# The Marinov Motor, Notional Induction without a Magnetic B Field

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The force **F** of induction on a charge $q$ due to a slowly time changing magnetic vector potential **A** is $F = -q\mathrm{d}\mathbf{A}/\mathrm{d}tc = -q\partial\mathbf{A}/\partial tc - q(\mathbf{V}\cdot\nabla)\mathbf{A}/c$, where $\mathbf{V} = \mathbf{v} - \mathbf{v}'$ is the relative velocity between the charge $q$ with a velocity **v** and the source of the **A** field with the velocity $\mathbf{v}'$. For the Marinov motor, described below, $\mathbf{v}' = 0$, $\partial\mathbf{A}/\partial t = 0$, $\nabla\cdot\mathbf{A} = 0$ and $\mathbf{B} = \nabla\times\mathbf{A} = 0$, so the force driving the motor is given by $-q(\mathbf{v}\cdot\nabla)\mathbf{A}/c$, and the Lorentz-Maxwell theory, requiring a **B** field to produce a ponderomotive force, fails.

## 1. Introduction

The force of induction **F** on a charge $q$ is given by

$$\mathbf{F} = -q\mathrm{d}\mathbf{A}/\mathrm{d}tc\,, \tag{1}$$

where **A** is the usual magnetic vector potential defined by

$$\mathbf{A}(r) = \int \frac{\mathrm{d}^3 r' J(r')}{|r - r'|c}\,, \tag{2}$$

where $J$ is the current density. Slowly varying effects are assumed here, where the basic theory may be given as a true relativity theory, involving the separation distance between two charges and its time derivatives.

This force of induction, Eq. (1), yields Faraday's law of electromagnetic induction for the special case of an electromotive force (emf) around a fixed closed loop. In particular,

$$\begin{aligned}\text{emf} &= \oint \frac{\mathrm{d}s\cdot F}{q} = \oint \mathrm{d}s\cdot\left(\frac{\mathrm{d}\mathbf{A}}{\mathrm{d}tc}\right) = -\frac{\partial}{\partial tc}\int \mathrm{d}a(\nabla\times\mathbf{A})\cdot n \\ &= -\frac{\partial}{\partial tc}\int \mathrm{d}a\,\mathbf{B}\cdot n = -\frac{\partial\Phi}{\partial tc}\end{aligned}\,, \tag{3}$$

where $\Phi$ is the magnetic flux through the loop.

It is observed in the laboratory that an emf is also induced when $\partial\mathbf{A}/\partial tc = 0$, and the magnetic flux through the loop is changed by moving the loop, so Faraday's law becomes

$$\text{emf} = -\frac{\mathrm{d}\Phi}{\mathrm{d}tc}\,. \quad - \tag{4}$$

Francisco Müller's (1987) experiments show that induction occurs locally and that the force of induction does not have to involve an entire closed current loop, so the most fundamental law for the force of induction is given simply by the point law, Eq. (1), instead of the integral Faraday law, Eq. (3) or (4).

In addition, according to the Faraday law, Eq. (3) or (4), the magnetic field may be zero in the wires in which a current is induced, such as in the outer secondary winding of a toroidal transformer. The force of induction that drives electrons to produce a current cannot, thus, be, in fact, the zero **B** field itself. The actual force of induction is produced by the action of the **A** field, as given by Eq. (1), on the electrons in the wires, which is not zero. The Maxwell-Faraday flux rule, Eq. (3) or (4), cannot, thus, be used as a fundamental explanation of induction, nor can it be used to yield the observed force of induction in general.

The force of induction, Eq. (1), yields many possible types of induction. In particular,

$$\mathbf{F} = -\frac{q\mathrm{d}\mathbf{A}}{\mathrm{d}tc} = \frac{q\partial\mathbf{A}}{\partial tc} - \frac{q(\mathbf{V}\cdot\nabla)\mathbf{A}}{c}, \tag{5}$$

where

$$\mathbf{V} = \mathbf{v} - \mathbf{v}', \tag{6}$$

is the relative velocity between the charge $q$ moving with the velocity **v** and the source of **A** moving with the velocity $\mathbf{v}'$. Motional induction occurs when $\partial\mathbf{A}/\partial t = 0$, so from Eq. (5)

$$\mathbf{F}(\text{motional}) = -\frac{q(\mathbf{V}\cdot\nabla)\mathbf{A}}{c}. \tag{7}$$

In addition, various types of motional induction may also be distinguished, depending upon whether the charge q moves or the source of the **A** field moves and upon the particular nature of the **A** field involved. To help to distinguish various geometries Eq. (7) may also be rewritten using a vector identity to give

$$\mathbf{F}(\text{motional}) = \frac{q\mathbf{V}\times(\nabla\times\mathbf{A})}{c} - \frac{q\nabla(\mathbf{V}\cdot\mathbf{A})}{c}, \tag{8}$$

where the del operator operates on **A** only here. (For the force per unit fixed volume $f$ on a current density $j$, Eq. (8) needs to be written as $f = j\times(\nabla\times\mathbf{A})/c - \nabla(j\cdot\mathbf{A})/c + \mathbf{A}\times(\nabla\times j)/c + (\mathbf{A}\cdot\nabla)j$.) For the case of a stationary source for the **A** field and **A** perpendicular to $q\mathbf{v}$ the second term on the right of Eq. (8) vanishes, and the case of unipolar induction arises, where

$$\mathbf{F}(\text{unipolar induction}) = \frac{q\mathbf{v}\times(\nabla\times\mathbf{A})}{c} = \frac{q\mathbf{v}\times\mathbf{B}}{c}. \tag{9}$$

This formula (9) yields the force on the Faraday disc, causing it to turn. (This force is also equal to the second term of the Lorentz force.)

The induction of particular interest here for the Marinov motor involves fixed current loop sources for the **A** field, so $\nabla\cdot\mathbf{A} = 0$, and $q\mathbf{v}$ parallel to **A**, so $\nabla\times\mathbf{A} = 0$. In particular this type of motional induction involves

$$\frac{\partial\mathbf{A}}{\partial t} = 0, \qquad \nabla\cdot\mathbf{A} - 0, \quad \text{and} \quad \mathbf{B} = \nabla\times\mathbf{A} = 0. \qquad .\ (10)$$

Induction involving a zero magnetic field is generally neglected, because the Maxwell-Lorentz theory says that no such induction can occur when the magnetic field is zero. This type of motional induction has been used to account for the Aharonov-Bohm (1998) effect and the Hooper (1974)-Monstein (1997) experiment.

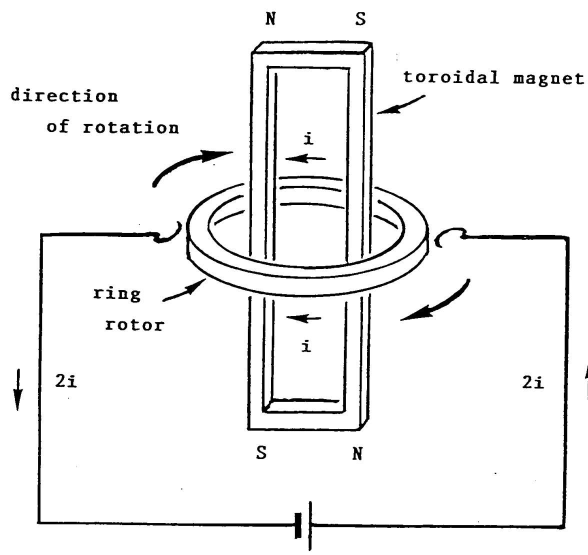


Fig. 1. The essential elements of the Marinov motor.

## 2. Description of the Marinov motor

This induction motor was apparently first investigated by S. Marinov (1997). The essential features are indicated in Fig. 1. The rotating ring rotor may be a solid copper ring fed current through brushes, as indicated. The rotor may also be conveniently replaced by an insulated annular trough filled with circulating mercury. The current needed may then be simply supplied by fixed wire ends immersed in the mercury at the locations indicated. The ring rotor passes around a toroidal magnet, as indicated. The direct current is fed into the ring at the two opposite points nearest the magnet. When the current is made to flow, the ring rotor rotates.

## 3. Derivation of the net force driving the rotor

To a satisfactory approximation the toroidal magnet may be regarded as two thin infinitely long solenoids oppositely wound with centers located at $y = +b$ and $y = -b$, as indicated in Fig. 2. The magnetic vector potential **A** produced by an infinitely long thin solenoid is given by

$$\mathbf{A} = \frac{K e_\phi^*}{r^*}\,, \tag{11}$$

in cylindrical coordinates with $r^*$ centered on the axis of the solenoid, where $e_\phi^*$ is a unit vector in the increasing $\phi^*$ direction, and where the constant $K$ is given by

$$K = \frac{2\pi\eta a^2}{c^2} = \frac{\Phi}{2\pi c}$$

where $\eta$ is the current per unit length in the solenoid, $a$ is the radius of the solenoid ($a \ll r^*$), and $\Phi$ is the magnetic flux in the solenoid.

The magnetic vector potential **A** at any point in the setup shown in Fig. 2 is then given as the sum of the potentials due to the two solenoids of opposite polarity at $y = +b$ and $-b$; thus the $r$ and $\Phi$ components of the **A** field are given by

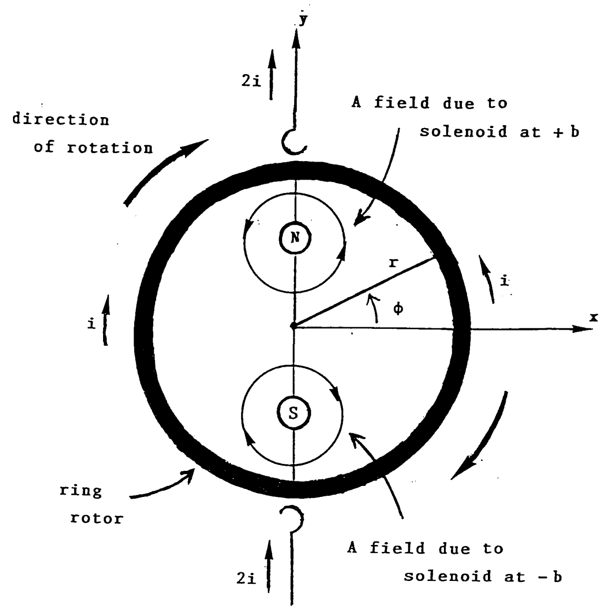


Fig. 2. Choice of coordinates, location of the infinite thin solenoids at $y = +b$ and at $-b$, the direction of the current flow in the rotor, and the direction of the rotation produced.

$$\mathbf{A}_r = \frac{2Kb\left(r^2 + b^2\right)\cos\phi}{Q^4},$$
$$\mathbf{A}_\Phi = \frac{2Kb\left(r^2 - b^2\right)\sin\phi}{Q^4}, \qquad (13)$$

where

$$Q^4 = \left(r^2 + b^2\right)^2 - 4b^2 r^2 \sin^2\phi ,(14)$$

for cylindrical coordinates $r$ and $\phi$ centered at the center of the rotor.

Making the replacement for charges flowing in terms of the current,

$$q\mathbf{v} = i\,\mathrm{d}s = ri\,\mathrm{d}\phi\, e_\phi , \qquad (15)$$

where $i$ is the current in the ring, $r$ is the radius of the ring, and $e_\phi$ is a unit vector in the positive $\phi$ direction, the net force on the rotor from Eq. (1) for the segment of the ring from $\phi_1$ to $\phi_2$ is given by

$$F_\phi = -i\int_1^2 (\mathrm{d}s\cdot\nabla)A_\phi = -i\int_1^2 \frac{\mathrm{d}\phi\partial\,\mathrm{A}_\phi}{\partial\phi} = i\left[A_\phi(\phi_1) - A_\phi(\phi_2)\right]. \qquad (16)$$

Noting the direction of current flow, positive in the first quadrant, negative in the second and third quadrants, and positive in the fourth quadrant, each quadrant delivers the same tangential force on the ring. The net tangential force on the ring rotor then becomes from Eqs. (13), (14), and (15)

$$F_\phi = 4i\left[A_\phi(0) - A_\phi\left(\frac{\pi}{2}\right)\right] = -\frac{8Kbi}{\left(r^2 - b^2\right)}. \qquad (17)$$

And the net torque $T$ on the ring rotor causing it to rotate is then given by

$$T = rF_\phi = -\frac{8Kibr}{\left(r^2 - b^2\right)}. \qquad (18)$$

It may be shown that when the current is fed in at $\phi = 0$ and out at $\phi = \pi$ (instead of, as shown in Fig. 2, in at $\phi = 3\pi/2$ and out at $\phi = \pi/2$ ) the net torque on the ring will be zero, because the contributions in the second and fourth quandrants change sign, thereby cancelling the contributions from the first and third quandrants. The same geometry is achieved by simply rotating the toroidal magnet through 90°, which will also stop the rotor's rotation.

It is interesting that rotating the toroidal magnet through 180° will cause the rotor to rotate in the opposite direction. According to the insufficient Maxwell theory there is no way that one can know the direction of the circulating **B** field inside the toroidal magnet. Here the direction of rotation of the rotor in the Marinov motor yields the direction of the B field inside the toroidal magnet.

## 4. Discussion

4.1. *Force of induction from Weber electrodynamics*: Weber (1848) electrodynamics is the correct theory to use f6r slowly varying effects. Besides yielding the original empirically correct Ampere force law and the Faraday law of induction, it yields the general law for induction, Eq. (1), for the case of closed current loop sources for **A** as follows: From the Weber potential for charge $q$ moving with velocity **v** and charge $q'$ moving with velocity $\mathbf{v}'$

$$W = \frac{qq'}{R^2}\left[1 - \frac{(\mathrm{d}R/\mathrm{d}tc)^2}{2}\right], \tag{19}$$

where $R = |\mathbf{r} - \mathbf{r}'|$ is the separation distance between the charges, neglecting the Coulomb interaction and the negligibly small (and never detected) terms varying as $(\mathbf{v} \cdot \mathbf{R}/cR)^2$ and $(\mathbf{v}' \cdot \mathbf{R}/cR)^2$, the Weber potential of interest for induction becomes

$$W = \frac{qq'(\mathbf{v} \cdot \mathbf{R})(\mathbf{v}' \cdot \mathbf{R})}{c^2 R^2}. \tag{20}$$

For closed current loop sources, where $q\mathbf{v}' = I\mathrm{d}s'$, the Weber potential becomes

$$W = \frac{(qI/c^2)\mathbf{v} \cdot \oint \mathbf{R}(\mathbf{R} \cdot \mathrm{d}s')}{R^2} = \frac{(qI/c^2)\mathbf{v} \cdot \mathrm{d}s'}{R}. \tag{21}$$

And for a volume distribution of such closed current loops

$$W(r) = \frac{(q/c^2)\mathbf{v} \cdot \int \mathrm{d}^3 r' \mathbf{J}(\mathbf{r}')}{R} = \frac{q\mathbf{v} \cdot \mathbf{A}}{c}. \tag{22}$$

It may be noted that this physical potential, Eq. (22), equals the -negative of the traditional pseudo-potential (Goldstein 1950) arbitrarily introduce into an *ad hoc* Lagrangian devised to yield the Lorentz force.

To obtain the force of induction the rate that energy is taken from the potential at constant velocity **v** equals the rate work is done on the charge $q$, thus. -

$$-\frac{\mathrm{d}W}{\mathrm{d}t} = -\frac{q\mathbf{v} \cdot \mathrm{d}\mathbf{A}}{\mathrm{d}tc} = \mathbf{v} \cdot F, \tag{23}$$

so $F$ is then given by Eq. (1), as was to be shown.

4.2. *Total time derivative* d/d*t versus partial time derivative* $\partial/\partial t$: In physics the partial time derivative $\partial/\partial t$ means that actual time changes in a fixed coordinate frame of reference is involved, such as in the laboratory frame or the absolute frame of reference. When the total time derivative $\mathrm{d}/\mathrm{d}t$ is used, it means that time changes in a moving reference frame are involved. In a moving reference frame there are real time changes in the fields being observed and there are pseudo-time changes due to spatial variations in the fields being observed and the velocity of the coordinate frame **V**, that are given by ( $\mathbf{V}\cdot\nabla$ ). The net apparent time change in a moving frame is then given by

$$\frac{\mathrm{d}}{\mathrm{d}t}=\frac{\partial}{\partial t}+\left(\mathbf{V}\cdot\nabla\right).$$

For slowly varving effects in electrodynamics, where radiation is not involved, the Weber (1848) theory is correct. The Weber theory is a true relativity theory, depending only upon the relative distance between two charges and the time derivatives of this distance. In this case the moving center of mass defines the coordinate frame most appropriate for the theory. The total time derivative $\mathrm{d}/\mathrm{d}t$ is the appropriate time derivative to use in true relativity theories.

The Weber-Wesley (1990, 1997) field theory, the appropriate theory when radiation and rapidly varying effects are involved, is only valid in the fixed preferred absolute zero-velocity reference frame (as also true for the Maxwell field theory). This theory involves only partial time derivatives $\partial/\partial t$ . Physically the validity of a fixed absolute frame of reference is established by the empirical observations that the one-way velocity of energy propagation of light, or electrodynamic waves, is fixed as **c** relative to absolute space. It is clear that the Weber-Wesley (1990) field theory is not appropriate for motional induction (nor is the Maxwell theory).

4.3. *Forces on electron currents in a metal yield a ponderomotive force*: Any average net force acting on the electrons in a metal must be zero. If a force acts on an individual electron, it accelerates over a short distance until it collides with a positive ion (or with the crystal lattice). The net result of forces of external origin acting on the electrons is thus a net diffusion of the electrons in the metal with a constant average drift velocity. Since the net average effect is only a constant velocity and not a net acceleration, the electrons in a metal cannot themselves sustain any net force. The force on the electrons of external origin must be, thus, balanced by an equal in magnitude and oppositely directed net average force of internal origin.

The net average internal force on the electrons (opposite to the force of external origin) is produced by an effective charge separation inside the metal. This effective charge separation produces an effective internal electric field, that acts on the electrons in a direction opposite to the externally produced force and acts on the positive ions in the same direction as the externally produced force. Since the electrons themselves can sustain no net average force, a force of external origin acting on the moving electrons in a metal results in a ponderomotive force in the metal itself equal to the force of external origin in both magnitude and direction. This agrees with the observation that the externally applied force acts as a force on the metal itself, permitting an agreement with Newton's third law, when considering the reaction force on the source that produces the external force.

4.4. *Electromotive versus ponderomotive force*: The problem of when an electromotive force (emf) arises that drives an electron current and when a ponderomotive force arises that moves a conductor is a problem as old as electrodynamics itself. It is sometimes asked: Why is a ponderomotive force produced instead of an emf? This question is misleading, because, in response to an externally applied force on the electrons that produces an emf, there is also an effective charge separation that produces an effective electric field that produces a ponderomotive force on the positive ions equal in magnitude and in direction to the externally applied force. Thus, the electromotive and the ponderomotive forces are always necessarily simultaneously present. It is impossible to have the one without the other.

Ampere's original force law is between two current elements When the current is switched off, no force exists. This force law, thus, clearly involves the force between two electron current elements. Yet the force that Ampere actually observed was the force on the positive ions or on the metal itself. Only the mechanism of an internally produced effective charge separation and an effective internal electric field can account for the phenomena observed.

In the Marinov motor the ponderomotive force driving the rotor is parallel to the current flow. Since this ponderomotive force must be matched by an equivalent induced electromotive force in the same direction, a slightly greater current will flow on one side of the rotor as compared with the other.

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