Simulation of a modified homopolar generator

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Abstract

The homopolar generator or Faraday disk has been considered as a candidate device for producing energy from spacetime. In earlier studies of the AIAS institute, three types of possible resonances have been found. In this paper, the dynamics of mechanical and electric behavior of the generator is further studied by simulations. The original construction has been changed by adding an electromagnet, which realizes several kinds of positive feedback loops. In this way, the back EMF is reduced and energy from spacetime could be gained. If this electromagnet is operated with saturation of the magnetic core, very high efficiencies could be possible.

Keywords: Homopolar generator, Faraday disk, unipolar generator, N-machine, electrodynamics simulation.

1 Introduction

The homopolar generator or Faraday disk, the oldest electric motor or generator, was discovered by Michael Faraday in 1831. Machines of this kind were in use until about 1900, when they were replaced by modern induction motors and generators. Nevertheless, this machine has retained a nimbus of mystery, because it does not require time-varying fields and works on the principle of the Lorentz force, which has a life of its own in engineering. The supporting principle is not directly obvious from Maxwell's equations, which are the basis of electrodynamics. However, the Lorentz force is nothing more than the transformation law for moving charges, which Maxwell's equations are based on, so nothing cryptic is contained in the principle of homopolar induction.

In recent years, some engineers have argued that a homopolar machine can produce unusual effects and resonances that are not explainable by classical electrical engineering, and that even the transfer of "energy from the vacuum" should be possible. This hint was followed up by the AIAS research group, and they gave an explanation of the machine in the context of Einstein Cartan Evans (ECE) theory [1, 2]. Three possible types of resonances were found in connection with a variable rotational speed [3]. Two of them can be explained

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only by ECE theory. The third can be understood on a more classical level and seems to be the one that is most accessible to engineering. Therefore, we took this model as a basis for simulations, in which the mechanical aspects were also included so that we could give an energy balance. Starting with the standard homopolar design in Section 2, we present an extended design in Section 3, whose simulation results are presented in Section 4. The extended design leads to unforeseen results that allow a reduction of the back EMF and reveal a source of excess energy. This is further discussed in Section 5.

2 The standard homopolar generator

The homopolar generator (also called a unipolar generator) consists of a spun conducting disk in a static magnetic field. An electric field builds up between the shaft and the rim of the disk. The voltage provided by the electric field produces a current through the connectors, which have to be locally fixed with respect to the lab. Relative motion between the connectors and the disk is required for the machine to work. This all has been discussed in great detail in the literature, see for example [4, 5].

To derive the forces and torques of the homopolar generator, we actually have to consider two forces: the Lorentz force that induces a current, and a counter-acting Lorentz force that is a reaction to the induced current.

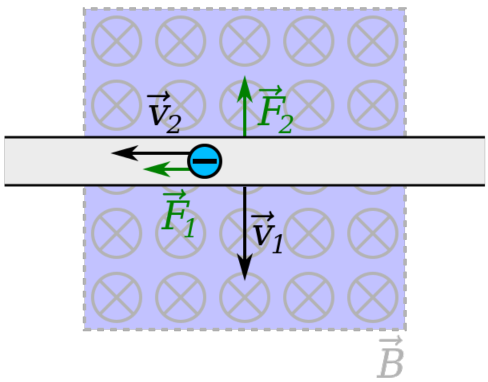

Figure 1: Lorentz force and Lorentz counter force in a conductor [7].

2.1 Lorentz force

The mechanical rotation of the disk produces a current, in the tangential direction, of vector form

$$\mathbf{F}_{L1} = q\,\mathbf{v}_1 \times \mathbf{B}_m \tag{1}$$

(see Fig. 1). B_m is the magnetic field through the disk, and the charge q moves with velocity $\mathbf{v}_1$ in the direction tangential to disk rotation. The force creates an electric field

$$\mathbf{E} = \frac{\mathbf{F}_{L1}}{q} = \mathbf{v}_1 \times \mathbf{B}_m, \tag{2}$$

which is the well-known, non-relativistic version of the electromagnetic transformation law, and is equivalent to the Lorentz force.

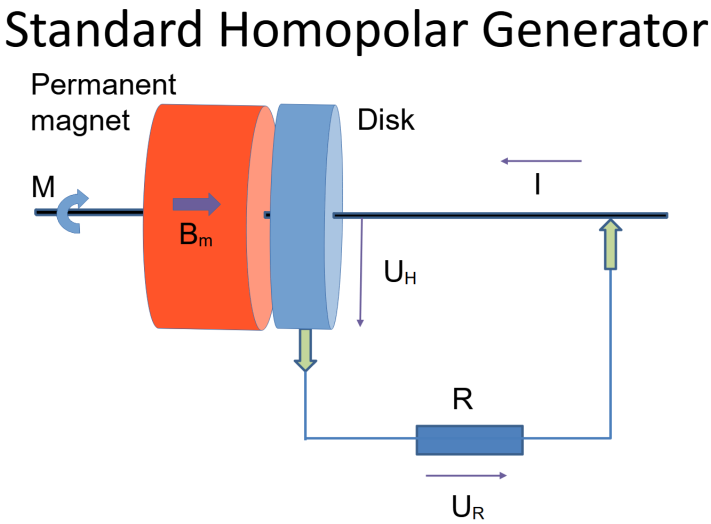

Figure 2: Principal operation of a homopolar generator.

2.2 Induced voltage

The induced voltage along the electric field is

$$U_H = \int \mathbf{E} \cdot d\boldsymbol{\ell}, \tag{3}$$

where $d\boldsymbol{\ell}$ is the infinitesimal line element along the electric field, which is present from the axis to the rim of the disk (see Fig. 2). The vectors $\mathbf{v}_1$, $\mathbf{B}_m$ and $\mathbf{E}$ are perpendicular to one another, and $d\boldsymbol{\ell}$ is parallel to $\mathbf{E}$. Therefore, we can use the moduli of the vector variables in all of the above equations. The velocity depends on the radius via $v_1 = \omega r$ with angular rotation frequency ω, so we have in total:

$$U_H = \int_0^{r_d} E d\ell = \int_0^{r_d} v B_m d\ell = \int_0^{r_d} \omega r B_m d\ell = \frac{1}{2}\omega r_d^2 B_m \tag{4}$$

with disk radius r_d. We have neglected the thickness of the drive axle. According to the Kirchhoff rule, the sum of the voltages in the circuit of Fig. 2 is

$$U_R + U_H = 0, \tag{5}$$

where U_H denotes the voltage created by the Lorentz force and U_R is the voltage of the load resistance (including the inner Ohmic resistance of the disk). With the induced current I_{ind}, it follows that

$$U_H = -I_{\text{ind}} R \tag{6}$$

or

$$I_{\text{ind}} = -\frac{U_H}{R} = -\frac{1}{2}\frac{\omega r_d^2 B_m}{R}. \tag{7}$$

The generator is idle when no current flows, i.e., when R is very high; for example, when one of the contacts to the disk is opened.

2.3 Counter Lorentz force

As depicted in Fig. 1, the charges of the current I_{ind} flow in a direction $\mathbf{v}_2$ perpendicular to $\mathbf{v}_1$ and give rise to a secondary Lorentz force $\mathbf{F}_{L2}$. If we consider a charge element Δq of the current, the voltage induced by this secondary Lorentz force can be computed in the following way. This Lorentz force at a single position in the disk is

$$\mathbf{F}_{L2} = \Delta q\ \mathbf{v}_2 \times \mathbf{B}_m, \tag{8}$$

where $\mathbf{v}_2$ is the radial transport velocity of a charge Δq in the magnetic field $\mathbf{B}_m$ that again is perpendicular to both $\mathbf{v}_2$ and the plane of the disk. The transport velocity of a charge in a conductor element $\Delta\boldsymbol{\ell}$ during a time Δt is

$$\mathbf{v}_2 = \frac{\Delta\boldsymbol{\ell}}{\Delta t}, \tag{9}$$

and the charge Δq, which is transported by the current I_{ind} during time interval Δt, is

$$\Delta q = I_{\text{ind}} \Delta t. \tag{10}$$

Multiplying both equations gives

$$\Delta q\ \mathbf{v}_2 = I_{\text{ind}} \Delta\boldsymbol{\ell}. \tag{11}$$

Inserting this into the Lorentz force (8), we obtain

$$\mathbf{F}_{L2} = \Delta q\, \mathbf{v}_2 \times \mathbf{B}_m = I_{\text{ind}} \Delta\boldsymbol{\ell} \times \mathbf{B}_m. \tag{12}$$

The total Lorentz force acting on the disk then is the summation over all conducting elements $\Delta\boldsymbol{\ell}$ along the radius of the disk:

$$\mathbf{F}_{L2,\text{tot}} = \int_0^{r_d} I_{\text{ind}} d\boldsymbol{\ell} \times \mathbf{B}_m. \tag{13}$$

Since I_{ind} is constant over a radial path and the path is perpendicular to the magnetic field, we have for the modulus of the Lorentz force:

$$F_{L2,\text{tot}} = I_{\text{ind}} B_m \int_0^{r_d} dr = I_{\text{ind}} r_d B_m. \tag{14}$$

The torque on the axis arising from the force of the induced current is also a sum over all radial contributions:

$$\mathbf{T} = \int_0^{r_d} d\mathbf{r} \times \mathbf{F}_{L2}(r). \tag{15}$$

Again, all vectors are perpendicular to one another, so we obtain

$$T = \int_0^{r_d} dr I_{\text{ind}}\, r\, B_m = \frac{1}{2} I_{\text{ind}} r_d^2 B_m. \tag{16}$$

After inserting Eq. (7), this becomes

$$T = \frac{1}{2} r_d^2 B_m \cdot \left(-\frac{1}{2} \frac{\omega r_d^2 B_m}{R} \right) = -\frac{1}{4} \frac{\omega r_d^4 B_m^2}{R}. \tag{17}$$

This torque is opposite to the driving torque of the generator.

2.4 Motor-generator equivalence

To operate this device as a generator, an external torque of at least the same size as the counter torque (17) has to be applied in the opposite direction. This approach can be reversed in the sense that, if we feed the machine with a current $I = I_{\text{ind}}$, it then delivers the torque of Eq. (17). Thus, the homopolar machine can be operated either as a generator or a motor.

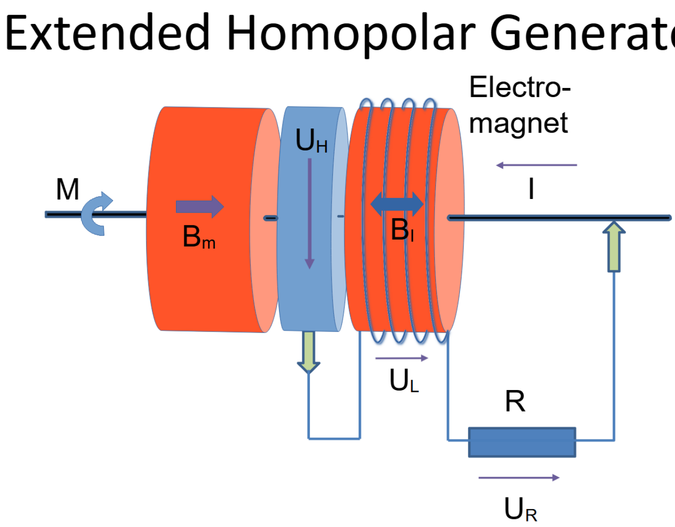

Figure 3: Design of the extended homopolar generator.

3 Extensions of the homopolar generator concept

In paper 107 of the AIAS UFT series [3], the third type of resonance was derived from a dynamic effect. In the conventional view, a Faraday disk is considered to have a constant magnetic field, which pervades the disk. In the design presented in Fig. 3, an electromagnet is added to the permanent magnet. The current produced by the machine flows through the electromagnet and provides a positive or negative feedback effect, depending on the direction of the windings. Although it is a simple design, nobody seems to have considered this before. The machine can be analyzed both in a static and a dynamic way. A static analysis was given in [3] and led to resonance-like enhancements of the current for certain rotation speeds. We will derive the dynamic behavior first and then reduce the result to the static case.

In extending Eq. (5), we see that the sum of voltages in the circuit of Fig. 3 is

$$U_L + U_R + U_H = 0, \tag{18}$$

where the voltages of the inductor coil (electromagnet) and the resistance are

$$U_L = L\dot{I}, \tag{19}$$
$$U_R = RI. \tag{20}$$

The dot denotes the time derivative of the current I. The additional magnetic field flowing through the disk is now a dynamic quantity, denoted by B_I. In addition, we keep the static field B_m of the permanent magnet. According to Eq. (5), the voltage through the disk is now

$$U_H = \frac{1}{2}\omega r_d^2 (B_m + B_I). \tag{21}$$

B_I is a dynamic magnetic field, which for a long solenoid is given by

$$B_I = \mu_0 \mu_r \frac{N}{l}\ I. \tag{22}$$

The inductor parameters are the number of windings N, the relative permeability of the material μ_r, and the length of the coil l. Instead of this, we use an abbreviation for the physical parameters:

$$\alpha = \mu_0 \mu_r \frac{N}{l} \tag{23}$$

so that[1]

$$B_I = \alpha\ I. \tag{24}$$

This abbreviation is appropriate, because the inductor normally is not a perfect solenoid and Eq. (21) is not very precise. The inductance of a coil is

$$L = \mu_0 \mu_r \frac{N^2 A}{l} = \alpha N A, \tag{25}$$

where A is the cross section of the solenoid. α is defined similarly to the A_L value (which is used in technical documentation):

$$A_L = \frac{L}{N^2} = \alpha \frac{A}{N}. \tag{26}$$

[1]With $\mu_0 = 4\pi \cdot 10^{-7},\ \mu_r = 3000,\ N = 30,\ l = 0.2\,\mathrm{m},\ r_d = 0.075\,\mathrm{m}$, we obtain $\alpha \approx 0.57$ T/A and $L \approx 0.6$ H.

The voltage induced by the solenoid then is

$$U_L = L\dot{I} = \alpha N A \dot{I}. \tag{27}$$

The definitions for α and L are valid for the linear range of the magnetization curve $B_I(I)$. Eq. (18) reads

$$L\dot{I} + RI + \frac{1}{2}\omega r_d^2 (B_m + B_I) = 0, \tag{28}$$

and inserting expression (24) for B_I gives us

$$L\dot{I} + I\left(R + \frac{1}{2}\omega\, r_d^2\, \alpha\right) + \frac{1}{2}\omega r_d^2 B_m = 0. \tag{29}$$

The term in parenthesis next to I is an effective Ohmic resistance that we define by

$$R_{\text{eff}} := R + \frac{1}{2}\omega r_d^2 \alpha. \tag{30}$$

Obviously, this expression can become zero and even negative. Resonance appears at $R_{\text{eff}} = 0$. This condition defines the resonance frequency:

$$\omega_{\text{res}} := -2\,\frac{R}{r_d^2 \alpha}, \tag{31}$$

which means that α must be negative to give resonances. This is surprising at first glance. From Eq. (23), α can only be positive, but from Eq. (24) we see that a negative α is equivalent to a sign reversal of B_I, i.e., the windings of the electromagnet must have such a direction that B_I is opposite in direction[2] to B_m.

To complete the theoretical analysis, we consider the static case. This is defined by

$$\dot{I} = 0, \tag{32}$$

and by means of Eq. (7) leads to the static current

$$I_{\text{static}} = -\frac{1}{2}\,\frac{\omega r_d^2 B_m}{R + \frac{1}{2}\omega r_d^2 \alpha} = -\frac{1}{2}\,\frac{\omega r_d^2 B_m}{R_{\text{eff}}}. \tag{33}$$

For the simulation of the time behavior, the time dependence of ω has to be respected. We assume that the disk is driven by an external motor with a constant torque β. Then, the angular velocity follows from the rotational Newtonian law

$$\Theta \dot{\omega} = \beta, \tag{34}$$

where Θ is the moment of inertia of all rotating parts. In analogy to Eq. (16), we now have two counter torques, that of the static magnetic field B_m:

$$T_m = \frac{1}{2} I r_d^2 B_m, \tag{35}$$

[2] In Eqs. (25 - 27), α must always be taken as positive to retain a positive L.

and that of the dynamic magnetic field B_I:

$$T_I = \frac{1}{2} I r_d^2 B_I. \tag{36}$$

The total counter torque induced by the current is

$$T = T_m + T_I = \frac{1}{2} I r_d^2 (B_m + B_I) = \frac{1}{2} r_d^2 (B_m I + \alpha I^2). \tag{37}$$

For the standard homopolar generator ($\alpha = 0$), I is negative so that T becomes negative and counteracts the driving torque β. In the case of a non-zero α, the term I^2 is always positive. It should be possible to minimize the counter torque by suitable choices of B_m and α.

The total mechanical equation of motion is

$$\Theta \dot{\omega} = \beta + \frac{1}{2} r_d^2 (B_m I + \alpha I^2). \tag{38}$$

Together with the electric equation (29),

$$L \dot{I} + I \left(R + \frac{1}{2} \omega \, r_d^2 \, \alpha \right) + \frac{1}{2} \omega r_d^2 B_m = 0, \tag{29'}$$

we obtain two coupled differential equations for two variables I and ω. These equations have to be solved simultaneously by simulation.

4 Simulation results

We have carried out simulations of several variants of the homopolar generator using the software package OpenModelica [6]. We started with the original design shown in Fig. 2, and then investigated the additional effects resulting from the extended version shown in Fig. 3. The parameters used for various simulation runs are listed in Table 1. For convenience, we have used a negative B_m so that we obtain a positive current[3].

Parameter	Set 1	Set 2	Set 3	Set 4
R	0.1	0.1	0.1	3.1
L	0	0.02	1.8	4.3
r_d	0.1	0.1	0.1	0.1
B_m	-1.0	-1.0	-1.0	-0.5
B_{sat}				1.0
α	0	± 0.06	-0.6	-1.1
β	0.03	0.03	0.03	0.3
Θ	0.01	0.01	0.01	0.01

Table 1: Simulation parameters (in SI units).

[3] As can be seen from Eqs. (38) and (29'), interchanging the signs of B_m and I leaves the equations unchanged.

4.1 The original homopolar generator

The original machine was simulated by solving Eqs. (38) and (29') with $\alpha = 0$:

$$L\dot{I} + IR + \frac{1}{2}\omega r_d^2 B_m = 0, \tag{39}$$

$$\Theta\dot{\omega} = \beta + \frac{1}{2} r_d^2 B_m I. \tag{40}$$

The parameters used are listed in Table 1, data set 1, using SI units.

All simulations were carried out with a constant torque β applied to the generator axis. Results are shown in Figs. 4-6, where only the curves with index 1 (red curves) are referring to the original homopolar generator. The angular velocity ω increases to a constant level (Fig. 4). After a certain time, the counter torque outperforms the driving torque so that the total torque is zero and the angular velocity remains constant. The same happens with the current (Fig. 5). Because of $\alpha = 0$, we have $R = R_{\text{eff}}$ and $I = I_{\text{static}}$.

To determine the coefficient of performance (COP), we have to consider the input and output power. The mechanical input power is

$$P_m = \beta\, \omega, \tag{41}$$

and the output power is purely Ohmic,

$$P_R = I^2\, R. \tag{42}$$

The COP is defined by

$$\eta = \frac{P_R}{P_m} \tag{43}$$

and is presented in Fig. 6. The COP approaches unity, i.e., the mechanical input power is completely transformed into the power loss of the circuit.

4.2 The extended homopolar generator

In the next stage, we have simulated the design that includes the additional electromagnet, which is shown in Fig. 3. There are two possibilities for directing the magnetic field B_I of the inductor: either parallel or antiparallel to the magnetic field B_m of the permanent magnet. In our simulations, we have chosen $B_m < 0$ to obtain a positive current, for convenience. As can be seen from Eq. (24), B_I is parallel to B_m, if $\alpha < 0$. For $\alpha > 0$, both magnetic fields are antiparallel (see Table 2).

A positive α leads to an enhancement of the torque, as can be seen from Eq. (38). Therefore, we denote this case as "positive feedback" in Table 2. However, from Eq. (30) we see that this increases the effective resistance. While increasing the torque gives higher output power, increasing the resistance diminishes output power significantly. Therefore, it is not clear if this will really give a performance boost.

In the case of a negative feedback, we have the opposite situation: for negative α, the torque $T_I < 0$ leads to a stronger counter torque, but R_{eff} becomes smaller than R so this counteracts the torque effect. How the system behaves can be decided only by inspecting the simulation results.

Mode	α	T_c	T_I	R_{eff}	B_m, B_I
Pos. feedback	$\alpha > 0$	$T_c < 0$	$T_I > 0$	$R_{\text{eff}} > R$	$B_m < 0, B_I > 0$
Neg. feedback	$\alpha < 0$	$T_c < 0$	$T_I < 0$	$R_{\text{eff}} < R$	$B_m < 0, B_I < 0$

Table 2: Feedback modes.

4.2.1 Positive torque feedback

We first consider the case where $\alpha > 0$ (data set 2 in Table 1). This gives us a positive feedback loop for the dynamic torque in the generator (see Table 2). A growing current enhances the torque so that the current becomes even larger and the angular velocity increases further, as can be seen in Figs. 4 and 5 from the blue curves (with index 2). However, at the same time, the counter-torque T_c increases, and the effective resistance R_{eff} increases with the angular frequency. In addition, the dynamic magnetic field B_I counteracts the fixed field B_m. As a result, the COP (or efficiency η) goes up to nearly 0.4 and then slowly goes down, so that the efficiency is further reduced (see Fig. 6). The dynamic magnetic field and the effective resistance are graphed in Fig. 7. B_I is positive and grows sub-linearly because of the counter torque. The modulus of the total magnetic field $B_m + B_I$ is reduced. R_{eff} increases in a linear manner.

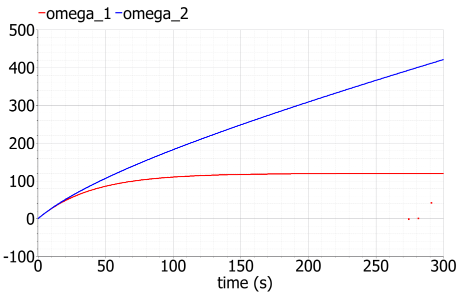

Figure 4: Angular velocity of the original (1) and extended (2) generator with $\alpha > 0$.

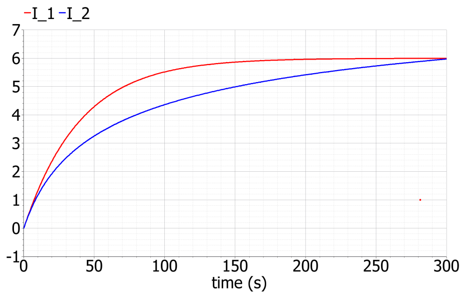

Figure 5: Current of the original (1) and extended (2) generator with $\alpha > 0$.

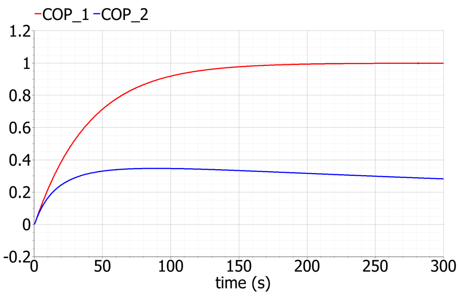

Figure 6: COP of the original (1) and extended (2) generator with $\alpha > 0$.

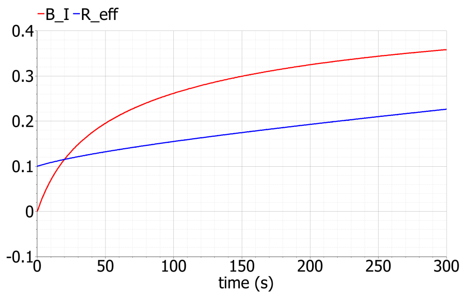

Figure 7: Magnetic field B_I [T] and effective resistance R_{eff} [Ω] of the extended generator with $\alpha > 0$.

4.2.2 Negative torque feedback

In the case where $\alpha < 0$, the situation is quite different. Now, the counter torque T_I produces a negative feedback, leading to a stationary value of the angular velocity (Curve 2 in Fig. 8). Because of this feedback effect, the final value of ω is lower than for the original generator (Curve 1 in Fig. 8).

Interestingly, the COP η of the generator with a negative feedback is larger than unity (Fig. 9). To understand this, we have to look at Eq. (29), which in short form reads

$$L\dot{I} + IR_{\text{eff}} + \frac{1}{2}\omega r_d^2 B_m = 0. \tag{44}$$

The effective resistance R_{eff} (Eq. (30)) diminishes for a negative α:

$$R_{\text{eff}} = R - \frac{1}{2}\omega r_d^2 |\alpha|. \tag{45}$$

This effect is enhanced for an increasing ω so that the effective current resistance in the circuit is reduced and overunity can be reached. The time evolution of R_{eff} is graphed in Fig. 10, as well as the development of the dynamic field B_I.

For data set 2 of Table 1, the homopolar generator moves into a stable state without oscillations. From enforced oscillations we know that this is an aperiodic limit of a damped oscillator. By changing the parameters, it is possible to bring the machine into an oscillating state. Applying parameter set 4 of Table 1, we obtain an oscillating behavior of the angular velocity (see Fig. 11). The oscillation can even become negative at the start, with the disk rotating in the opposite direction during these phases. Analyzing this behavior further, we see that the effective resistance becomes slightly negative during these phases (Fig. 12). The magnetic field B_I oscillates in the same way, and its amplitude becomes quite high, up to -3 T.

4.3 The extended homopolar generator with a nonlinear magnetic core

An extremely high magnetic field amplitude of -3 T is not realistic, because the magnetic core will become saturated before this amplitude can be reached. Therefore, we have modified Eq. (24) so that it is restricted to the modulus of the saturation induction B_{sat}:

$$B_I = \text{sign}(\alpha I) \min(|\alpha I|,\ B_{\text{sat}}). \tag{46}$$

For this calculation, we have used parameter set 4 of Table 1. In particular, the torque has been increased by a factor of 10, and an Ohmic resistance of 3.1 Ω has been used, which corresponds to that of a fan heater. The simulation result shows an oscillating behavior which converges to constant values (see Figs. 13-14). The output power is about 5 kW, the current is about 40 A, and the system has an asymptotic COP of about 40 (Fig. 13), which is enormous. These values are produced by the very low effective resistance, which drops from 3.1 Ω to 0.1 Ω. The value is even negative in the initial, strongly oscillating range. A negative resistance means that the circuit produces energy instead of consuming energy. The electromagnetic inductor operates in saturation mode. Both can be seen in Fig. 14.

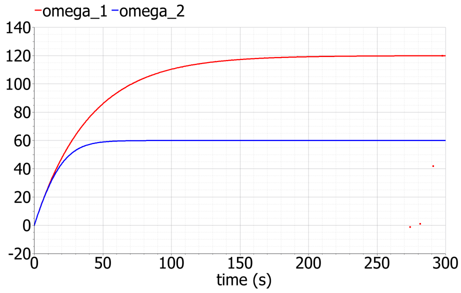

Figure 8: Angular velocity of the original (1) and extended (2) homopolar generator with $\alpha < 0$.

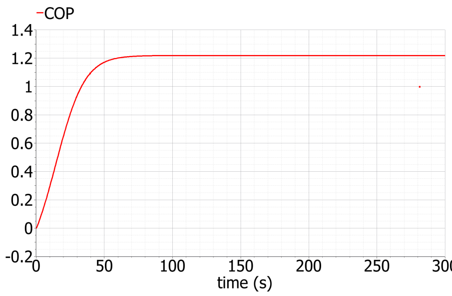

Figure 9: COP of the extended homopolar generator with $\alpha < 0$.

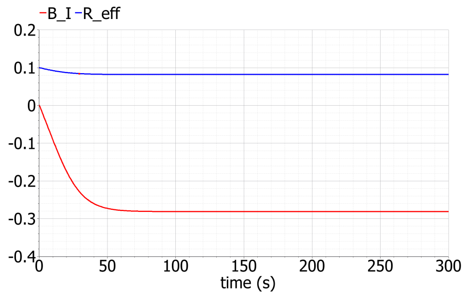

Figure 10: Magnetic field B_I [T] and effective resistance R_{eff} [Ω] of the extended generator with $\alpha < 0$.

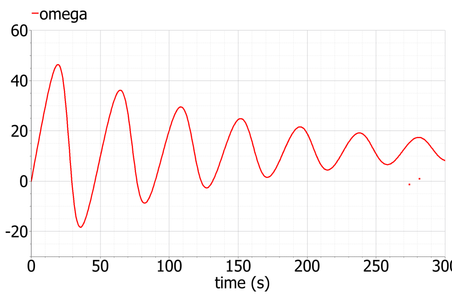

Figure 11: Angular velocity of the extended generator, third data set with $\alpha < 0$.

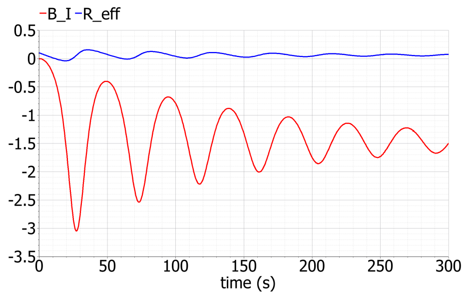

Figure 12: Magnetic field B_I [T] and R_{eff} [Ω] of the extended generator, third data set with $\alpha < 0$.

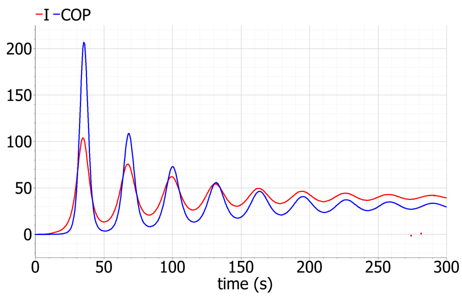

Figure 13: Current and COP of the extended generator, fourth data set with $\alpha < 0$, B_I saturated.

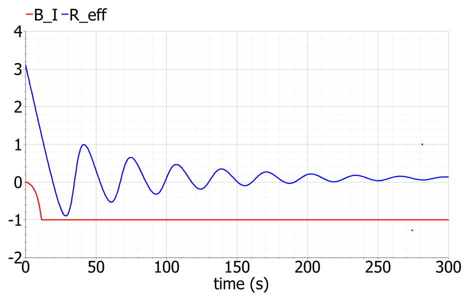

Figure 14: Magnetic field B_I [T] and R_{eff} [Ω] of the extended homopolar generator, fourth data set with $\alpha < 0$, B_I saturated.

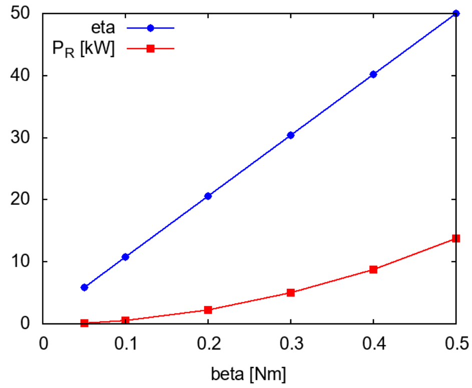

Figure 15: Dependence of η and P_R on external torque β.

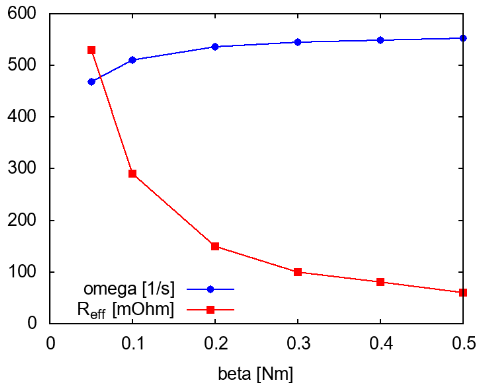

Figure 16: Dependence of ω and R_{eff} on external torque β.

Figs. 15 and 16 show various parameters that are dependent on a growing driving torque. According to Fig. 15, the COP η grows linearly, and the output power P_R rises roughly quadratically. From Fig. 16 it can be seen that the rotation speed ω shows no significant dependence and approaches an asymptotic limit. The effective resistance R_{eff} drops hyperbolically.

5 Discussion

We have shown by simulation that a design for a homopolar machine operating at overunity should be possible. The key point is that an electromagnet was added to the original design of the Faraday disk. A positive feedback effect can be achieved in three ways:

1. Additional torque from the magnetic field of the electromagnet;
2. Current enhancement through the magnetic field of the electromagnet;
3. High efficiency resulting from a reduced effective resistance (even a negative resistance is possible).

So far, no such device that operates in overunity mode has been presented publicly. There are reports, however, that Bruce DePalma [8, 9] had exhibited such a machine in 1986. The magnet and disk (the whole construction) were rotated together. This is also possible with our design, which is shown in Fig. 3. It is not known if DePalma had used an additional electromagnet.

Other propositions have been discussed in internet forums [10]. Tesla seems to have utilized a secondary magnetic field that is generated by the current flow from the axis to the current collector of the disk. Another interesting idea is to use a flat ("pancake") coil instead of the electromagnet and the conducting disk (Fig. 17). Then, the current is forced to flow in a spiraling path from the center of the coil to the rim. Such a flat coil generates a magnetic field that in principle has the same effect as the electromagnet of Fig. 3. Such a device would save material and space. However, the magnetic field would be weaker and not homogeneous. For the latter reason, it is more difficult to simulate such a device, and a FEM calculation would be required. It is not known if DePalma had used a similar design in his device.

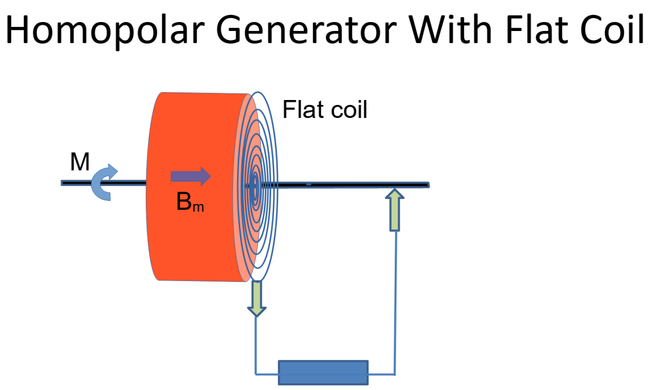

Figure 17: Homopolar design with Tesla flat coil.

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