EXPERIMENTAL PROOF OF AN ABSENCE OF MARINOV MOTOR EFFECT

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During past years several papers were published, where the authors observed a functioning of a so called Marinov's motor (MM) [1-4]. An approximate draft of MM is shown in fig. 1. Two elongated oppositely-oriented solenoids (or permanent magnets) are fixed in the laboratory. Surrounding (or between) the solenoids is a conducting ring supported in bearings in the *xy* plane, which allow it to rotate about the *z* axis. Direct current from an external power source is introduced into the ring through brushes that allow the ring to rotate. The current divides at the brushes and flows around the ring in opposite directions on the two halves (see, fig. 1).

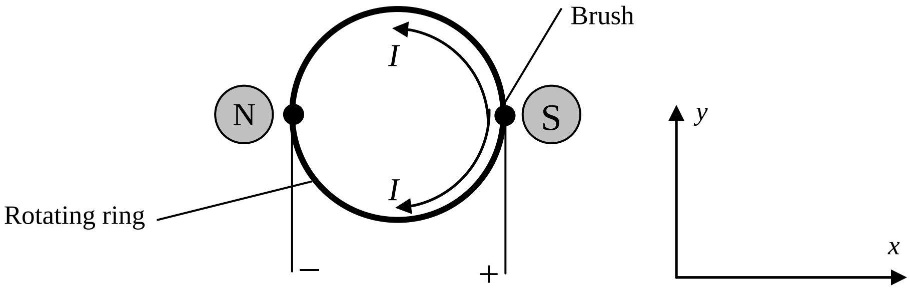


Fig. 1. Possible construction of Marinov motor

The observed Marinov's effect is a rotation of the ring about the *z* axis. The stationary frequency of rotation is proportional to the current *I* in ring. If the direction of the current in the external circuit of the motor is reversed, the sign of rotation reverses, too. It means that the torque in MM is proportional in first order to the current in circuit.

One can easy see that the fact of possible rotation of the ring is in a contradiction with the conventional Lorentz force law (LFL)

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}),$$

(where $\vec{E}, \vec{B}$ are the electric and magnetic fields, and $q$, $\vec{v}$ are the charge and velocity of particle, respectively). Indeed, in the MM we have an electrically neutral situation, and $\vec{B}$ is the static field. Hence, $\vec{E}$=0. Furthermore, in ideal situation $\vec{B}$=0 on the ring, too. In real conditions there is some non-vanishing value of $\vec{B}$ on the ring - a so called leakage magnetic field. (In order to decrease its value the magnetic fluxes of both solenoids are closed by soft ferromagnetic). However, any magnetic field on the ring cannot create a torque along the axis *z*. Indeed, the torque for some part of the ring with the volume *dV* is defined by Eq. (2)

$$d\vec{M} = (\vec{R} \times (\vec{j} \times \vec{B}))dV, \qquad (2)$$

where *R* is the radius of ring. Using a vector identity $\vec{a} \times (\vec{b} \times \vec{c}) = \vec{b}(\vec{a}\vec{c}) - \vec{c}(\vec{a}\vec{b}),$ one gets:

$$d\vec{M} = (\vec{R}\times(\vec{j}\times\vec{B}))dV = (\vec{j}(\vec{R}\vec{B}) - \vec{B}(\vec{R}\vec{j}))dV = \vec{j}(\vec{R}\vec{B})dV \qquad (3)$$

(here we take into account that $(\vec{R}\vec{j})$=0). One follows from Eq. (3) that any torque being induced by the magnetic field, lies in *xy* plane, while the ring in MM rotates around the *z* axis.

Thus, the hypothetical rotation of the ring in MM obviously contradicts to the conventional LFL.

A number of authors assumed that the MM functioning occurs due to an extra-force term in the LFL proportional to the vector potential $\vec{A}$. Some of the authors consider the MM effect as lying outside the conventional classical electrodynamics and special theory of relativity [1, 4]. Corresponding theoretical calculations give an extra-force term in the forms $\nabla_A\left(\vec{j}\vec{A}\right)$ or $\nabla\left(\vec{j}\vec{A}\right)$ in dependence on definition of total time derivative of vector field [4, 5]. Here $\vec{j}$ is the current density, and the operator $\nabla_A$ acts only on the vector $\vec{A}$.

Our own interest to the MM effect is explained by the fact, that the extra-force term in the LFL can be produced within the scope of classical electrodynamics under generalized procedure of minimization of action, which takes into account non-vanishing spatial partial derivatives of current density. Indeed, let us write an expression for action of some assembly of charged particles in the form [6]

$$S = \sum\int -Mc^2 ds - \int A_i j^i d\Omega, \qquad (4)$$

where $j^i = \rho\dfrac{dx^i}{dt}$ is the four-current density, and $d\Omega = dxdydzdt = dVdt$ is the elementary volume in four-dimensional space. For collective motion of charged particles (for example, conduction electrons in conductor) one may take

$$\sum\int -Mc^2 ds = -\int\sum Mc^2 ds = -\int mc^2 ds dV,$$

where *m* stands for the mass density of the assembly of particles. Hence, the action *s* per unit three-dimensional volume takes the form

$$s = \int -mc^2 ds - A_i j^i dt\,. \qquad (5)$$

Further, let us vary the action (5):

$$\delta s = \int -mc^2\delta ds - \delta A_i j^i dt - A_i\delta j^i dt - \rho A_i \delta\frac{dx^i}{dt}dt =$$

$$\int -mc^2 u_i d\delta x^i - \frac{\partial A_i}{\partial x^k} j^i\delta x^k dt - A_i\frac{\partial j^i}{\partial x^k}\delta x^k dt - \rho A_i d\delta x^i =$$

$$\int\left(mc^2 du_i\delta x^i - \frac{\partial}{\partial x^k}(A_i j^i)\delta x^k dt + d(\rho A_i)\delta x^i\right) - (mc^2 u_i + \rho A_i)\delta x^i \Big| =$$

$$\int mc^2\frac{du_i}{dt}\delta x^i dt - \frac{\partial}{\partial x^i}(A_k j^k)\delta x^i dt + \frac{d}{dt}(\rho A_i)\delta x^i dt = \int\left(mc^2\frac{du_i}{dt} - \frac{\partial}{\partial x^i}(A_k j^k) + \frac{d}{dt}(\rho A_i)\right)\delta x^i dt = 0$$

(Here we used the equalities $\delta ds = \dfrac{dx_i d\delta x^i}{ds} = u_i d\delta x^i, \delta A_i = \dfrac{\partial A_i}{\partial x^k}\delta x^k, \quad \delta j^i = \dfrac{\partial j^i}{\partial x^k}\delta x^k$). From there we get the motional equation

$$mc^2 \frac{du_i}{dt} = \frac{\partial}{\partial x^i}(A_k j^k) - \rho \frac{dA_i}{dt} . \quad (6)$$

(Here we take into account that for isolated system of charged particles $d\rho/dt = 0$). Using the equality $\rho \frac{dA_i}{dt} = \frac{\partial A_i}{\partial x^k} j^k$ one may transform Eq. (6) into the form

$$mc^2 \frac{du_i}{dt} = \frac{\partial A_k}{\partial x^i} j^k + A_k \frac{\partial j^k}{\partial x^i} - \frac{\partial A_i}{\partial x^k} j^k = F_{ik} j^k + A_k \frac{\partial j^k}{\partial x^i} \quad (7)$$

The spatial components of (7) give the force law in form:

$$\frac{d\vec{p}}{dt} = \rho\vec{E} + \vec{j} \times \vec{B} - \varphi\nabla\rho + \nabla_j(\vec{j}\vec{A}) \quad (8)$$

where $\vec{p}$ is the impulse of particles per unit volume, and the operator $\nabla_j$ acts only on the components of $\vec{j}$. Further, time component of Eq. (7) gives the energy conservation law:

$$mc^2 \frac{d}{dt} \frac{1}{\sqrt{1 - v^2/c^2}} = \vec{E}\vec{j} + \varphi \frac{\partial \rho}{\partial t} - \vec{A} \frac{\partial \vec{j}}{\partial t} , \quad (9)$$

which can be transformed into the nice form

$$\frac{d}{dt}\left( \frac{Mc^2}{\sqrt{1 - v^2/c^2}} - q\varphi + q\vec{v}\vec{A} \right) = q\vec{E}\vec{v} - q \frac{d\varphi}{dt} + q\vec{v} \frac{d\vec{A}}{dt} . \quad . \quad (10)$$

Taking in Eq. (8) $\nabla\rho = 0$ we get the extra-force term in form $\nabla_j(\vec{j}\vec{A})$.

Our further experiments were aimed to reveal an extra-force term in the LFL and to choose its concrete form among three possible $\nabla_A(\vec{j}\vec{A})$, $\nabla(\vec{j}\vec{A})$ and $\nabla_j(\vec{j}\vec{A})$. On this way we constructed the MM similar to fig. 1, where we used a pendulum method to measure a torque. The radius of ring was *r*=5.0 cm, the radius of magnets a=2.75 cm, the distance between the axes of magnets was *L*=16.5 cm. The minimal value of measured torque was not more than $10^{-5}$ N×m. The resistant torque in brushes was $2.0\times10^{-4}$ N×m. Evaluated value of torque in MM caused by extra-force term in LFL has an order of magnitude $M \approx kBa^2 I$, where the coefficient *k* depends on concrete form of the extra-force term, as well as the values of *r*, *a* and *L*. Under chosen *r*, *a*, *L*, the magnitude of *k* lies in the range (2...4) for three possible forms of the extra-force term. In our experiment *B*=0.6 T, and the maximum value of *I*=5 A. Under these numerical values the range of expected torque $M \approx (5...8)\times10^{-3}$ N×m, that greatly exceeds a resistant torque of brushes. Nevertheless, we observed no rotation of the ring in our construction of MM. This is an agreement with the result recently obtained by Valvende [7]. However, it was found by us [8], that the high spatial gradient of current in the region of the brushes creates the torque with opposite sign to the torque on ring. Moreover, in case of extra-force term in form $\nabla(\vec{j}\vec{A})$ this compensating torque exactly equals in modulus to the ring's torque. Thus, our results allow to exclude the extra-force term in forms $\nabla_A(\vec{j}\vec{A})$ and $\nabla_j(\vec{j}\vec{A})$, but do not resolve a problem about possible existence of $\nabla(\vec{j}\vec{A})$ extra-force term. In order to find a hypothetical action of the force $\nabla(\vec{j}\vec{A})$ we realized an additional experiment. The ring has been removed, and a special conductive loop has been introduced into the experimental scheme as depicted in fig. 2. This loop consisted of two elongated straight conductive wires, fixed in the laboratory, two very soft conductive springs, and a conductive half-ring connected with the springs. The half-ring was suspended on filaments so that it was almost free to move along the axis *x*. Its radius was equal to *a*. One can show that in such the case the extra-force term $\nabla(\vec{j}\vec{A})$ induces the force $F=kBaI$ along the axis *x*, where the coefficient *k* depends on the distance between the axis of nearest magnet and axis of half-ring. When this distance is close to 2*a*, k≈1. Under B=0.6 T, *a*=2.75 cm, and *I*=5 A, the force $F\approx 8\times 10^{-2}$ N.

One should notice that a leakage magnetic field also creates a parasitic force at the same direction due to conventional LFL. In our experiment the maximal value of such magnetic field along the axis *z* upon the half-ring was equal to $B_l\approx 0.01$ T, that corresponds to the conventional Lorentz force of about $1.3\times 10^{-3}$ N. This is more than 50 times less than the force produced by the extra-force term $\nabla(\vec{j}\vec{A})$.

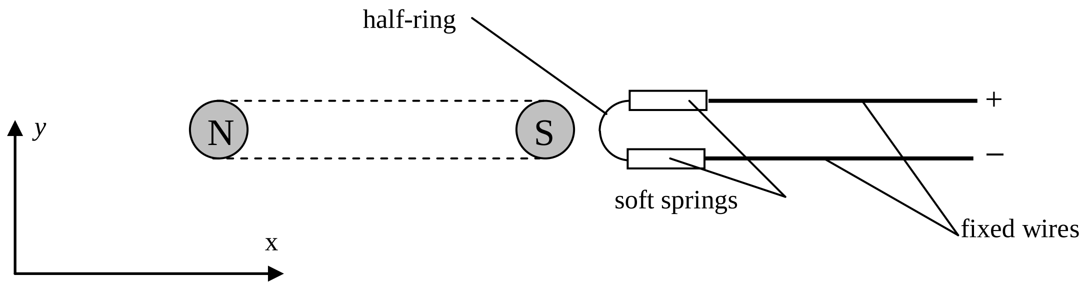


Fig. 2. Scheme of experiment for revealing the force term $\nabla(\vec{j}\vec{A})$.

We estimated the force acting on the half ring by means of the pendulum method, which provided a minimal observable magnitude of force $2\times 10^{-4}$ N. Initial mechanical resistance of springs is less than this value, and can be taken as negligible. In our experiment we obtained a dependence of the measured force on the current *I* in the half-ring in the range of currents 0...5 A. The measured dependence was a straight line with the slope coefficient $b=(2.5\pm 0.1)\times 10^{-4}$ N/A. Since $b\approx Ba$, that the force observed corresponds to $B=(0.9\pm 0.1)\times 10^{-2}$ T, that is in agreement with estimated value of $B_l$, acting via conventional Lorentz force law.

Thus, our experiments reveal no extra-force term in the Lorentz force law at least at the level of measuring precision.

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