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Amorphous magnetic wires for medical locator applications

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Abstract:

This paper evaluates the feasibility for implanting short segments of Barkhausen wires in treatment volumes of patients requiring radiation therapy. Such locating of deep-seated sites prior to each treatment is not done routinely or is usually achieved through imaging with ionizing radiations. Present therapeutic procedures can result in substantial heterogeneities in the dose distributions or significant doses to surrounding normal tissues, resulting in poorer control of the tumors and/or increased complications. The implants make it possible to accurately locate the wire by way of re-entrant flux measurements and hence pinpoint the treatment volume prior to and during treatment.

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We have measured voltage pulses as a function of position, induced in a small pickup coil due to re-entrant flux reversal from amorphous magnetic wires. Our interest in this spatial mapping lies in exploring the feasibility of an implanted wire in patients as a locator tag for medical treatments, e.g. radiation therapy requiring precise position accuracy [1]. While magnetic domains of amorphous magnetic wires have been studied in considerable detail, neither the induced voltage as a function of position resulting from re-entrant flux reversal nor use of the wire as locator tags have been previously reported [2-5]. The importance of the medical application relates to the fact that internal organs requiring radiation therapy are subject to movement within the body over time. Therefore, location of a tumor determined by an x-ray CAT scan or magnetic resonance imaging (MRI) prior to the onset of the radiation treatment becomes inaccurate once organs readjust position due to eating, walking or other bodily motions. As a result, radiation extending periodically over days or weeks can miss the intended target with collateral damage to neighboring tissue. By sensing the position of a small implanted tag magnetically it becomes possible to pinpoint a tumor's location just prior to or during treatment.

We show that scanning the re-entrant flux reversal driven by a sinusoidal magnetic excitation field can be used to accurately determine the position of a remotely located amorphous wire. The preliminary measurements reported here are three dimensional but for a limited set of initial conditions. However, the data illustrate the feasibility of the method for the intended medical application. A small pickup coil (1.5 cm diameter) with 300 turns of wire and a ferrous core is moved manually to different positions with respect to the wire to measure the induced voltage from re-entrant flux reversal. Both 50 and 125 micron diameter wires were used, ~3 cm and ~7-9 cm in length respectively. The experimental arrangement is shown in Fig 1. To excite the wire, a 60-80 Hz sinusoidal ac signal from a signal generator is amplified by a Kepco bipolar current supply to provide ac magnet current. The magnet can deliver ~ 2.5 gauss, well above the critical field, H* required to switch amorphous wires which exceed the minimum length required for switching[4]. The induced voltage is amplified by a preamplifier followed by a differential amplifier prior to oscilloscope display or signal averaging when used with a boxcar integrator. For the data presented, a differential amplifier was used with one input preceded by a low pass filter to cancel the low frequency excitation field in the display.

Voltages are plotted in Fig 2 for the pickup coil positioned with its circular plane perpendicular to the vector extending outward from the center of the dipole. The **r** component of the re-entrant flux reversal is measured by the pickup coil as a function of distance along r from the midpoint of the dipole wire of length L, with polar angle θ as shown in Fig. 1. The voltage for $\theta = 30^0$ as a function of r is plotted in Fig. 2 a) on a log-log scale, shown behaving as a dipole field, as predicted by Eq. 1,

$$V(\mathbf{r}) = d/dt\,[\,k\,m(t)L(\cos\theta)/r^3\,]. \qquad (1)$$

Here V is the induced voltage, L the length of the dipole (amorphous magnetic wire), m(t) the time varying magnetic pole strength and k a proportionality constant. The dashed line in Figure 2 a is a normalized plot of $1/r^3$, in close agreement with the data points and Eq.1. Figure 2 b) is a plot of $V(\mathbf{r})$ at $r = 8$ cm as a function of θ with θ varying from 0 to 90^0. Shown also are points representing $V_0 \cos\theta$ with V_0 the normalization factor equal to the experimentally determined voltage at $\theta = 0^0$. The experimental and theoretical values are in good agreement, indicative of the utility of the wire as a locator tag. Both 2 a) and 2 b) are for a 3 cm long wire, 50 microns in diameter. Voltages for fields in the θ direction have also been measured but are not presented here due to space limitations.

To test the wire in a manner approximating our intended medical tag application, we used a 125 micron diameter wire, 8.9 cm in length and measured induced voltages in the xy plane of the wire at a height $z = 10$ cm above the wire. Here, the wire lies along the y direction with x perpendicular to y and both x and y lying in the plane of the wire. The plane of the pickup coil was maintained parallel to the xy plane. In this coordinate system, the points x=0, y=0 correspond to the center of the dipole. The array of voltages obtained in this manner are shown in the matrix of Table I. Based on the data, the resolution of the coil is better than +/- 0.5 cm in the x direction though valid measurements up 30 cm from the wire have been taken with the aid of a boxcar integrator and additional amplifiers. The data in Table I indicates the induced voltage to be 0 at y=0 (center of dipole) for all values of x due to the cosine dependence of V (Fig 1) and the axial symmetry of the wire.

Following these measurements, a 6.4 cm thick rectangular slab of raw bovine tissue (steak) was placed over the wire to simulate an implanted wire onto a human. The tissue is non- attenuating to the re-entrant magnetic field as we expect and we find experimentally, so that the same values of Table I can again be found by scanning the now covered region. The maximum value of V will lie along the y direction for x=0 as shown in Table I. Once that value has been found, it is straightforward to locate x=0, y=0 'blind', i.e. the center of the dipole with the wire covered. This type of scanning is precisely what we desire for locating the medical tag .

The present measurements of re-entrant flux reversal as a function of position confirm that short sections of implanted wire will be useful in locating visibly inaccessible living tissue and hence have the desired medical applications. Initial conditions have so far required that the wire be straight and its length known. A more difficult task remains, namely that of locating the magnetic dipole for an arbitrary unknown initial position which corresponds more realistically to a medical implant. We are presently working on finding the algorithm to solve this problem using multiple sets of interrogation coils. To date we are encouraged that even very short wires (2.7 cm, 50 microns in diameter) have the potential of being used as tags to accurately locate hidden portions of the human body requiring medical treatment.

References:

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4) Isamu Ogasawara, 6th MMM-Intermag '94 Satellite Workshop on Rapidly Quenched Magnetic Wire & Applications, June 24, 25, Albuquerque, NM (1994).

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Figure Captions:

Fig. 1. Experimental arrangement of dipole wire and associated electronics.

Fig. 2. Measured values of pickup voltage V, (wire 3 cm long, 50 micron diameter) proportional to Eq. 1 as a function of a) distance **r** measured from the center of the dipole, (squares) and b) as a function of θ (squares). Shown also are normalized curves for a) $1/r^3$ fit, the log-log plot and b) $V_0 \cos\theta$ (diamonds) indicating close agreement between experiment and theory. .

Table I. An xy array of voltages scanned at several points (x) perpendicular to the axis of the wire and points y, parallel to the axis of a 125 micron wire, pickup at z =10 cm above the plane of the wire's support table. Subsequently, the region was covered by raw bovine tissue, 6.4 cm high; the wire's center was located 'blind' by way of the unchanged dipole voltages.

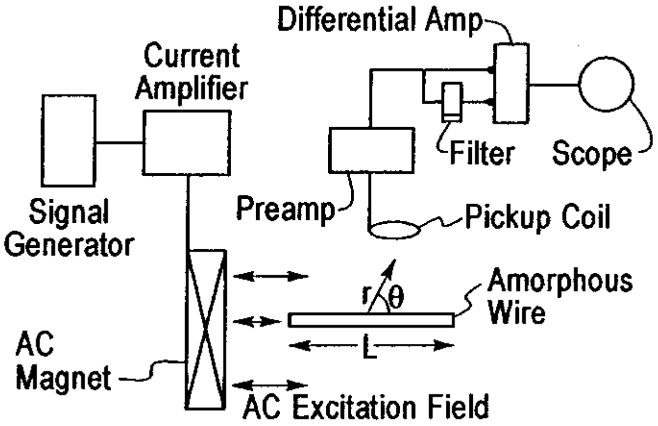

Fig 1

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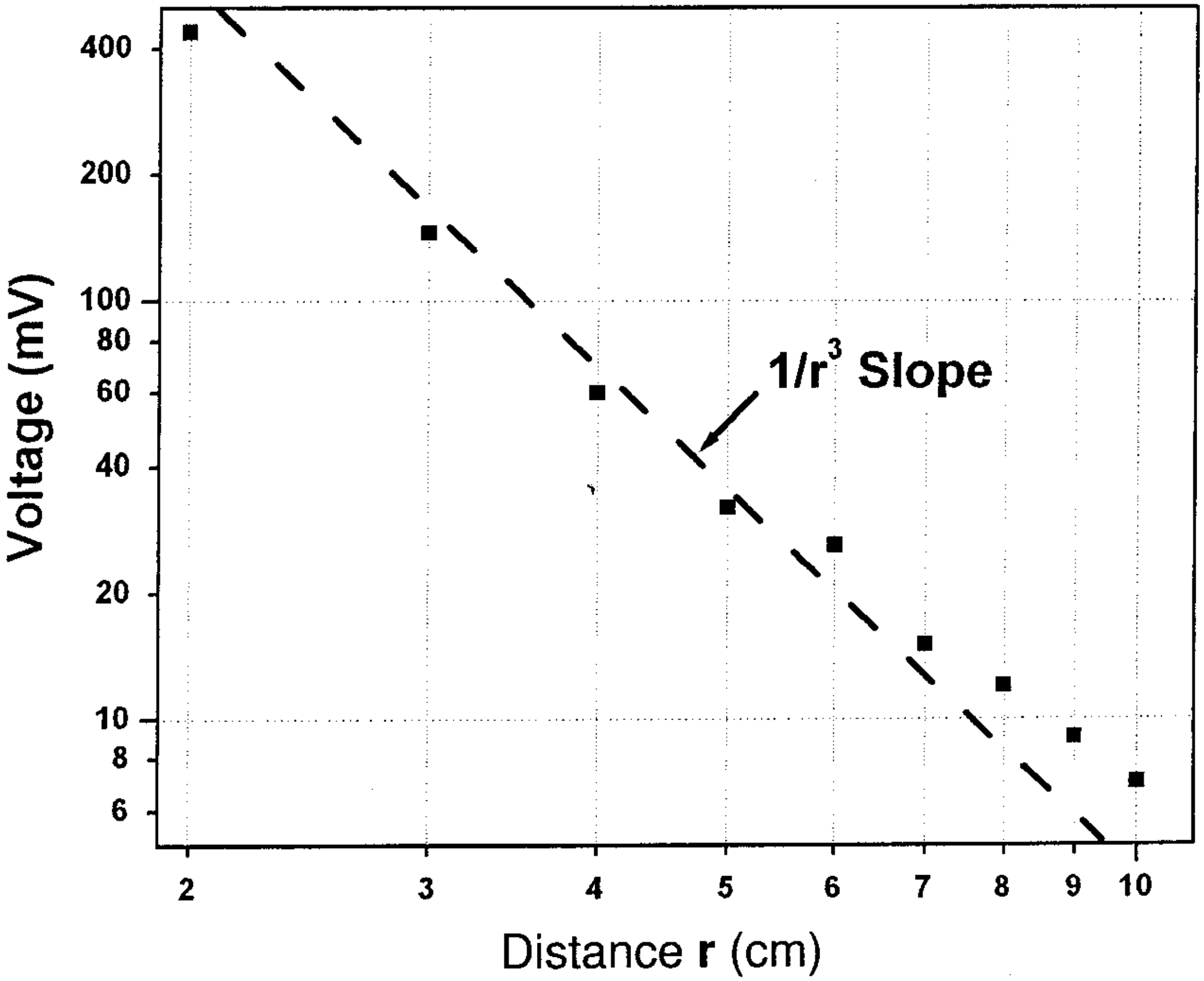
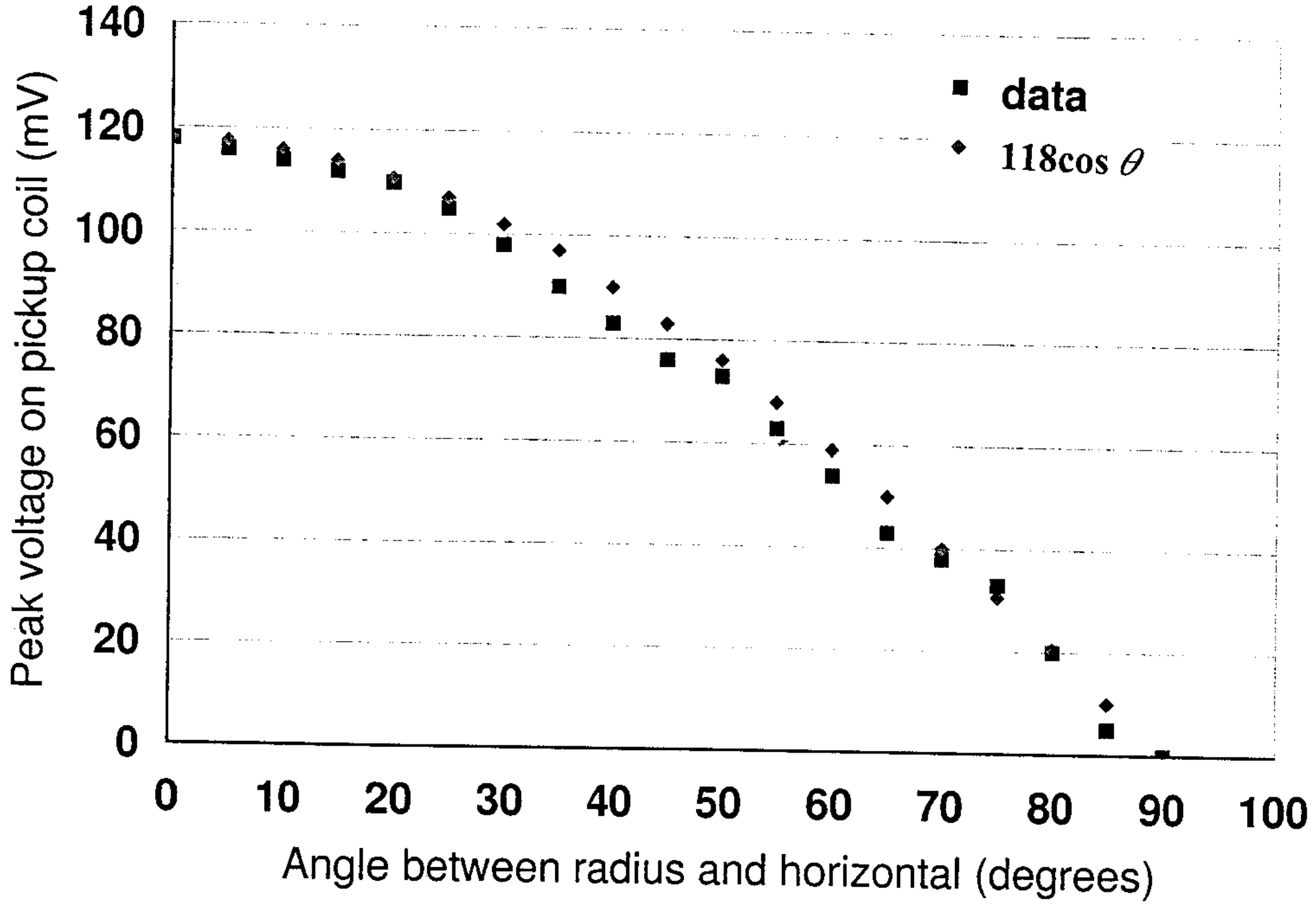


400
200
100
80
60
40
20
10
8
6
Voltage (mV)
1/r³ Slope
2
3
4
5
6
7
8
9
10
Distance r (cm)

Fig 2a



140
120
100
80
60
40
20
0
Peak voltage on pickup coil (mV)
0
10
20
30
40
50
60
70
80
90
100
Angle between radius and horizontal (degrees)
data
118cos θ

Fig 2b

Voltage (mV) as a function of position

	x=-2cm	-1cm	-0.5cm	0cm	0.5cm	1cm	2cm
y=8cm	66	69	70	72	70	69	66
7cm	68	72	73	74	73	72	68
6cm	72	75	76	77	76	75	72
5cm	74	77	78	79	78	77	73
4cm	64	68	70	71	70	68	63
3cm	53	54	56	58	56	54	52
2cm	36	38	39	39	38	38	36
1cm	16	17	18	19	18	17	16
0cm	0	0	0	0	0	0	0
-1cm	-17	-18	-19	-20	-19	-18	-17
-2cm	-37	-40	-41	-42	-41	-39	-36
-3cm	-52	-54	-56	-57	-55	-54	-51
-4cm	-63	-68	-69	-70	-69	-68	-62
-5cm	-73	-76	-77	-78	-76	-75	-69
-6cm	-71	-74	-75	-77	-75	-73	-67
-7cm	-69	-72	-73	-74	-72	-71	-66
-8cm	-64	-66	-67	-69	-66	-65	-62

APL

Table I
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Voltage (mV) as a function of position

	x=-2cm	-1cm	-0.5cm	0cm	0.5cm	1cm	2cm
y=8cm	66	69	70	72	70	69	66
7cm	68	72	73	74	73	72	68
6cm	72	75	76	77	76	75	72
5cm	74	77	78	79	78	77	73
4cm	64	68	70	71	70	68	63
3cm	53	54	56	58	56	54	52
2cm	36	38	39	39	38	38	36
1cm	16	17	18	19	18	17	16
0cm	0	0	0	0	0	0	0
-1cm	-17	-18	-19	-20	-19	-18	-17
-2cm	-37	-40	-41	-42	-41	-39	-36
-3cm	-52	-54	-56	-57	-55	-54	-51
-4cm	-63	-68	-69	-70	-69	-68	-62
-5cm	-73	-76	-77	-78	-76	-75	-69
-6cm	-71	-74	-75	-77	-75	-73	-67
-7cm	-69	-72	-73	-74	-72	-71	-66
-8cm	-64	-66	-67	-69	-66	-65	-62

Table I