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Invertibility Principle in Faraday Unipolar Machines

Abstract

It is shown that the existence of electromagnetic momentum flow and from the law of angular momentum conservation gives an explanation of the action principle of Faraday generator

1. Introduction

Electric unipolar machines, the prototype for which was provided by the Faraday generator, have a wide scope and are manufactured by many large companies. There naturally exists a calculation method [1]. However, the scientific validity of this technique, and, simply put, there is no generally accepted explanation of the action of this generator.

It would seem the easiest way to explain the generator is by using the principle of invertibility of electric machines for explanation of the principle of the Faraday motor. But the problem is that the invertibility principle itself is ill-founded (and proof of this is just the inability to "invert" to be applied to the generator).

Below we shall use the explanation of the principle of the Faraday motor given in [2], and show that a similar approach can be used for the explanation of the principle of action of Faraday generator.

2. Simulation of Faraday Motor

In Faraday motor (see Fig. 1) has a electroconductive magnet with induction B, the line of current I passing along the axis of rotation, along the magnet's radius and the fixed contact K. On electroconductive radius has electric intensity

$$E = j\rho, \tag{1}$$

where j - the current density, ρ - resistivity. Magnetic intensity H is proportional to the induction B. Vectors of these intensities are mutually perpendicular and therefore there flows of electromagnetic energy

$$S = EH . \tag{2}$$

arises. Note that this flow occurs in a static electromagnetic field. Flow of static field is closed (due to the law of conservation of energy) and therefore is shown in Fig. 1 as cylinders. Radius of the magnet, where the current I flows, is the line of contact of these cylinders. Flow vector, lying on the surface of the magnet, is perpendicular to said radius. This flow S creates a force, that directed opposite to the flow vector S and that rotates the magnet at a speed v. This force is neither Lorentz force nor the Ampere force. This force is the force Khmelnik [2] and calculated by the formula

$$F = V \cdot S \cdot \sqrt{\varepsilon\mu}/c, \tag{3}$$

where

- S - the energy flow density,
- V - volume of body, which is penetrated by the flow of electromagnetic field,
- ε - relative permittivity of body, the relative permittivity of the magnet, more specifically, that portion on which a current flows,
- μ - relative permeability of the magnet,
- c - light speed in vacuum.

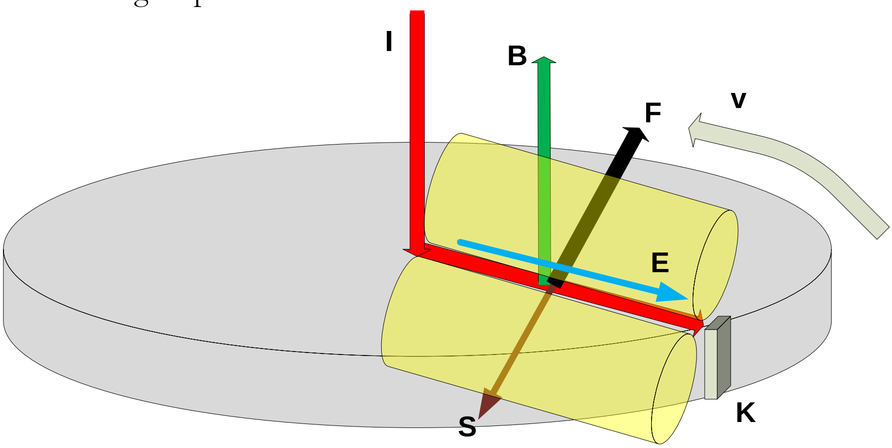

Рис. 1.

In [3] it was shown that the permittivity of a current conductor depends only on μ and ρ:

$$\varepsilon = \left(\frac{c\mu_o}{\rho}\right)^2 \mu, \tag{4}$$

where μ_o - permeability of vacuum, ρ - resistivity. Combining (1, 3, 4), we get

$$F = VjB, \tag{5}$$

where j - the current density, B - magnetic inductivity, or

$$F = IBL, \tag{6}$$

where I - current, L - length of the radius. Formally this formula coincides with the formula of Ampere force, but it is only formally, because here the force is applied to a magnet.

> **For example,** for $B=1[T]$, $j=4[A/sm^2]=4\cdot10^4[A/m^2]$ from (5) we find that $F[N]=4\cdot10^4 V[m^3]$. In particular, for $V=10^{-3}[m^3]$ we find that $F=40[N]$.

Let us denote

U - voltage source,
R - general resistance,
L - length of radius,
$l=L/2$ - average radius of the force application,
J - moment of inertia,
ω - rotational speed,
$v=\omega l=\omega L/2$ - average linear speed,
P_H - power of motor load,
M_H - load moment.

According to the law of angular momentum conservation we have:

$$J\frac{d\omega}{dt}=Fl-M_H. \tag{7}$$

Therefore

$$\frac{d\omega}{dt}=\left(FL/2-M_H\right)/J. \tag{8}$$

Power developed by the force F,

$$P_F=vF=\omega FL/2 \tag{9}$$

Or, considering (6),

$$P_F=\omega IBL^2/2. \tag{10}$$

$$UI=I^2R+P_F. \tag{11}$$

or

$$U=IR+e, \tag{12}$$

where

$$e=B\omega L^2/2, \tag{13}$$

i.e. Faraday motor creates a voltage source for counter-emf. Thus, a conductor moving in a stationary magnetic field generates emf. In our case the conductor moves with the source of magnetic field. But in this case also ems should be generated in it, as the magnetic field does not move with the object that generates it.

From (12) we have:

$$I = \frac{U - e}{R}, \tag{14}$$

From (6, 8) we have:

$$\frac{d\omega}{dt} = \left(IBL^2/2 - M_H\right)/J \,. \tag{15}$$

Evidently,

$$P_H = M_H \omega \,. \tag{16}$$

The above equations (13-16) allow us to find all the unknowns as the functions of time for $\omega(0) = 0$ - see Fig. 2 for L=0.2, J=0.02, R=0.5, U=5.9, B=1, Mh=0.2 in SI system.

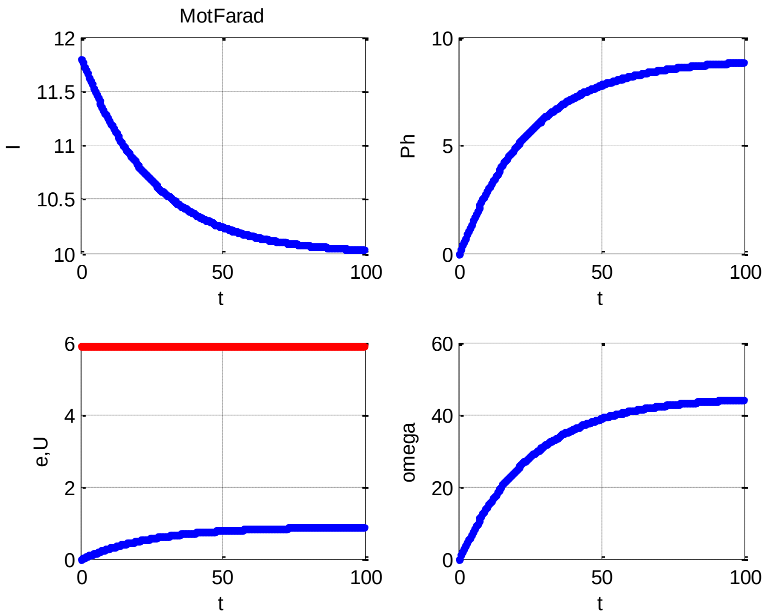

Fig. 2.

In the steady state

$$I = 2M_H / BL^2, \tag{17}$$

$$e = U - IR, \tag{18}$$

$$\omega = 2e/BL^2 \,. \tag{19}$$

Combining the equations (13-15), we find:

$$\frac{d\omega}{dt} = \left(\frac{\left(U - \frac{BL^2\omega}{2} \right) BL^2}{2R} - M_H \right) \Big/ J \,. \tag{20}$$

or

$$\frac{d\omega}{dt} = -a\omega + d,\ b = BL^2,\ a = \frac{b^2}{4RJ},\ d = \frac{2bU - 4RM_H}{4RJ}. \tag{21}$$

Consequently

$$\omega = \frac{d}{a}\left(1 - \exp(-at)\right), \tag{22}$$

$$\omega_{\max} = \frac{d}{a} = \frac{2bU - 4RM_H}{b^2} \tag{22a}$$

And duration of acceleration is

$$\tau \approx \frac{3}{a} = \frac{12RJ}{b^2} \tag{23}$$

3. Simulation of Faraday Generator

For simulation of Faraday generator we shall use the principle of invertibility of electric machines.

Suppose that in the generator there also is a power F f the form (6). At the initial moment it may appear as a result of the current induced by the Lorentz force - in this case, it should be very minor, as experimentally such current is not detected.

Let us denote the moment of motor and moment of force F as M_D, M_F. Then

$$M_F \approx FL/2 = IBL^2/2\,. \tag{31}$$

The power developed by force F, is determined according to (10), and the motor power is

$$P_D = M_D\omega \tag{32}$$

Using the principle of electric machines invertibility, let us write by analogy with (20) the equation of the of impulse moment conservation for the generator:

$$J\frac{d\omega}{dt} = \frac{P_D}{\omega} - M_F\,. \tag{33}$$

Consequently,

$$\frac{d\omega}{dt} = \left(\frac{P_D}{\omega} - M_F \right) \Big/ J. \tag{34}$$

The equation of power balance is:

$$P_D = I^2 R + P_F. \tag{35}$$

From (10, 35) we find:

$$P_D = I^2 R + \omega IBL^2/2$$

or

$$I^2 R + eI - P_D = 0. \tag{36}$$

where

$$e = \omega BL^2/2. \tag{37}$$

This formula coincides with formula (13) for the motor and with formula of Tamm [4] that was obtained another way. From (36) follows that Faraday generator is a current source

$$I = \frac{-e + \sqrt{e^2 + 4RP_D}}{2R}, \tag{38}$$

The voltage on the generator is

$$U = IR. \tag{39}$$

Electrical power of the generator is

$$P = UI = I^2 R. \tag{40}$$

From (34, 31) we find:

$$\frac{d\omega}{dt} = \left(\frac{P_D}{\omega} - IBL^2/2 \right) \Big/ J. \tag{41}$$

For steady state we find (41):

$$\left(\frac{P_D}{\omega} - IBL^2/2 \right) = 0. \tag{42}$$

Therefore, if the motor produces power P_D with speed ω, then the current of generator is

$$I = 2P_D/\omega BL^2. \tag{43}$$

The above equations (37-41) permit to find all the unknowns as functions of time with given initial conditions $I(0) = 0,\ \omega(0) = \omega_o$ - see Fig. 3 for $\omega_o = 10$, J=0.02, L=0.2, R=0.5, B=1, P_D=11, $\omega_{\max} = 50$ in SI system. Functions on Fig. 3, written to the left of the windows, are listed according to the graphs downwards; the color of the line is indicated in parentheses.

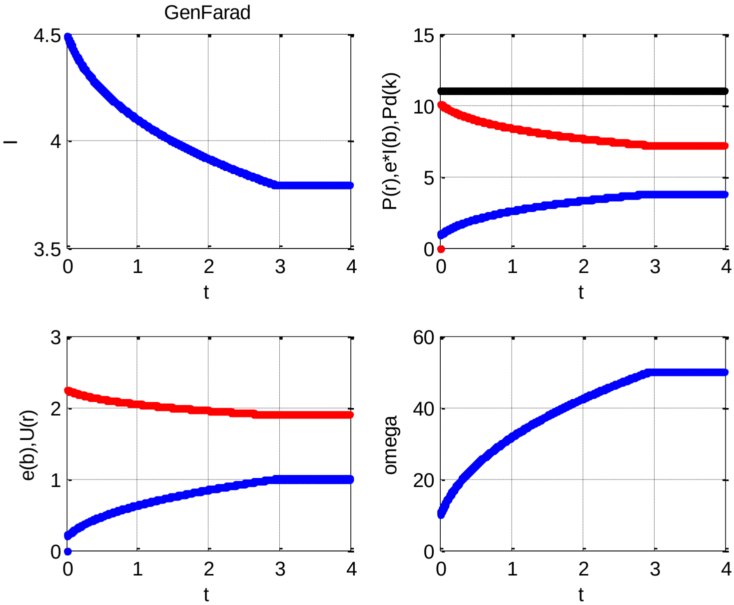

Fig. 3.

The solution of the equations exists for the giver initial conditions $I(0)=0,\ \omega(0)=\omega_o$. If at some point during the rotation a current arises, then after a while it will increase dramatically, and subsequently begins to decrease with the increase of the rotational speed ω. When stabilizing the speed $\omega=\omega_{\max}$ of the motor (torque generator) the current I of the generator will take the value (43).

The initial current surge can be provided (as already mentioned) by the Lorentz force. The force F should arise as a consequence of the law of conservation of angular momentum.

References

1. Electric unipolar machines (in Russian), http://www.vbega.ru/engineering/uniolyar/1/index.html
2. Khmelnik S.I. Khmelnik force, http://vixra.org/pdf/1407.0076v3.pdf
3. Khmelnik S.I. Lorentz Force, Ampere Force and Momentum Conservation Law Quantitative. Analysis and Corollaries, http://vixra.org/pdf/1407.0066v1.pdf