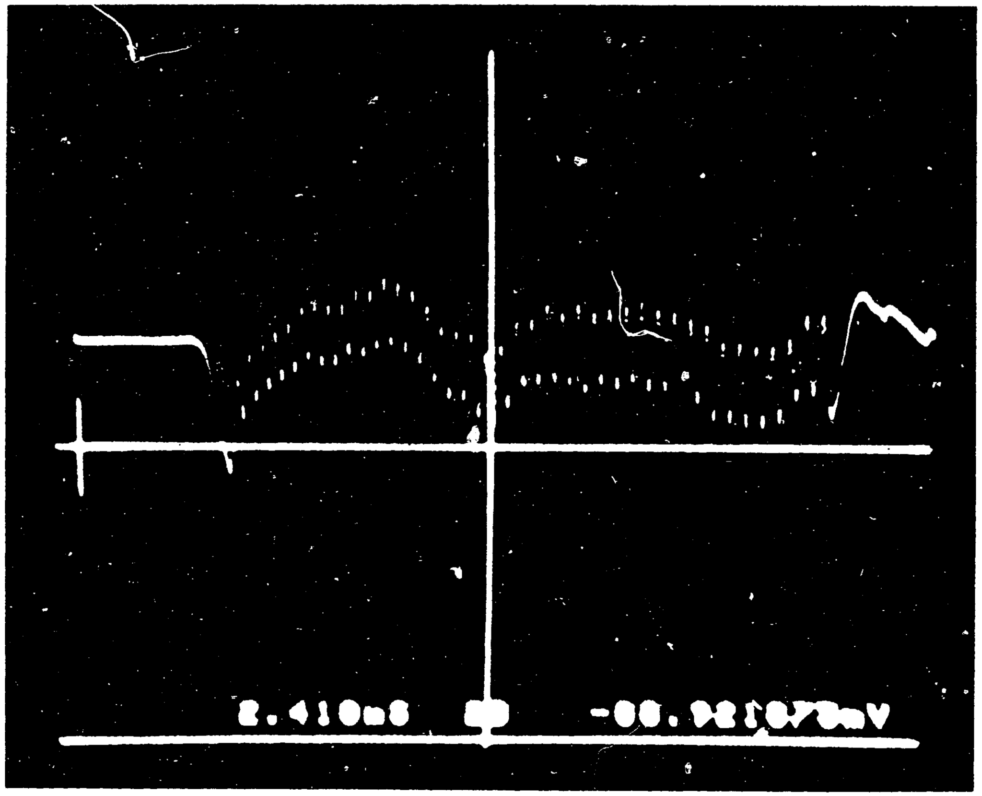

fig 2

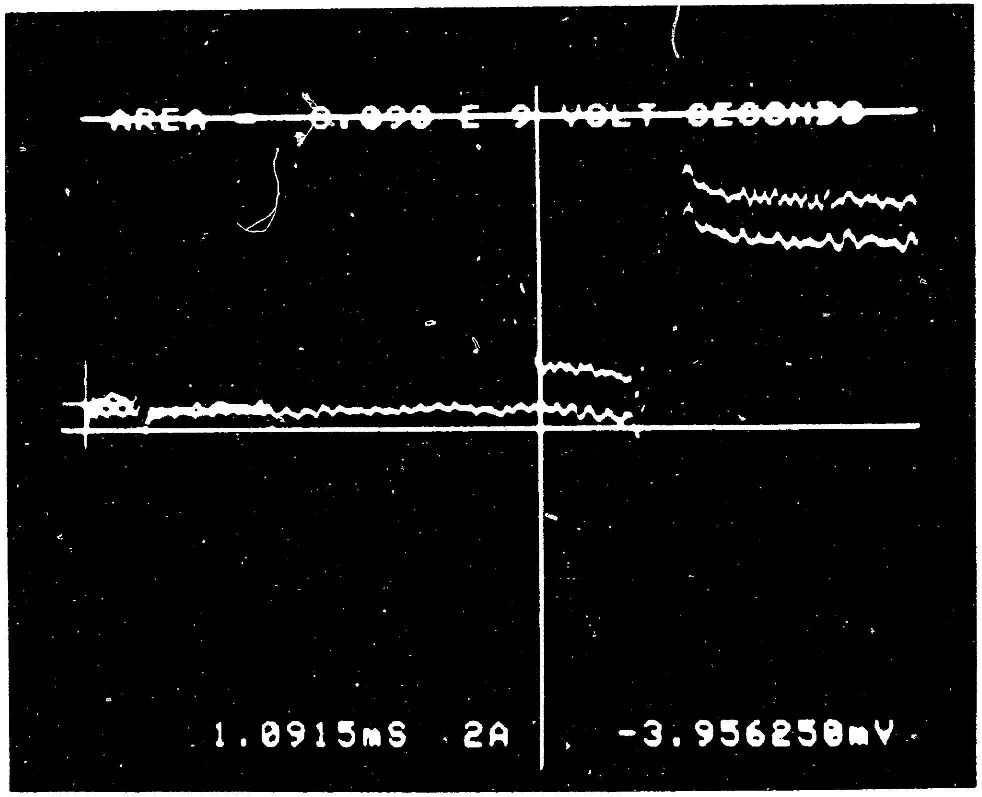

fig 3

END

DATE FILMED

12 / 09 / 91