Magnetohydrodynamic Cocktail Stirrer

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Abstract

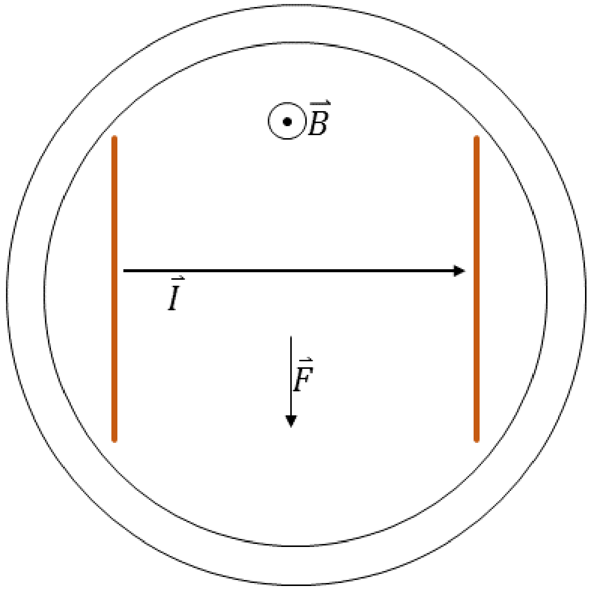

Figure 1: First iteration of contactless stirrer

1 Background

The first attempt at a contactless cocktail stirrer was based on a simple application of the Lorentz force. Two copper electrodes placed in a glass tumbler passed a current through the liquid, while a strong magnet (a 2"x1"x¾" N45 block from United Nuclear Scientific LLC) under the tumbler provided an orthogonal magnetic field (Fig. 1). Assuming time-invariance, the force applied on a differential element dV in a current field $\vec{J}$ and an orthogonal magnetic field $\vec{B}$ can be found from the element length dℓ parallel to the current and cross-sectional area dA normal to the current:

$$\vec{F} = q\vec{V} \times \vec{B} \tag{1}$$

$$\vec{F} = I\vec{\ell} \times B \tag{2}$$

$$I = |J|\mathrm{d}A \tag{3}$$

$$\tag{4}$$

(Valid because dA is defined to be normal to $\vec{J}$.)

$$\mathrm{d}\vec{F} = |\vec{J}|\mathrm{d}A\mathrm{d}\ell \times \vec{B} \tag{5}$$

Since, in this case, the magnetic and current fields are orthogonal, and since the current field is approximately uniform between the electrodes (simply the total current divided by the electrode area),

$$\mathrm{d}\vec{F} = |\vec{J}||\vec{B}|\mathrm{d}A\,\mathrm{d}\ell \tag{6}$$

$$\vec{F} = \iiint\limits_V |\vec{J}||\vec{B}|\mathrm{d}A\,\mathrm{d}\ell \tag{7}$$

Given an electrode area of A and spacing of L and approximating both the current and magnetic field to be uniform between the electrodes,

$$\vec{F} = |\vec{B}|L \iiint\limits_A |\vec{J}|\mathrm{d}A = |\vec{B}|IL \tag{8}$$

This design did work in principle; the Lorentz force produced a pumping action, where fluid would flow down the centerline between the electrodes and recirculate along the walls of the tumbler. However, since a large current was flowing through a fluid, significant electrolysis occurred, which, in addition to producing potentially dangerous hydrogen and oxygen gas, affected the taste of the cocktail due to the electrolysis products.

2 Theoretical Background

Since the basic application of Lorentz force to pumping was effectively validated (and is in fact well studied [1]), the major problem remaining was the electrolysis of the cocktail. As per Faraday's Law of Electrolysis:

$$\dot{m} = \frac{I}{F}\frac{M}{z} \tag{9}$$

Where:

- $\dot{m}$ is the mass of electrolysis products appearing at an electrode per unit time;
- I is the total current flowing into or out of the electrode;
- F is the Faraday constant, 96485 mol/C;
- M is molar mass of the original substance;
- z is the number of valence electrons of the substance.

Since F is a constant and M and z are properties of the substance, in order to minimize $\dot{m}$, I must be minimized. However, pumping force is also directly proportional to I. The central proposal of this project is that currents which circulate entirely within a fluid will not result in electrolysis, because the *net* current flow through the fluid is zero.

The obvious question is how to produce currents without an external EMF source such as a battery. The proposed solution is to use an external, time-variant magnetic field to induce circulating currents (eddy currents) in a conductive fluid.

For the purposes of a first-pass analysis, the following model will be considered:

- The fluid will be a 3" diameter, 3" tall cylinder (based on an approximate cocktail tumbler);
- The fluid will be considered to have electrical resistivity ρ and magnetic properties equal to a vacuum (water is in fact weakly diamagnetic, but this is expected to be a negligible contribution);

Since, at this point, the goal is to find the form of the current field and its dependence on $B_{s,max}$ and ρ, it is not necessary to accurately know the resistivity of an actual cocktail; those values are calculated separately.

In fact, this application is an adaption of the well-studied eddy current brake (Fig. 2). In this case, however, the magnets are made to spin, resulting in "dragging" of the cylinder. Specifically, if a magnetic field passing through a conductive cylinder radially is made to rotate about the cylinder's axis, currents will be produced in the cylinder, which interact with the field via Lorentz force. Since the strength of the eddy currents, and by extension the resulting force, is proportional to $\frac{\mathrm{d}B}{\mathrm{d}t}$, both the strength of the applied magnetic field and its rate of change should be maximized.

2.1 General Design

The obvious way to produce a strong time-variant magnetic field is with an AC solenoid: they are well characterized and fairly easy to control, and of course relatively easy to build. Unfortunately, to produce the high field strengths needed (on the order of 1 T), the power required for a normal solenoid exceeds the

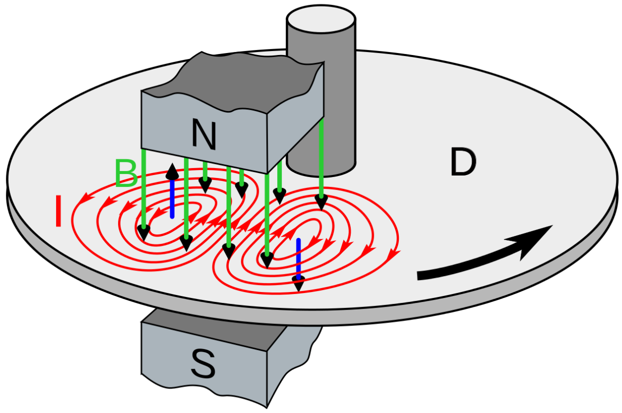

Figure 2: Eddy current disk brake

capabilities of household circuits. Due to the expense and safety issues, a superconducting solenoid was not practical. Therefore, large permanent magnets were considered. 3” dia. x 1” thick NdFeB45 magnets from United Nuclear Scientific LLC were chosen based on field strength per dollar (\$140 and maximum $\vec{B} \cdot \vec{n}$ of $\approx$0.42 T). In order to produce the greatest possible magnetic field, four of these magnets are arranged in a quadrupole configuration. In addition, high-permeability material (in this case, 1020 steel) is used to provide return paths for the field, further increasing the intensity inside the assembly (Fig. 3).

The downside of permanent magnets, of course, is that they must be in motion to produce a time-variant field. In this case, the quadrupole assembly must be spun about the axis of the cocktail, producing circular forces on the liquid (Fig. 4).

3 Rotor Design

4 Property Measurements

4.1 Cocktail Resistivity

4.2 Rotor Field Measurement

References

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[3] Bowler, John R., and Theodoros P. Theodoulidis. “Eddy Currents Induced in a Conducting Rod of Finite Length by a Coaxial Encircling Coil.” Journal of Physics D: Applied Physics 38.16 (2005): 2861-868. Web. 23 Aug. 2016.

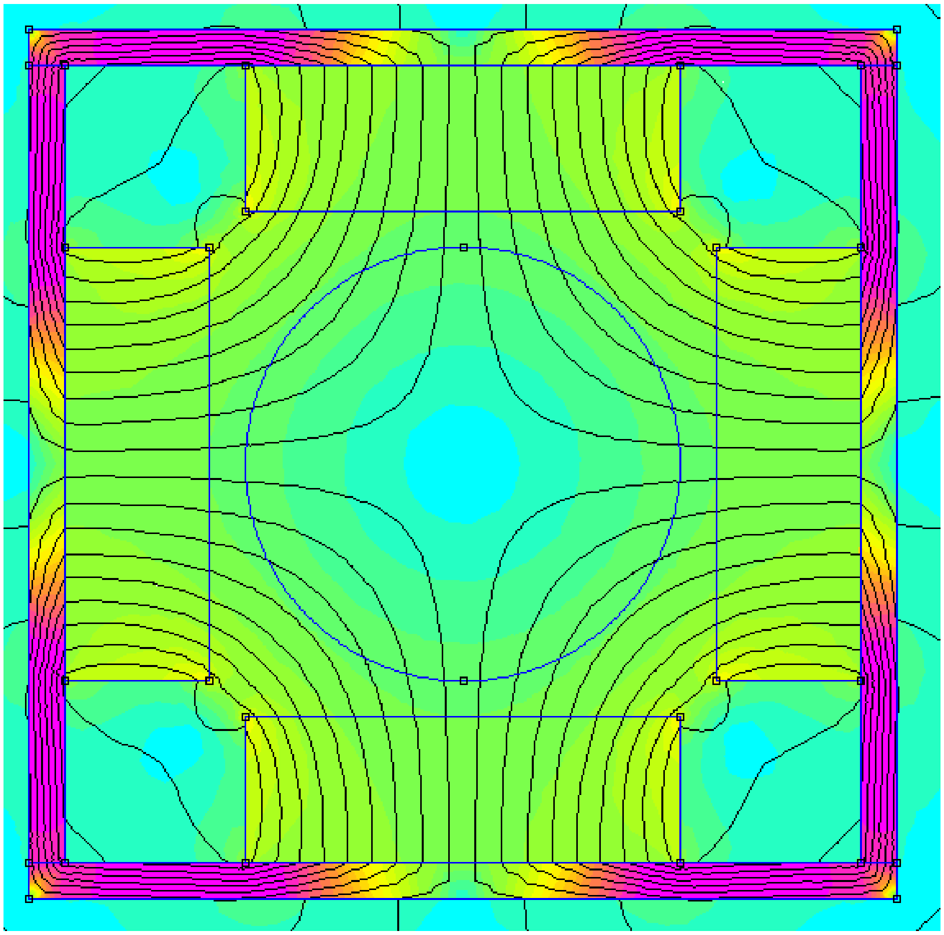

Figure 3: Quadrupole magnet assembly with steel shunts

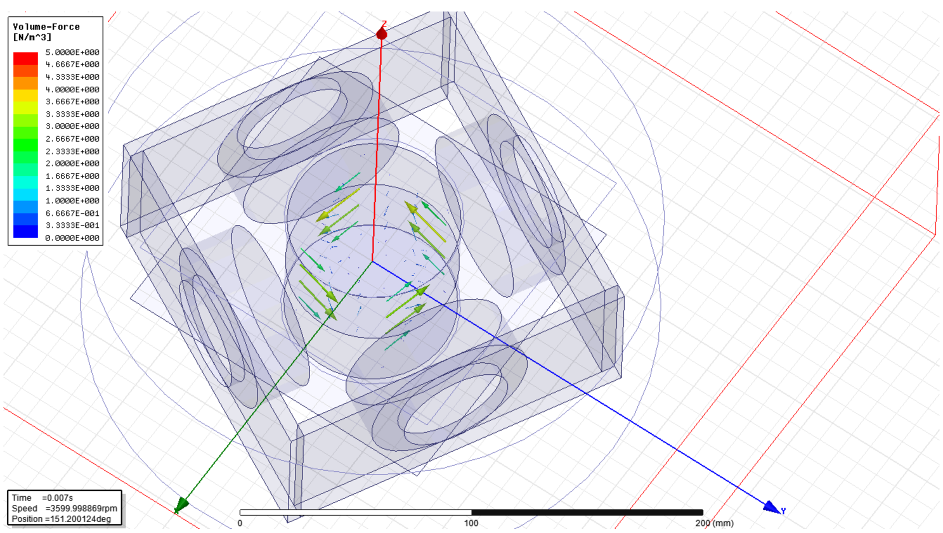

Figure 4: Volume force density caused by counterclockwise spinning quadrupole