Ampère: The *Avis Phoenix* of Electrodynamics

J. Guala-Valverde* & R. Achilles*†

Recent definitive experimentation unveils –on Newtonian basis- standard field theory limitations in explaining homopolar torque production.

PACS codes: 01.50.My,41.20.-q

Keywords: Field, distant action, relative motion, torque production, Ampère force, Grassmann force, Newton third law.

1 Introduction

A renewed interest has come about to disclose the presumptive equivalence of the Ampère's (1827) and Grassmann's (1845) force expressions describing the ponderomotive interaction of a closed carrying-current circuit, and a current element belonging to another or the same circuit [1,2,3,4,5].

Nowadays, none of the reported experiments appears to be conclusive on this respect. A recent publication in this journal [6]

* Fundación Julio Palacios – Neuquén, Argentina fundacionjuliopalacios@usa.net

† Confluencia Tech University – P. Huincul, Argentina achilles@ieee.org

clearly shows that motional induction, as applied to homopolar engines, enlights the issue.

The relational (true relativistic) underlying physics of homopolar devices was experimentally disclosed at the beginning of the 21st Century [7,8,9] for both, generator and motor operating modes.

The essential homopolar-motor components include:

i. A magnet creating a uniform $\vec{B}$ – field.

ii. A radial conductive bar (*RB* from herein) able to rotate about a vertical, also conductive, shaft. The ends of the bar are terminated in contacts to allow it to slide on the shaft perimeter and on a metallic ring attached to the magnet's outer rim. A *DC emf* source is inserted in the shaft as shown in Figure 1.

iii. A closing-circuit wire (*CW* from herein) also terminated in sliding contacts touches both, an upper shaft perimeter and the magnet peripheral ring.

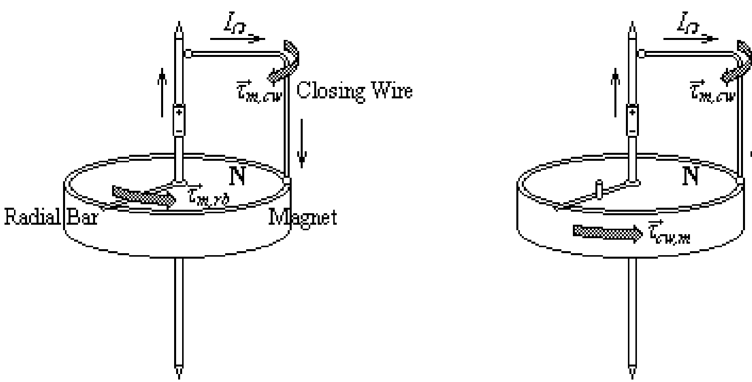

Figure 1 – Homopolar Motor Case 1 (left) and Case 2 (right) Configurations

Both ends of the shaft are terminated in sharp points. While the lower end lays on a hard-polished surface the upper one, centred by a conical bearing, enables an almost frictionless rotation. The outcome of the experiments is described below [7,8]:

1.1 Case 1

When a centripetal *DC* ohmic current I_Ω is injected in the conductive loop with the magnet at rest to the lab, while *RB* (on the magnet's North pole) rotates counter-clockwise, *CW* turns clockwise.

The main interaction takes place between the magnet and each wire, being the intra-wire interplay negligible [10].

As substantiated based on indisputable experimentation [7,8], two active and two reactive torques are involved:

· $\vec{\tau}_{m,rb}$ is the active torque produced by the magnet on *RB*.

· $\vec{\tau}_{m,cw}$ is the active torque produced by the magnet on *CW*.

These equal-magnitude torques are opposite so that:

$$\vec{\tau}_{m,rb} = -\vec{\tau}_{m,cw} \tag{1}$$

RB reacts to $\vec{\tau}_{m,rb}$ producing the reaction torque $\vec{\tau}_{rb,m}$ on the magnet, being:

$$\vec{\tau}_{rb,m} = -\vec{\tau}_{m,rb} \tag{2}$$

CW reacts to $\vec{\tau}_{m,cw}$ producing the reaction torque $\vec{\tau}_{cw,m}$ on the magnet, being:

$$\vec{\tau}_{cw,m} = -\vec{\tau}_{m,cw} \tag{3}$$

1.2 Case 2

With *RB* attached to the magnet as indicated in the right side of Figure 1, the injection of I_Ω in the conductive loop produces a counter-clockwise rotation of both, and a clockwise turn of *CW*. The attachment of *RB* to the magnet gives no chance for *relative motion* between them, an unavoidable requirement for having a machine. The action-reaction cancellation condition between the equal-magnitude opposite torques $\vec{\tau}_{rb,m} = -\vec{\tau}_{m,rb}$ acting on the magnet plus *RB* assemble, forbids its rotation.

However, a machine is kept between the magnet and *CW*, mechanically decoupled with relative motion allowed. *The torque exerted by the closing wire on the magnet* $\vec{\tau}_{cw,m}$ *is the only cause for the experimentally observed magnet rotation.* This fact, ignored since Faraday's days, is the main outcome of the developed experiments [7,8].

For a detailed account on the actual experiments performed on the lapse 1995-2002, see *www.fjp.org.ar* or *www.andrijar.com*.

2. Ampère's Virtual Current Elements and Force

As it is well known, Ampère's force law for differential current elements satisfies Newton's third law in its strong form [11,12,13]. Ampère's formulation for the force between two current elements $I_\Omega d\vec{l}_\Omega$ and $I_A d\vec{l}_A$ (see Figure 2) is expressed in obvious notation as:

$$d^2\vec{F}_{A,\Omega} = -d^2\vec{F}_{\Omega,A} = -\frac{\mu_0}{4\pi}\frac{I_\Omega dl_\Omega \cdot I_A dl_A}{r^3}\left(2\cos\varepsilon - 3\cos\alpha\cos\beta\right)\vec{r} \quad (4)$$

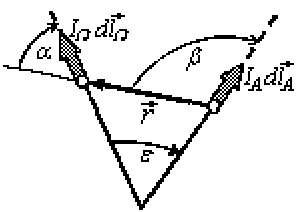

Figure 2 – Ampère's Force Law Angles

With the purpose of applying this formulation to homopolar machines, the magnet may be modelled resorting on Ampère virtual magnetizing currents as sketched in Figure 3.

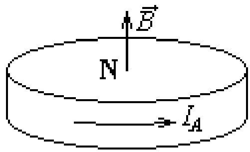

Figure 3 – Ampère Virtual Magnetizing Current

3. Understanding Torque Production

3.1 Case 1, Grassmann-Biot Savart Formulation

In this approach the interaction takes place between the $\vec{B}-$field created by the magnet, and the two current-carrying wires considered. The Grasmann's force $d\vec{F}^{G}_{m,\Omega} = \left(I_\Omega d\vec{l}_\Omega\right) \times \vec{B}$ exerted by the $\vec{B}-$field in the radial position $\vec{r}$ of an ohmic current element $I_\Omega d\vec{l}_\Omega$ (of, either, *CW* or *RB*), allows formulate the active-torque $\vec{\tau}^{G}_{m,\Omega}$ produced on the piece as:

$$\vec{\tau}^{G}_{m,\Omega} = \int_\Omega \vec{r} \times d\vec{F}^{G}_{m,\Omega} \neq 0 \tag{5}$$

To determine the reactive torque we have to evaluate, based on Biot-Savart's law [10,11,12], the $d\vec{B}_\Omega$ field created by the ohmic current element $I_\Omega d\vec{l}_\Omega$ on the Ampère's virtual current element $I_A d\vec{l}_A$ located on the magnet's periphery. The force exerted by this field on $I_A d\vec{l}_A$ takes the form:

$$d^2\vec{F}^G_{\Omega,m} = \left(I_A d\vec{l}_A\right) \times d\vec{B}_\Omega \tag{6}$$

drawing the reactive torque expression:

$$\vec{\tau}^G_{\Omega,m} = \oint_m \int_\Omega \vec{R} \times d^2\vec{F}^G_{\Omega,m} \tag{7}$$

This integration has to be developed over the whole magnet periphery and over the considered –*CW* or *RB*- wire section. Here $\vec{\tau}^G_{\Omega,m}$ labels the torque produced by the wire segment on the magnet, being $\vec{R}$ the magnet's peripheral radius.

According to equation (6) $d^2\vec{F}^G_{\Omega,m}$ acts at right angles to $I_A d\vec{l}_A$ for both, *CW* and *RB*, cancelling any possibility of having a reactive torque on the magnet, i.e.:

$$\vec{\tau}^G_{cw,m} = \vec{\tau}^G_{rb,m} = 0 \tag{8}$$

This equation becomes a physical nonsense, in flagrant contradiction with equations (1,2,3) sustained on irrefutable experimentation.

3.2 Case 1, Ampère Formulation

Ampère force, free of the orthogonality constrain, satisfies Newton third law in its strong form, allowing tangential force components on the virtual current element $I_A d\vec{l}_A$, responsible for the experimentally observed magnet's rotation. Therefore:

$$\vec{\tau}^A_{\Omega,m} = \oint_m \int_\Omega \vec{R} \times d^2\vec{F}^A_{\Omega,m} \neq 0 \tag{9}$$

and the reactive and net torques on the magnet become:

$$\vec{\tau}^A_{cw,m} = -\vec{\tau}^A_{rb,m} \neq 0 \text{, and } \vec{\tau}^A_m = \vec{\tau}^A_{cw,m} + \vec{\tau}^A_{rb,m} = 0 \tag{10}$$

in full agreement with equations (1,2,3).

The torque $\vec{\tau}_{cw,m}$ can be evaluated without resorting on integration. In fact, on account of equations (1) and (3) we get:

$$\vec{\tau}_{cw,m} = \vec{\tau}_{m,rb} \tag{11}$$

For the configuration adopted (Figure 1, left), the torque $\vec{\tau}_{m,rb}$ is trivially evaluated as advanced by Maxwell [14]:

$$\vec{\tau}^{\,A}_{m,rb} = \vec{\tau}^{\,G}_{m,rb} = \int_0^R \vec{r} \times \left(I_\Omega d\vec{r} \times \vec{B} \right) = \frac{1}{2} \vec{R} \times \left(I_\Omega \vec{R} \times \vec{B} \right) \tag{12}$$

In this particular case, closed peripheral magnetizing current acting on a discrete circuit segment, both Ampère and Grassmann formulations agree.

3.3 Case 2, Grassmann-Biot Savart and Ampère Formulations

Grassmann-Biot-Savart force again fails to explain the observed magnet's rotation since:

$$\vec{\tau}^{\,G}_{cw,m} = \vec{\tau}^{\,G}_{rb,m} = 0 \text{, and } \vec{\tau}^{\,G}_{m} = \vec{\tau}^{\,G}_{cw,m} + \vec{\tau}^{\,G}_{rb,m} = 0 \tag{13}$$

Conversely, Ampère force, by stressing the interaction between the closing wire and –respectively- the magnet and the radial bar, confirms the experimental facts drawing a non-zero reactive torque on the magnet. Three not null torques act on the magnet:

$$\vec{\tau}^{\,A}_{m} = \vec{\tau}^{\,A}_{cw,m} + \vec{\tau}^{\,A}_{rb,m} + \vec{\tau}^{\,A}_{m,rb} \tag{14}$$

where the last term takes into account the attachment of *RB* to the magnet ("dragging effect"). Applying here equation (2) the action-reaction interplay of $\vec{\tau}^{\,A}_{rb,m}$ and $\vec{\tau}^{\,A}_{m,rb}$ produces its mutual cancellation, becoming:

$$\vec{\tau}^{\,A}_{m} = \vec{\tau}^{\,A}_{cw,m} \neq 0 \tag{15}$$

4 Miscellaneous Considerations

The equivalence of Ampère and Grassmann's formulations only survives for the action of a *closed* current loop on a current element, belonging to another or the same circuit [11,1]. In our Case-2 analysis, the interaction takes place between *only a part* of an ohmic circuit (the closing-wire) and an arbitrary virtual-current element of the magnet.

The performed analysis compels us to incorporate Ampère's force law in energy-conversion physics. We cannot refrain ourselves to quote Assis on this extremely relevant issue [11, chapter 4]:

> *Another reason for the neglect of Ampère's force is that Einstein's special theory is based on Maxwell's equations plus Lorentz's force. But it happens that Grassmann's force is compatible with Lorentz's one (we only need to substitute $q\vec{v}$ for $Id\vec{l}$ in Lorentz's expression), while Ampère's force is not compatible with Lorentz. Due to the success and popularity of the relativity theory, all models that were not compatible with Lorentz's force were abandoned.*

As it is well known, an extension of Ampère's force law for charged particles, in full compliance of instantaneous distant action, is Weber's force law (1846). Weber's force is expressed in terms of charges, and its instantaneous separation's zero, first and second time derivatives [11]. Weber's law has been successfully applied to gravitational interaction allowing the first rigorous implementation of Mach's principle [15,16,17,18].

In the same highly recommended- book, Assis also wrote [11, chapter 8]:

> *It would be very important to develop the equivalent to the magnetohydrodynamic equations of plasma physics beginning with Weber's force instead of Lorentz's one. If this is done some interesting comparison between these two theories will be possible.*

It is worthwhile to remark the important job developed by Phipps [4] who was able to rescue and update the Hertz's (Galilean invariant) formulation of Maxwell's equations, taking it in total instead of partial time derivatives. Moreover, Phipps was able to extend his findings to the realm of high velocities (Neo-Hertzian Electrodynamics). Phipps's views are shared by M. J. Pinheiro [19]. An important outcome of the Phipps-Pinheiro approach is that Lorentz's force is no longer separated from Maxwell's equations.

We cannot close this essay without quoting a misjudging on the whole issue by Jackson [12]:

> *Although $\vec{E}$ and $\vec{B}$ thus first appear just as convenient replacements for forces … they have other important aspects. First, their introduction decouples conceptually the sources from the test bodies experiencing electromagnetic forces.*

Needless to say that Jackson's statement does not apply to homopolar machines, since a given $\vec{B}-$field pattern behaves in an entirely different way depending on the $\vec{B}-$source motional state [5,9]. P. & N. Graneau wrote [13, preface, 20]:

> *In the twenty-first century, students of electromagnetism may have no choice but become familiar with Newtonian electrodynamics as well as field theory.*

5. Acknowledgements

The authors are indebted to A. Radovic, R. Blas and F. Pereira Sosto for the profitable discussions on electrodynamics held along the last decade.

References

[1] G. Cavalleri *et al.* "Experimental proof of standard electrodynamics by measuring the self-force on a part of a current loop" *Phys .Rev. E*, **58** (2), 2505 (1998).

[2] A. K. T. Assis, "Comment on 'Experimental proof of standard electrodynamics by measuring the self-force on a part of a current loop'". *Phys. Rev. E*, **62**, 7554 (2000).

[3] P. & N. Graneau, "Electrodynamics force law controversy" *Phys. Rev. E*, **63**, 58601-1 (2001).

[4] T. E. Phipps, "Old Physics for New" Apeiron, Roy Keys Inc. (2006).

[5] R. Achilles & C. Moreno, "Spinning magnets and relativity: Guala-Valverde *vs*. Barnett" *Physica Scripta* **74**, 449 (2006).

[6] J. Guala-Valverde & R. Achilles, "A manifest failure of Grassmann's force" *Apeiron* **15** (2), 591 (2008).

[7] J. Guala-Valverde & P. Mazzoni, "The homopolar motor, a genuine relational engine" *Apeiron* **8** (4), 41 (2001).

[8] J. Guala-Valverde, P. Mazzoni & R. Achilles, "The homopolar motor, a true relativistic engine" *Am. J. Phys*. **70** (10), 1052 (2002).

[9] J. Guala-Valverde, "Spinning magnets and relativity. Jehle *vs*. Bartlett" *Physica Scripta* **66**, 252 (2002).

[10] R. Achilles & J. Guala-Valverde, "Action at a distance: a key to homopolar induction" *Apeiron* **14** (3), 169 (2007).

[11] A. K. T. Assis, "Weber's Electrodynamics" Kluwer Acad. Pub. Dordrecht. (1994).

[12] J. D. Jackson, "Classical Electrodynamics" Second Edition, Section 5. John Wiley & Sons, New York (1975).

[13] P. and N. Graneau, "Newtonian Electrodynamics", page 3. World Scientific Pub.(1996).

[14] J. C. Maxwell, “A Treatise on Electricity & Magnetism”, Vol. 2, part IV, pages 150-151. Dover Pub. Inc. New York (1954).

[15] A. K. T. Assis, “Relational Mechanics” Apeiron, Canada (1999).

[16] J. Guala-Valverde, “A new theorem in relational mechanics” *Apeiron* **8** (3), 132 (2001).

[17] R. A. Rapacioli, “More on the claimed identity between inertial mass and gravitational mass” *Apeiron*, **4** (3), 139 (2001).

[18] J. Guala-Valverde & J. E. Guala, Jr., “Again on inertial mass and gravitational mass” *Physics Essays* **12** (4), 785 (1999).

[19] M. J. Pinheiro, “Do Maxwell’s equations need revision?” *www.arXiv.org/abs/phys* (2006).

[20] P. Graneau, “Electromagnetic jet propulsion in the direction of current flow” *Nature* **295**, 311 (1982).