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Net Magnetic Force Generation in Discontinuous Circuits: A Force Symmetry-Breaking Phenomenon

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Abstract

This paper explores the potential for generating a net magnetic force in circuits with open sections, where the asymmetry of interacting forces can produce a resultant force. It is shown that the forces between two wires can be decomposed into reciprocal and directional components. Reciprocal forces generally produce no net force, and directional forces vanish in closed circuits, while they may not vanish in discontinuous circuits. It is also shown that if the open sections are replaced with capacitors, there is a possible non-reciprocal interaction between the capacitors and the wires. The central concept behind this work stems from a nuanced idea that may have been overlooked or remained unnoticed. The proposed idea's simplicity could lead to the development of propellantless propulsion systems for space applications, such as the repositioning of satellites.

This work originates from a thought experiment. Before diving into it, let's consider the famous example of two point charges moving perpendicular to each other, both approaching a common origin with a distance from it [1, 2]. Due to the Lorentz force and Biot-Savart law, these point charges will experience equal forces perpendicular to their moving path in distinct directions, seemingly violating Newton's third law.

Now, imagine two wire loops carrying currents. If we neglect the retardation effect[3], Newton's third law mandates that they must exert equal and opposite forces on each other. Can we design the loops' geometry and orientation to create a scenario similar to the point charge experiment, where interaction forces act in different directions without canceling each other?

A strict physicist might immediately assert that this is impossible. Indeed, the mathematics presented in the Methods section proves that any two closed

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loops exert equal and opposite forces, resulting in overall cancellation. However, a question immediately arises: if two closed loops must produce equal and opposite forces, does removing part of a loop break this symmetry? As we will subsequently see, discontinuous circuits can indeed exhibit this force symmetry breaking.

In the study by Mohammadpour [3], it is argued that Newton's Third Law is only locally applicable at the point of interaction between fields and charges, where an instantaneous exchange of momentum occurs. It is deemed inappropriate to extend Newton's Third Law to interactions at a distance where retardation effects may occur and the state of the charges may change. Sebens [4] discusses since fields exert forces on charges and, conversely, charges exert forces on fields, Newton's Third Law is preserved. Without contradicting Newton's Third Law and using the Lorentz force as defined in equations (6) and (7), we can demonstrate that forces acting on two open wires might not always exhibit symmetry (Please refer to section Methods).

The accuracy of calculated forces using the Lorentz force is difficult to dispute. This is because the Lorentz force is deducible from Faraday's law of induction and Maxwell's equations using the Leibniz integral rule. Since Maxwell's equations offer an accurate description of fields for most classical electromagnetic applications, it's reasonable to consider the Lorentz force equally accurate when representing forces within the mentioned domain of application.

Methods

In the electrodynamic causality context, the magnetic field's exact solution around the wire from the Maxwell equation is presented in [5]. However, when neglecting the retardation effect and assuming a low rate of change in current, this description simplifies to the more familiar Biot-Savart law [1]

$$\mathbf{B} = \frac{\mu_0 I}{4\pi} \oint \left(\frac{d\mathbf{l}^s \times \mathbf{r}}{r^3} \right) \quad (1)$$

where μ_0 represents the permeability of vacuum and I denotes the current. Furthermore, $d\mathbf{l}^s$ represents an infinitesimal length element of the source, r is the distance from that source element, and \mathbf{r} is the displacement vector. The force exerted by wire A on wire B can be determined using the Lorentz force law

$$F_A^B = I_B \oint_B d\mathbf{l}^B \times \mathbf{B}_A \quad (2)$$

by converting the triple cross products to dot products, it follows

$$F_A^B = \frac{\mu_0 I_A I_B}{4\pi} \left[\oint \oint \frac{d\mathbf{l}^A (d\mathbf{l}^B \cdot \hat{\mathbf{r}}_{BA})}{r^2} - \oint \oint \frac{\hat{\mathbf{r}}_{BA} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (3)$$

where $\hat{\mathbf{r}}_{BA} = \mathbf{r}_{BA}/r$ represents the unit vector pointing from the infinitesimal element $d\mathbf{l}^A$ toward $d\mathbf{l}^B$, and r is the distance between these elements. The

second term on the right-hand side of Equation (3) implies equal and opposite forces on wires A and B. By expanding the differentials in spherical coordinates, it follows

$$d\mathbf{l}^B \cdot \hat{\mathbf{r}} = d\mathbf{r} \cdot \hat{\mathbf{r}} = dr \quad (4)$$

Using the identity (4), the force term (3) can be written as

$$F_A^B = \frac{\mu_0 I_A I_B}{4\pi} \left[\oint_A d\mathbf{l}^A \oint_B \frac{dr}{r^2} - \oint \oint \frac{\hat{\mathbf{r}}_{BA} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (5)$$

The closed integral $\oint \frac{dr}{r^2}$ equals zero for a closed wire. This is because the integration is performed over a closed loop on a differential. Conclusively, two closed loops exert equal and opposite forces on each other. The second integral in Equation (5) can be named the "reciprocal force," possessing symmetry and is directionally dependent on both wires. In contrast, the first term in Equation (5) can be termed the "directional force," as its direction depends only on one of the wires and exhibits asymmetry. As previously stated, the directional force vanishes for a closed loop.

Now, consider two open-circuit wires. Each wire has a specific disconnection point, with a sufficiently small gap to act as a capacitor. Therefore, this configuration allows current to flow, dependent on the applied voltage and the charge accumulated at the disconnection points. Importantly, no discharge occurs between these disconnected points. Let's denote the disconnection points for wire A as O_A and O'_A and for wire B as O_B and O'_B (moving in the direction of the current). The interaction forces on wires A and B can be expressed as follows

$$F_A^B = \frac{\mu_0 I_A I_B}{4\pi} \left[\int_A \left(\frac{1}{r_{O'_B}} - \frac{1}{r_{O_B}} \right) d\mathbf{l}^A - \int \int \frac{\hat{\mathbf{r}}_{BA} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (6)$$

and

$$F_B^A = \frac{\mu_0 I_A I_B}{4\pi} \left[\int_B \left(\frac{1}{r_{O'_A}} - \frac{1}{r_{O_A}} \right) d\mathbf{l}^B - \int \int \frac{\hat{\mathbf{r}}_{AB} (d\mathbf{l}^B \cdot d\mathbf{l}^A)}{r^2} \right] \quad (7)$$

Here, r_O denotes the distance between point O and the infinitesimal element on the other wire. The reciprocal forces cancel each other. The net force between the two wires resulting from directional forces is then expressed as

$$F_A^B + F_B^A = \frac{\mu_0 I_A I_B}{4\pi} \left[\int_A \left(\frac{1}{r_{O'_B}} - \frac{1}{r_{O_B}} \right) d\mathbf{l}^A + \int_B \left(\frac{1}{r_{O'_A}} - \frac{1}{r_{O_A}} \right) d\mathbf{l}^B \right] \quad (8)$$

It can be demonstrated that in many configurations, the net magnetic force between the open wires is nonzero. A clear illustration of this occurs when wire A and wire B lie in perpendicular planes, and the differential elements $d\mathbf{l}^A$ and $d\mathbf{l}^B$ are independent of each other.

A valid question to consider is: if we treat the open sections as a capacitor, what effect does the electric field have on the net force? It is trivial to assume that the force on the accumulated charge at both ends of the open sections cancels out. There is a corresponding charge at the other end for every charge on one side of the capacitor. Another aspect to consider is the capacitor's rearrangement and movement of charges. This movement generates a magnetic field, and the magnetic field of other wires exerts force on the capacitor. Equation (8) does not account for this effect. If the capacitance is due to a small gap between two wires with a strong dielectric material in between, the electric charge predominantly accumulates close to the outer surface, as shown in Figure 1(a). In such cases, the length of the capacitor zone, denoted as l_c , can be very small. During the charging or discharging processes, the charges rearrange both radially and along the axis of l_c . For thin wires and a small l_c relative to the gap distance d , the contribution of the magnetic force due to this rearrangement might be negligible, and Equation (8) can be applicable. However, in general, the magnetic force resulting from charge rearrangement in a capacitor should not be overlooked.

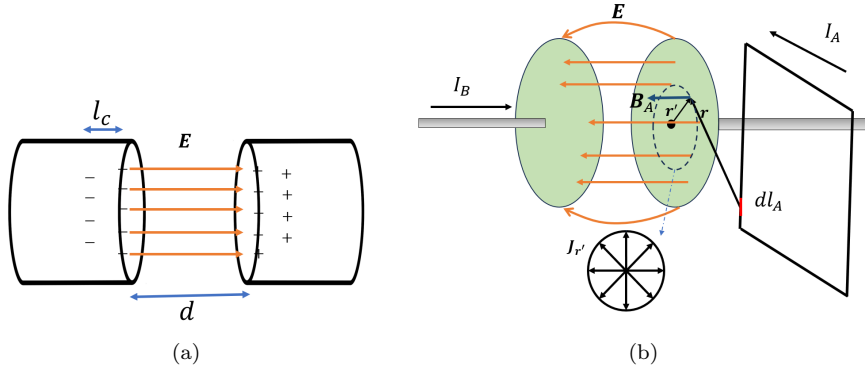


Figure 1: (a) The capacitor formation by a distance gap of d in a segmented wire, with charge accumulating on both sides of the wire. (b) Depiction of the electric field between two plates of the capacitor and the radial current density distribution in a circular capacitor. The interaction between a differential element dl_A and a point on the capacitor is depicted through the magnetic field B_A and the current density J_r .

For simplicity, this work examines the force exerted by a closed wire on a circular capacitor and vice versa. We will demonstrate the breaking of the reciprocity of forces, which can lead to a resultant force. We assume that the charge is symmetrically distributed on the circular plate. The capacitor is sufficiently charged such that the electrostatic forces predominantly determine the charge distribution, while the influence of nearby current-carrying wires on this distribution is considered negligible. Consider that the outer radius of the capacitor

is R , and the inner radius a is equal to that of the thin wire. The density of the charge per unit thickness of the capacitor, neglecting fringing effects, can be described as follows:

$$\rho = Q(t)/(\pi(R^2 - a^2)) \quad (9)$$

The Q is the charge on the plate, and the rate of change of charge on the plate is equal to the current entering the capacitor. The balance of charge in the circular plate necessitates:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{J} = 0 \quad \text{and} \quad \mathbf{J}(R) = 0 \quad (10)$$

Due to radial symmetry, the divergence operator $\nabla \cdot \mathbf{J}$ simplifies in polar coordinates to $\frac{1}{r'} \frac{\partial (r' J_{r'})}{\partial r'}$. With reference to the charge density equation (Equation (9)) and the continuity equation (Equation (10)), we can derive the following relationship:

$$J_{r'} = \frac{1}{2} \frac{I_B}{\pi(R^2 - a^2)} \left(r' - \frac{R^2}{r'} \right) \quad (11)$$

The force exerted by closed wire A (as shown in Figure 1(b)) on one side of capacitor C can be derived from the Lorentz force equation as follows:

$$\begin{aligned} F_A^C &= \frac{\mu_0 I_A}{4\pi} \oint_A d\mathbf{l}^A \int_0^{2\pi} \int_a^R \frac{(\hat{\mathbf{r}}' \cdot \hat{\mathbf{r}})}{r^2} r' J_{r'} dr' d\theta \\ &- \frac{\mu_0 I_A}{4\pi} \oint_A \int_0^{2\pi} \int_a^R \frac{\hat{\mathbf{r}} (\hat{\mathbf{r}}' \cdot d\mathbf{l}^A)}{r^2} r' J_{r'} dr' d\theta \end{aligned} \quad (12)$$

where $\mathbf{r} = \mathbf{r}_{MA} + \mathbf{r}'$ and \mathbf{r}_{MA} represents the distance from the center of the capacitor to wire A, and the hat symbol denotes the unit vector. The vector \mathbf{r}' indicates the distance from the center of the capacitor to a corresponding point on the capacitor (as shown in Figure 1(b)). The first integral in Equation (12) depends on the direction of the current in wire A. Meanwhile, the second term demonstrates reciprocity, exerting opposing forces that act in the same direction on both the capacitor and wire A.

It can easily be shown that the directional force of the capacitor on a closed wire A is zero. Then, the sum of the force of wire A on the capacitor and the capacitor on wire A is nonzero (reciprocity breaks) and is given by

$$F_A^C + F_C^A = \frac{\mu_0 I_A}{4\pi} \oint_A d\mathbf{l}^A \int_0^{2\pi} \int_a^R \frac{(\hat{\mathbf{r}}' \cdot \hat{\mathbf{r}})}{r^2} r' J_{r'} dr' d\theta \quad (13)$$

The capacitor can be considered analogous to open wires, where charge flows radially from the center to the edges. Consequently, we can expect that the sum of the forces will not be reciprocal, as is the case with open wires. The net force resulting from the interactions between wire B and its positioned capacitor can be demonstrated to be zero when the capacitors at both ends of the disconnection point are identical and the wire set-up are symmetrical with respect to the capacitor's mid-plane.

Examples and discussions

Consider a scenario where alternating current (AC) passes through a primary circuit with two open sections. A circular capacitor with a dielectric material is placed within these openings with no electrical discharge. The circuit voltage is sufficient to maintain the current flow in the primary circuit. Secondary circuits are positioned near the main circuit's open segments to produce a net force in the desired direction. These secondary circuits can operate in-phase or out-of-phase with the primary circuit depending on the intended force direction. System symmetries are designed to eliminate any potential net moment. Figure 2 provides a circuit schematic. O and O' denote the open section. Secondary circuits are placed near the open sections to the right and left of the primary circuit.

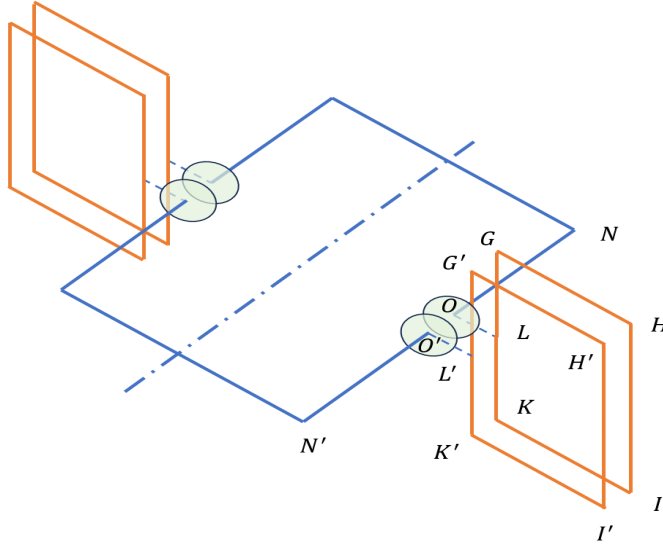


Figure 2: A simplified diagram of a novel AC-powered propulsion system. Capacitors are placed at open sections between points O and O' while secondary circuits are positioned for upward directional force generation. Secondary circuits are identical and symmetrical with respect to the main circuit plane (i.e., $GL = LK$).

The circuit design presented in Figure 2 aims to produce a net upward force. Segments GH and IK , as well as $G'H'$ and $I'K'$, negate each other's effects. KG and $K'G'$ contribute the most to the upward force, while HI and $H'I'$ have lesser contributions due to their distances, as outlined in equations (7) or (6). The Alternative current in circuit $GHIK$ is out-of-phase with that of $G'H'I'K'$ to prevent force cancellation. The selection of AC is sinusoidal here. Therefore, the average force is half of the maximum force. There are no limitations on the number of open sections or turns in either the primary

or secondary circuits, allowing for scalable force generation. However, we'll consider a simple application here. A current of 1000 amps is used for both the primary and secondary circuits. The distance between O and O' varies, and GL and LK lengths are chosen 15cm each. To minimize counteracting forces, the wire HI is positioned further away, at a distance of 25cm . The secondary circuits are positioned opposite on each side to cancel out the moment produced in the main circuit and maintain symmetry. The capacitor radius has been set at 0.8cm . This small size was chosen primarily to focus on the forces exerted by the wires on each other. However, there is no limitation on the size of the capacitor. Figure 3(a) illustrates the average net force for varying distances between point L (in the secondary circuits) and the main circuit, ranging from 1cm to 20cm . Figure 3(b) illustrates the effect of distance between the gap OO' on produced average net force.

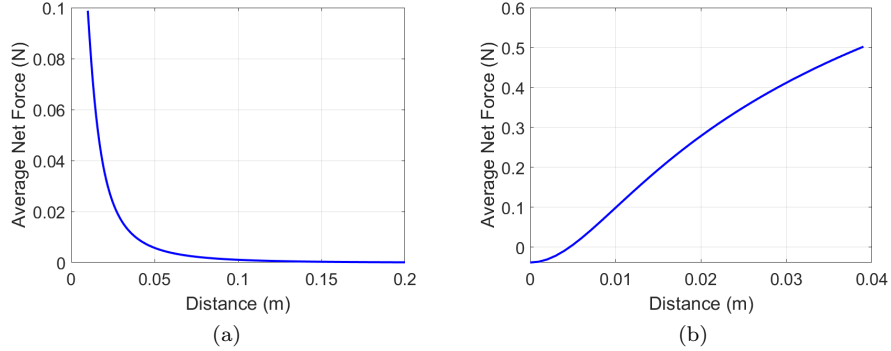


Figure 3: The average net force produced in the setup depicted in Figure 2, as a function of (a) the distance between secondary and main circuits (with a fixed $OO' = 1\text{cm}$) (b) the OO' distance (with a fixed initial distance of 1 cm between the main and secondary circuits).

To understand how discontinuous circuit sections can break force symmetry, consider the contribution of directional force (described by the first integral in Equation (3)) exerted by a unit length at the midpoint of line KG on a unit length along line NN' . This force is plotted for continuous and discontinuous (with open sections) cases. Figure 4(a) illustrates the symmetry of directional forces in a continuous wire, leading to overall cancellation and no net force production. In contrast, Figure 4(b) demonstrates how open sections break this symmetry, resulting in a nonzero net force.

To effectively mitigate the capacitive reactance in the circuit, it is possible to use a two-element LC circuit by adding an appropriate inductor and setting the main circuit's operating frequency to match its natural resonant frequency. The design of the secondary circuit can also be modified to match this frequency. The power of proposed propulsion systems can be significantly enhanced by

incorporating multiple turns and open sections. For example, using 20 turns and 20 sets of open sections instead of one can increase the forces depicted in Figure 3 by a factor of 400. For instance, by selecting a distance of 1 cm for the open section gap and the distance between the secondary and the primary circuits, we could potentially generate a force of approximately five kilograms. This force is sufficient to accelerate a probe with the mass of Voyager 1 (approximately 722 Kg) [6] such that it reaches the same distance travelled by Voyager 1 (up to January 2024) in less than a year. This cannot be achieved with traditional propellant-based propulsion systems, as they require a vast amount of mass for constant acceleration.

Incorporating superconductors into this propulsion system could provide significant advantages and expand its potential applications to include terrestrial and aviation transportation. Unlike traditional electric motors, which lose energy through friction within their mechanical parts, this proposal eliminates such losses due to its lack of moving components. This characteristic paves the way for a highly efficient propulsion system.

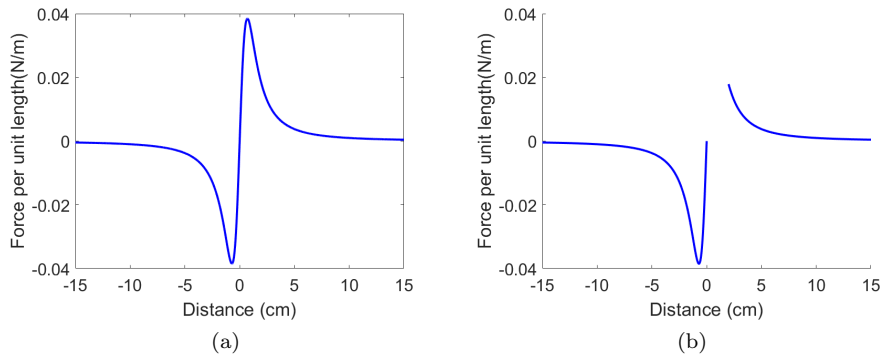


Figure 4: Directional force exerted by a unit length at the midpoint of line KG on a unit length along line NN' for two cases: (a) no open sections, and (b) a 2cm gap for the open section. The current in both main and secondary circuits is 1000 amps.

Conclusions

This research explored the breaking of symmetry in interaction forces of discontinuous circuits. It is demonstrated that in closed circuits, force interactions adhere to classical physics' expectations of reciprocity. Contrarily, this symmetry breaks in discontinuous circuits and can lead to a net resultant magnetic force. This claim aligns fully with the Lorentz force and interacting fields.

Acknowledgments

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Call for collaboration

Ideas regarding this work are developed and patented. I extend an open invitation for collaboration and support to develop these concepts further to benefit the scientific community and humanity.

References

- [1] D. J. Griffiths, Introduction to electrodynamics (2005).
- [2] R. P. Feynman, R. B. Leighton, M. Sands, The feynman lectures on physics; vol. i, American Journal of Physics 33 (9) (1965) 750–752.
- [3] A. Mohammadpour, Net force in the absence of external forces in systems with retardation: Emphasis in electromagnetism, working paper or preprint (Feb. 2024).
- [4] C. T. Sebens, Forces on fields, Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 63 (2018) 1–11.
- [5] O. D. Jefimenko, Causality, electromagnetic induction, and gravitation: a different approach to the theory of electromagnetic and gravitational fields, Princeton University Press, 2000.
- [6] NASA, Voyager 1 mission overview, <https://science.nasa.gov/mission/voyager/voyager-1/>, accessed: 2024-04-17 (2024).