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Alternative Electric Current in Dynamics of Unclosed Conductor

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ABSTRACT
Even quasi-static fields can carry momentum, and this would appear to contradict a general theorem that the total momentum of a closed system is constant if its center of mass is at rest. In this case, there must be some other (hidden) momentum and reactive force that cancel the electromagnetic momentum and the electromagnetic force. In unclosed systems with changing electric current, the electromagnetic force equals to the self-force and can be very large.

Keywords – Conservation of momentum, Hidden force, Magnetic field, Reactive motion, Self-force

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I. INTRODUCTION

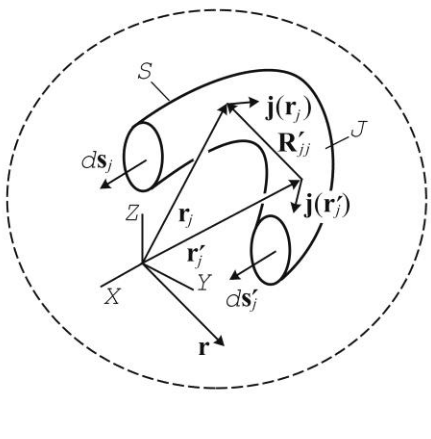
In the past few decades there has been a renewed interest in propulsion based on violating Newton's third law in electrodynamics [1-3]. Even though the momentum conservation law proclaims that support-less movement does not exist because it contradicts Newton's third law, this issue arises from time to time due to experimental achievements in this field. Unfortunately some of these projects are left without theoretical foundation and therefore are in doubt. First of all, conservation of linear momentum can be preserved, however, by saying that the field can possess momentum. The hidden momentum compensating the electromagnetic momentum, stored in electromagnetic field, is experimentally found out [4]. The time derivative of the hidden momentum can be considered, in a certain sense, as a reactive force. In this case the sum of the ordinary electromagnetic forces, by means of which electromagnetic field acts on charges and currents, and the reactive force equals zero [5]. The reactive force does act on the system of current and charges, therefore the system can accelerate. Unfortunately, the magnitude of the reactive force is too small that the effect is difficult to observe.

Secondly, currents of a conductor generate magnetic field, which exert forces back on the currents which generated them. If an electric circuit is unclosed, it will experience a self-force by means of which the unclosed current acts on itself [6]. Nevertheless, it is not possible for isolated unclosed circuit with direct current to exist in nature, and the forces should be considered in their integral forms, referring current loop. Though the elementary form of Newton's third law does not hold for a part of a closed electric circuit, for the closed loop, the sum of all the forces of action, reaction and self-action equals zero, so linear or angular momentum conserves [7]. Alternative current can pass through vacuum via what is called displacement current. To all appearance, these two problems prove to have the common solution.

II. ELECTROMAGNETIC FORCE AND SELF-FORCE

Consider an alternative current distribution of current density $\mathbf{j}(\mathbf{r}_j)$, occupying volume J bounded by the closed surface S.

Fig 1. Changing electric current in volume J



As it takes place in the case of self-inductance, the changing current acts back on itself producing the force

$$\mathbf{F} = \int_J [\mathbf{j}(\mathbf{r}_j) \times \mathbf{B}(\mathbf{r}_j)] d^3 r_j \, , \qquad (1)$$

where the integration sweeps over the conductor volume *J*.

Using the Maxwell equation

$$[\nabla\times\mathbf{B}(\mathbf{r}_j)]=\mu_0\mathbf{j}(\mathbf{r}_j), \qquad (2)$$

and since

$$(\nabla\mathbf{B}(\mathbf{r}_j))\mathbf{B}(\mathbf{r}_j)=$$
$$\mathbf{B}(\mathbf{r}_j)(\nabla\mathbf{B}(\mathbf{r}_j))+(\mathbf{B}(\mathbf{r}_j)\nabla)\mathbf{B}(\mathbf{r}_j), \qquad (3)$$

one can obtain

$$\mathbf{F}=\frac{1}{\mu_0}\int_J(\nabla(\frac{B^2(\mathbf{r}_j)}{2})-(\nabla\mathbf{B}(\mathbf{r}_j))\mathbf{B}(\mathbf{r}_j))d^3r_j, \qquad (4)$$

This may be converted to a surface integral

$$\mathbf{F}=\frac{1}{\mu_0}\oint_S(d\mathbf{s}_J\cdot\frac{B^2(\mathbf{r}_j)}{2}-(d\mathbf{s}_J\cdot\mathbf{B}(\mathbf{r}_j))\mathbf{B}(\mathbf{r}_j)), \qquad (5)$$

where *S* is the surface enclosing *J*. The magnetic field exists in all space. Converting the integration over surface *S* by integration over space *V* outside the conductor, we have

$$\mathbf{F}=\frac{1}{\mu_0}\int_V[[\nabla\times\mathbf{B}(\mathbf{r})]\times\mathbf{B}(\mathbf{r})]d^3r. \qquad (6)$$

In the empty space the ordinary currents absent, but there exists displacement current for which $[\nabla\times\mathbf{B}]=\partial\mathbf{D}/\partial t$, and the hidden force density $-[\partial\mathbf{D}/\partial t\times\mathbf{B}]$ cancels the electromagnetic force.

All that remains is to calculate this force. One may use the Biot-Savart law to describe the magnetic field produced by electric currents in the conductor, for which

$$\mathbf{B}(\mathbf{r})=\frac{\mu_0}{4\pi}\int_J\frac{[\mathbf{j}(\mathbf{r}'_j)\times(\mathbf{r}-\mathbf{r}'_j)]}{|\mathbf{r}-\mathbf{r}'_j|^3}d^3r'_j, \qquad (7)$$

and

$$[\nabla\times\mathbf{B}(\mathbf{r})]=-\frac{\mu_0}{4\pi}\int_J\Delta\frac{\mathbf{j}(\mathbf{r}_j)}{|\mathbf{r}-\mathbf{r}_j|}d^3r_j. \qquad (8)$$

Changing the order of integration in (6) and using the formal expression for the Dirac delta-function [8]

$$\Delta\frac{\mathbf{j}(\mathbf{r}_j)}{|\mathbf{r}-\mathbf{r}_j|}=-4\pi\mathbf{j}(\mathbf{r}_j)\delta(\mathbf{r}-\mathbf{r}_j), \qquad (9)$$

at integration over all $\mathbf{r}$, one obtains

$$\mathbf{F}=\frac{\mu_0}{4\pi}\int_J d^3r_j\int_J[\mathbf{j}(\mathbf{r}_j)\times\frac{[\mathbf{j}(\mathbf{r}'_j)\times(\mathbf{r}_j-\mathbf{r}'_j)]}{|\mathbf{r}_j-\mathbf{r}'_j|^3}]d^3r'_j. \qquad (10)$$

This force is proved to be absolutely equivalent to the self-force [6,7]. In the next section, it will be shown that this force is often very large.

III. SUPPORT-LESS PROPULSION

One can look at the calculations of the previous section in a somewhat different way. As a final result, an aim here is not confirming the existence of the hidden momentum but consideration of a new kind of propulsion. A simple example demonstrating the efficiency due to the hidden electromagnetic force is needed. For this purpose, it is convenient to consider a Π-shaped conductor through which an alternating electric current *I* flows (Fig. 2).

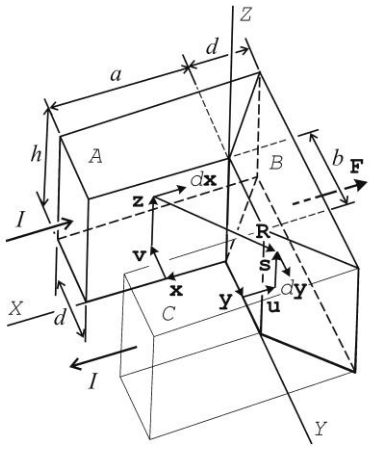


Fig.2. Support-less thruster

Magnetic forces are transverse. Therefore, a current element is acted upon by a magnetic force perpendicular to the current element. As a result, the magnetic action of the part *B* on the part *A* cancels the magnetic force exerted on the part *C* by the same part *B*, but currents flowing in *A* and *C* parts exert forces collinear to *X*-axis. Since

$$\mathbf{R}=\mathbf{y}+\mathbf{u}+\mathbf{s}-\mathbf{x}-\mathbf{v}-\mathbf{z},$$

and

$$\mathbf{j}(\mathbf{r}'_j)dr'_j=jd\mathbf{x};\ \mathbf{j}(\mathbf{r}'_j)dr_j=jd\mathbf{y},$$

then

$$\mathbf{F}=\frac{\mu_0 j^2}{2\pi}\int_J\frac{d\mathbf{x}(y+v)dy}{R^3}dvdzduds, \qquad (11)$$

where

$$R^2=(x+u)^2+(y+v)^2+(s-z)^2.$$

Only two integrals in (11) can be evaluated analytically. For sizes of the unclosed conductor shown in Fig 2, the *X*-component of the self-force is

$$F_x = -\frac{\mu_0 I^2}{2\pi\eta^2\delta^2}\int_0^\delta d\upsilon\int_0^\delta d\omega\int_0^\eta d\sigma \times$$

$$\int_0^\eta \ln\frac{f_1(\upsilon,\omega,\sigma,\zeta)\,f_2(\upsilon,\omega,\sigma,\zeta)}{f_3(\upsilon,\omega,\sigma,\zeta)\,f_4(\upsilon,\omega,\sigma,\zeta)}d\zeta, \qquad (12)$$

where

$$\upsilon = u/b\,;\ \omega = v/b\,;\ \sigma = s/b\,;\ \zeta = z/b, \qquad (13)$$

$$\alpha = a/b\,;\ \eta = h/b\,;\ \delta = d/b, \qquad (14)$$

$$f_1(\upsilon,\omega,\sigma,\zeta) =$$
$$\upsilon-\omega+((\upsilon-\omega)^2+(1+\upsilon+\omega)^2+(\sigma-\zeta)^2)^{1/2},$$
$$f_2(\upsilon,\omega,\sigma,\zeta) =$$
$$\alpha+\upsilon+((\alpha+\upsilon)^2+(\upsilon-\omega)^2+(\sigma-\zeta)^2)^{1/2},$$
$$f_3(\upsilon,\omega,\sigma,\zeta) =$$
$$\alpha+\upsilon+((\alpha+\upsilon)^2+(1+\upsilon+\omega)^2+(\sigma-\zeta)^2)^{1/2},$$
$$f_4(\upsilon,\omega,\sigma,\zeta) = \upsilon-\omega+(2(\upsilon-\omega)^2+(\sigma-\zeta)^2)^{1/2}.$$

Note that the reduced value $2\pi F/\mu_0 I^2$ depends on the relative variables (14). This means that this does not necessarily make us to create a very large system to provide the significant self-force. It is enough to find parameters (14) for which the self-force is significant.

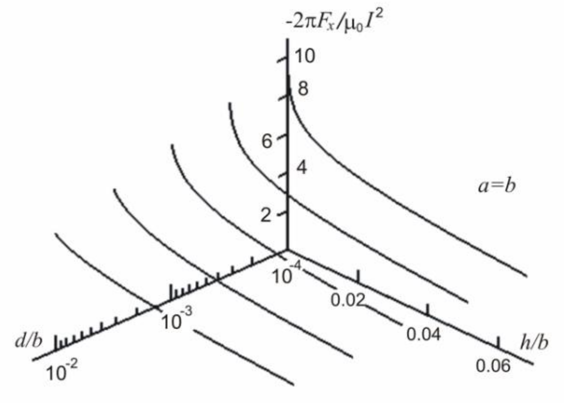


Fig. 3. Behavior of the force exerted by the thruster as sizes of system

Shown in Fig. 3 is the dependence of the reduced self-force versus reduced high *h*/*b* and thickness *d*/*b* of the conductor with alternative current. One should pay attention to the region of small values of the thickness *d* and *h* where the self-force is large.

In the limit as the thickness *d* of the conductor becomes infinitesimally small, the integration of (12) is elementary, and the limit of the self-force can be shown to be

$$F_{0x} = -\frac{\mu_0 I^2}{2\pi\eta^2}\{2\eta\arctan\frac{\eta\alpha}{\sqrt{\alpha^2+\eta^2+1}}+$$
$$\eta^2\ln\frac{(\sqrt{\alpha^2+\eta^2}+\alpha)\sqrt{\eta^2+1}}{\eta(\sqrt{\alpha^2+\eta^2+1}+\alpha)}-$$
$$\eta\alpha\ln\frac{(\sqrt{\alpha^2+\eta^2}-\eta)(\sqrt{\alpha^2+\eta^2+1}+\eta)}{(\sqrt{\alpha^2+\eta^2}+\eta)(\sqrt{\alpha^2+\eta^2+1}-\eta}-$$
$$\ln\frac{(\sqrt{\alpha^2+1}+\alpha)\sqrt{\eta^2+1}}{\sqrt{\alpha^2+\eta^2+1}+\alpha}-$$
$$\alpha(\sqrt{\alpha^2+\eta^2}-\alpha-$$
$$\sqrt{\alpha^2+\eta^2+1}+\sqrt{\alpha^2+1})\}. \qquad (15)$$

This equation also shows that for given α=*a/b* the self-force (15) logarithmically diverges (Fig.4), and this is for one conductor only. Real constructions may consist of number of the unclosed conductors.

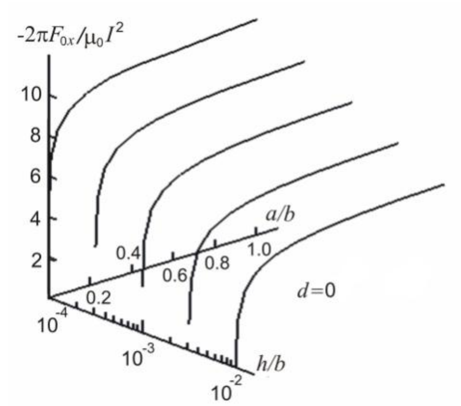


Fig. 4. Behavior of the force exerted by the thruster at infinitesimally small thicknesses *d*

There are no reasons to doubt this result since the reactive torque is experimentally found [4] and the measured self-force coincides with the theoretical calculations [6].

IV. CONCLUSION

We do not discuss here how to make alternative current flow in such a conductor. Variants are possible. Having suspended the conductor between two poles of an electromagnet with alternating current, one may make electromagnetic induction produce the changing current in the unclosed conductor. Such a variant corresponds to the magnetic interaction between one closed and one unclosed contour for which electromechanical Newton's third law does not hold but linear momentum conserves [9].

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