On Electro-Magnetic Inertia and Thrust

1. Introduction

When electric or magnetic systems are charged with energy, it is to be expected that the effective mass of the system increases according to Einstein's mass-energy equivalence $W = mc^2$ (we have used the symbol W to represent energy instead of the usual E to prevent confusion with the use of E as electric field), i.e. the mass increase is given by

$$m = \frac{W}{c^2} \tag{1}$$

Many texts refer to this as *electrostatic mass* or *electromagnetic mass*, which for practical purposes is negligible because of the large magnitude of c^2.
However there are other mass contributions induced dynamically which could be called *electrodynamic mass*. This paper deals with these dynamic situations where the mass contribution can be positive or negative.

2. Electrically Induced Inertia.

Consider two electrically charged spheres separated by a distance r, Q_2 being fixed while Q_1 is accelerated, Figure 1.

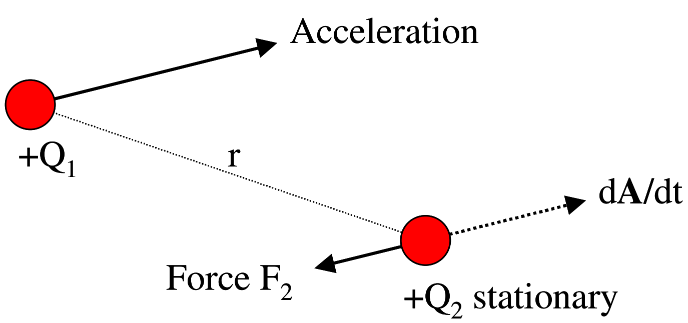

Figure 1. Force induced by acceleration

The moving charge Q_1 creates at Q_2 a vector magnetic potential field **A** proportional to its velocity given by

$$\mathbf{A} = \frac{\mu_0 Q_1 \mathbf{v}}{4\pi r} \tag{2}$$

and since Q_1 is accelerating the **A** field is changing with time

$$\frac{d\mathbf{A}}{dt} = \frac{\mu_0 Q_1}{4\pi r} \cdot \frac{d\mathbf{v}}{dt} \tag{3}$$

The changing **A** field creates an electric field **E** given by

$$\mathbf{E} = -\frac{d\mathbf{A}}{dt} \tag{4}$$

so that Q_2 endures a force $Q_2\mathbf{E}$ from that induced **E** field

$$\mathbf{F}_2 = -\frac{\mu_0 Q_1 Q_2}{4\pi r} \cdot \frac{d\mathbf{v}}{dt} \quad \text{Newtons} \tag{5}$$

This is simply the near-field radiation from one accelerating charge affecting a second nearby charge.

If we move our reference frame from that fixed in Q_2 to one fixed in Q_1, we find that Q_2 is accelerating with reference to Q_1, so that Q_1 endures a force

$$\mathbf{F}_1 = +\frac{\mu_0 Q_1 Q_2}{4\pi r} \cdot \frac{d\mathbf{v}}{dt} \quad \text{Newtons} \tag{6}$$

see Figure 2.

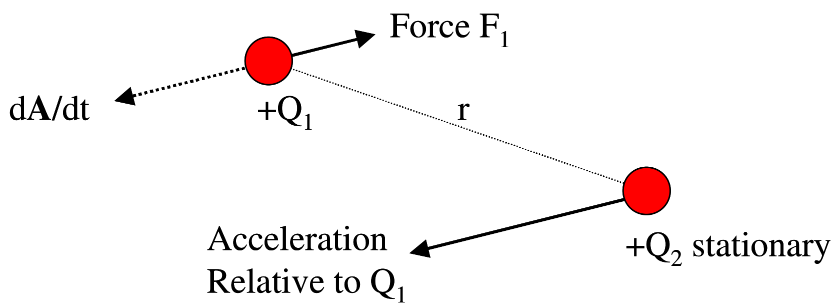

Figure 2. Induced Reaction Force

Equations (5) and (6) may be considered to be manifestations of Newton's third law of action and reaction. Note that (6) is an inertial effect occurring at Q_1, in this case of two like charges a negative form of inertia that aids the acceleration, rather than opposing it. If Q_2 were of opposite polarity, (6) would predict positive inertia.

Equation (6) can be manipulated into a version using the electrostatic potential ϕ_E from Q_2 which is given by

$$\phi_E = \frac{Q_2}{4\pi e_0 r} \quad \text{volts} \tag{7}$$

yielding

$$\mathbf{F}_1 = +\frac{Q_1 \phi_E}{c^2} \cdot \frac{d\mathbf{v}}{dt} \quad \text{Newtons} \tag{8}$$

where we have also used $\mu_0 e_0 = \frac{1}{c^2}$. We could surround Q_1 with a "universe" of fixed charges, and still use (8) where ϕ_E is then the sum of potentials from that universe. The inertial effect given by (8) could be represented by an induced inertial mass m_i which adds to the actual mass of Q_1

$$m_i = -\frac{Q_1 \phi_E}{c^2} \quad \text{Kilograms} \tag{9}$$

So far we have not considered retardation effects due to the finite propagation delay. This certainly affects the force on Q_2 (or on all the other charges in our "universe") because that force is time-delayed by a time r/c. But the electric potential ϕ_E through which Q_1 accelerates is not part of that time delay, that potential already exist so the *inertial* effect at Q_1 (8) or (9) is instantaneous.

3. Magnetically Induced inertia

There are many duals between electric and magnetic effects where equations follow similar formats, in particular the forces between point charges and between point magnetic poles. Although magnetic poles don't really exist as such, the formulae are still useful for predicting magnetic effects. Thus by analogy to (9) it is to be expected that a magnetic pole of strength Q_m amp-meters, when placed in a scalar magnetic potential of ϕ_m amps, will inherit a magnetically induced inertia which can be represented by an inertial mass m_m kilograms given by

$$m_m = \frac{\mu_0 Q_m \phi_m}{c^2} \qquad \text{Kilograms} \qquad (10)$$

3.1. Translatory Movement

Isolated magnetic poles don't exist, so we must examine a pair of magnetic poles representing a magnetic dipole, a permanent magnet. For translatory movement where we must consider the total inertia of the magnet, in a uniform scalar potential the induced inertia of the pair would cancel, it requires the scalar potential on one pole to be different in value from that on the other pole, viz. there must be an H field component along the dipole axis (rotation is considered separately below). Denoting this component as H_μ, we can deduce the induced inertial mass of the system to be represented by

$$m_m = \frac{\mu_0 Q_m H_\mu l}{c^2} \qquad \text{Kilograms} \qquad (11)$$

where l is the length of the dipole. Note that this is an *inertial* effect separate from the usual quasi-static magnetic forces on the poles that come from the gradient of the potential (i.e. an H field) producing an angular alignment force on the magnet.

In the case of a permanent magnet the pole strength Q_m is given by

$$Q_m = Ms \qquad \text{Amp-metres} \qquad (12)$$

where s is the surface area of the pole face and M is the magnetization. Hence (11) becomes

$$m_m = \frac{\mu_0 M H_\mu V}{c^2} \qquad \text{Kilograms} \qquad (13)$$

where V is the volume of the magnet. Now since

$$\mu_0 M = B_{sat} \qquad (14)$$

we can rewrite (13) as

$$m_m = \frac{B_{sat} H_\mu V}{c^2} \qquad \text{Kilograms} \qquad (15)$$

Taking a typical small magnet volume as 10 cm^3 (10^{-5} m^3), using 1Tesla magnets close to each other so that $H \approx 1/\mu_0$ we can estimate the mutually induced inertias as 8.83E-17 Kg. That is so small as to be negligible.

3.2. Constant Rotation

For rotation about the dipole centre, because the induced inertial mass (10) at opposite poles is of opposite polarity, even in a uniform potential we get an unbalance with respect to centrifugal forces. Again the effect is found to be small except for the special case detailed next.

Although the magnetic ***field*** from the Earth is quite weak, the same cannot be said for the magnetic scalar ***potential*** ϕ_m. The magnetic Earth can be modelled as a magnetic dipole at its centre whose dipole moment μ_E is 8.24×10^{22} amp-m^2. The scalar magnetic potential for a dipole is given by

$$\phi_m = \frac{\mu_E \cos\theta}{4\pi r^2} \text{ amps} \qquad (16)$$

where r is the radial distance and θ is measured from the dipole axis. The radius of the Earth is 6.37×10^6 meters. At the equator where θ is 90º the potential is zero, but at a latitude of say 30º where $\cos(\theta)$ is 0.5 we get a value of 8×10^7 amps, and at the Earth's magnetic poles the value would be 1.6×10^8 amps.

Putting (12) and (14) into (10) we get for the inertial mass induced at the poles of a permanent magnet by the presence of ϕ_m

$$m_m = \pm\frac{B_{sat} s \phi_m}{c^2} \qquad (17)$$

The induced mass appears as an increase in the real mass at one pole and a decrease at the other pole. If we rotate the magnet about its centre at constant speed, we obtain a dynamic unbalance where the radial centrifugal forces do not cancel, there is a net force in one direction. From the centrifugal force equation

$$F = mr\omega^2 \qquad (18)$$

we find that the imbalance creates an anomalous force

$$F_A = \frac{B_{sat} s l \phi_m \omega^2}{c^2} \qquad \text{Newtons} \qquad (19).$$

The radial force vector F_A is of course rotating with the magnet and points along its axis. Converting the product of pole area s and length l into the volume V, using (14) for B_{sat} and since the product MV is the dipole moment of the magnet we get the satisfying result that applies to any dipole of moment $\boldsymbol{\mu}$

$$F_A = \frac{\mu_0 \boldsymbol{\mu} \phi_m \omega^2}{c^2} \qquad \text{Newtons} \qquad (20)$$

Taking a 1 Tesla magnet of pole area s=4cm^2 and of length 20cm, if we rotate this about its centre at say 3000rpm then from (19), in the notional Earth's magnetic potential, we find an induced unbalancing force of 7×10^{-9} Newtons. Again this is rather small to be of any practical use.

However it is well known that high-speed rotation of a magnetic dipole can be obtained using high permeable material excited by coils. Thus a sphere or disc of permeable material driven from a pair of coils at right angles and in phase quadrature can create rotation speeds of its magnetization of MHz and higher. If the above magnet were simulated in this manner at a rotation speed of 1MHz, the induced force anomaly would be in the order of 2.8 Newton, which is much more respectable. Get rotation at 10MHz and we have a 28Kg force!!

The force unbalance will create the equivalent of a rotating force vector acting on the whole body. Thus along a given axis this will constitute a vibratory force at the rotation frequency, *this force being induced because of the presence of the earth's magnetic field in the form of its local scalar potential.* We have the technology for measuring such a vibratory force and this experiment would seem to be worth doing in order to validate the theory.

3.3. Angular Acceleration

The dynamic unbalance of mass at the poles of the magnet also creates an anomalous force on the system when it is accelerated angularly. We find that in this case the anomalous force F_A is given by

$$F_A = \frac{B_{sat} s l \phi_m}{c^2} \cdot \frac{d\omega}{dt} \quad \text{Newtons} \tag{21}$$

which can be expressed for any dipole $\boldsymbol{\mu}$ as

$$F_A = \frac{\mu_0 \mu \phi_m}{c^2} \cdot \frac{d\omega}{dt} \quad \text{Newtons} \tag{22}$$

In this case the radial force acts at right angles to the dipole axis. This could account for anomalous translatory impulse forces when a magnet suddenly receives a rotation impulse, perhaps it explains the Steorn effect. The anomaly would disappear at the equator, and be a maximum at the Earth's magnetic poles.

3.4. Potential Thrust Motor

A series of alternate polarity rotation impulses (i.e. alternate angular acceleration and deceleration) timed to occur each 180° of rotation could create a net unidirectional force. Again at speeds associated with moving masses this would be quite small, but if engineered to occur within a disc of magnetically permeable material using coils driven by appropriate waveforms the force could be significant. Could this form the basis for a thrust motor using the Earth's scalar magnetic potential? It would seem to be something worth exploring.