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Journal of Electron Microscopy **58(4)**: 251–252 (2009)
doi: 10.1093/jmicro/dfp002

Physical: Notes

Reduction of time-varying nanotesla magnetic fields from electric power lines by twisting

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Abstract Time-varying magnetic fields generated by electrical power lines in the laboratory can disturb electron microscope imaging. Modern microscopes require these fields to be below 10 nT [2]. We calculated and measured magnetic fields from straight and twisted current-carrying wires, and show that without twisting, this value cannot be reached.

Keywords electron microscopy, instrumentation, magnetic fields, disturbance, electric circuitry, calculations

Received 4 December 2008, accepted 23 December 2008, online 24 January 2009

To calculate the field for (twisted) wire pairs, Shenfeld [3] starts with a magnetic scalar potential based on a series expression by Buchholz [1]. This method does not allow for finite wire lengths. Therefore, we chose to start from the vectorpotential,

$$\vec{A}(\vec{r}_1, t) = \frac{1}{4\pi\epsilon_0 c^2} \int_{-L/2}^{L/2} \frac{I(t)}{r_{12}} d\vec{r}_{\text{wire}}, \qquad (1)$$

where L is the length of the wire, $\vec{r}_1$ is the location where the vectorpotential is calculated and $\vec{r}_2$ is the position of the current element and $r_{12} = |\vec{r}_1 - \vec{r}_2|$. This integral is analytically integrated using computer software. Using the superposition principle, we calculate the vectorpotential for a single wire, parallel wires and a twisted wire pair (TWP) with spatial frequency k and separation $2R$:

$$\vec{r}_{\text{wire }1,2} = \begin{pmatrix} l \\ \pm R \cos(k \cdot l) \\ \pm R \sin(k \cdot l) \end{pmatrix}. \qquad (2)$$

The resulting magnetic fields can be calculated by taking the curl of the vectorpotential.

The magnetic field was measured using a Meda fluxgate hall probe in combination with a PSI lock-in amplifier. An alternating current was generated by a Kepko power supply connected to a sine wave generator running at 133.33 Hz. The same signal served as reference signal for the lock-in amplifier. This setup allows us to measure fields with an accuracy of 0.01 nT in a bandwidth of 0.1 Hz. Since we measure at a frequency where disturbance from other 50-Hz sources and their harmonics is minimal, the background field (shortcut power supply) was only 0.03 nT. To verify the experimental setup, we measured a single wire of 6 m length. The measurements agree with theory within 3.5%.

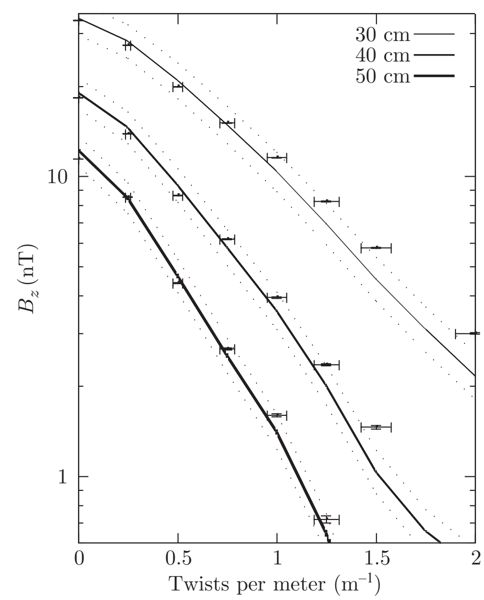

Fig. 1. Calculated and measured magnetic field from a TWP running 4 A_{RMS}.

Figure 1 shows the calculated maximum z-component of the field of a TWP, spaced at 3.6 mm with a length of 6 m and a current of 6 A_{RMS}, as a function of twist and distance from the wire. The calculations are shown as continuous lines, with error boundaries due to uncertainties in current, distance from the wires, measured distance between the wires

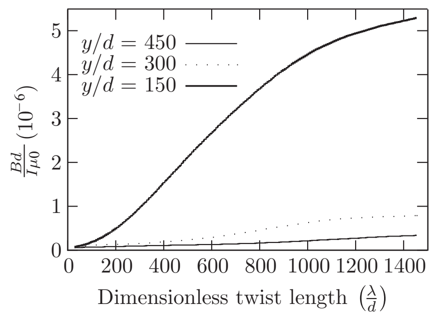

Fig. 2. Dimensionless magnetic field strength at various distances.

and twists per meter. Within these measurement uncertainties, the calculations agree well with measurements.

In order to facilitate design of electrical circuitry, we have plotted our calcuations in dimension less units in Fig. 2. B is the magnetic field in z-direction; d the distance between the wires; I the current; y the distance from the wire; λ the length of one twist; and μ_0 the magnetic permeability. For instance, for a wire pair of 4 mm spacing (d), at 16 A, the 10 nT limit corresponds to a vertical axis value of 2×10^{-6}. At a distance of 2 m ($y/d = 150$), this requires a twist length of 6 m ($\lambda/d = 450$).

Calculations and measurement were done at 3 m distance from the end of the wire, which is half of the total lenght of the wire. It should be noted, however, that there are strong edge effects at the end of the wire, resulting in a stronger magnetic fields. Also, when back and forth currents are out of phase or unequal, stronger magnetic fields will arise. This can only occur if there is a significant leakage current to ground in the apparatus (in the order of 50 mA to produce undesirably strong magnetic fields), and when the ground wire does not run along the two current-carrying wires.

In our laboratory, XMvK (plu 608, 3G, 2.5 mm^2) cables are used for electrical wiring. Interestlingly, it appears that these are twisted with about 2 twists per meter (tpm) for mechanical purposes. The twist direction reverses every 4.2 m. Using these cables, one can ensure that the produced field of 16 A currents is below 10 nT at distances above 50 cm.

As a rule of thumb, for a 16 A standard parallel wire configuration ($d = 3$ mm), 10 nT fields are generated up to 3 m. Twisting the wires with 2 tpm, reduces this distance to 0.3 m. When taking care of leakage currents and end effects, twisting therefore provides a cheap and effective way to reduce the influence of power circuitry near electron microscopes.

References

1 Buchholz H (1957) *Elektrische und magnetische Pötentialfelder* Berlin: Springer.

2 Muller D A, and Grazul J (2001) Optimizing the environment for sub-0.2 nm scanning transmission electron microscopy. *J. Electron Microsc.* **50**: 219–226.

3 Shenfeld S (1969) Magnetic fields of twisted-wire pairs. *IEEE Transactions on Electromagn Compatibility* **EMC-11**: 164–169.