Measuring Strong Currents by Their Magnetic Field: A New Method

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I. Problem

The current of a cable with a huge current needs to be measured. The current is so strong that no current measurement device can measure it without breaking down. This happens very often. One example of this is in the making of aluminum where solid alumina is put into a hot "oven". Alumina is Al_2O_3 and electricity is used to release the O_3, thus leaving aluminum. However, the current needed is so strong it cannot be measured directly.

What then needs to be measured is the magnetic field. If there was only one cable, we could stop at that, but in many cases (as in the case of aluminum), there are two cables. Thus each cable's magnetic field would affect a sensor and the current of one of the cables could not be determined without costly equipment. We designed an algorithm that, with only four regular sensors placed on opposite sides of the cable (two on the right and two on the left), could efficiently figure out the current of one of the cables.

II. Method

The first thing that is needed is to somehow simulate the sensor output. Let us denote the current of the first cable as I, and the current of the second cable as I'. Let us choose the coordinate system in such a way that the first cable is located at $(0,0)$; let's denote the coordinates of the second cable by (X,Y). The radius of the cables will be denoted by r_0. The four sensors' outputs are denoted by s_1, s_2, s_3, s_4. To simulate the sensor outputs we use the following formulas:

$$s_1 = -I'\frac{Y}{R^2 - 2r_0X + r_0^2},$$

$$s_2 = -I'\frac{Y}{R^2 + 2r_0X + r_0^2},$$

$$s_3 = -\frac{I}{r_0} + I'\frac{X - r_0}{R^2 - 2r_0X + r_0^2},$$

$$s_4 = \frac{I}{r_0} + I'\frac{X + r_0}{R^2 + 2r_0X + r_0^2}.$$

When we get the sensor outputs, we use the algorithm we devised to figure out the current of the first cable, I. To simplify the calculations, we will use two auxiliary variables c_x and c_y calculated as follows:

$$c_x = \frac{s_1 - s_2}{s_1 + s_2},$$

$$c_y = \frac{s_2 - s_1}{s_4 - s_3}.$$

Then we calculate the distance R between the centers of the cables with the following formula:

$$R = \frac{r_0(\pm\sqrt{1 - c_x^2} + \sqrt{1 + c_y^2})}{\sqrt{c_x^2 + c_y^2}}.$$

After that we use the following formula to find I:

$$I = -r_0(s_3 + s_1\frac{c_xR^2 + (c_x - 2)r_0^2}{c_y(R^2 - r_0^2)}).$$

To simulate the noise in real life sensors we choose a noise-level N, generate a random number n between 0 and 1, and compute the simulated noise (to add to each sensor's output) with the following formula: $(n - 0.5)N$.

III. Conclusion

The conclusion of the project is that the above algorithm does in fact work. When noise is added, the result is still pretty close to the original current. The current of the first cable does not affect the distance of the calculated current with noise from the original current much, but the second cable affects it much more. This happens because the sensors are on the first cable and thus have a more even distribution of the first cable's magnetic field. However, two of the sensors are $2r_0$ farther from the second cable than the other two sensors, and thus the magnetic field is not distributed as evenly.

References

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