Magnetic Delay plus Capacitive Loading, the Route to Over-Unity?

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1. Introduction

Prof. Turtur has offered a capacitively loaded PM generator as an overunity device. He argues that a travelling electric or magnetic field wavefront is converting zero-point energy (zpe) into field energy or vice versa, so any zpe converter must take account of these wavefronts, i.e. must involve the propagation time which is usually ignored in electrical machines. He arrived at this view having demonstrated an electric machine (i.e. one using electric fields) that free-runs, producing small but verifiable amounts of free energy. He claims that his analysis of the proposed magnetic machine automatically takes this propagation delay into account using the differential equation relating voltage to current in the inductance of his coil, arguing that the effect really comes about due to the E-field velocity within and along the copper wire. This paper gives the result of a magnetic domain analysis that shows the machine as presented by Turtur is not overunity. By ensuring that the mmf drive is sinusoidal, there is a direct analytical solution that gives exact answers whereas Turtur's iterative solution is subject to sampling errors. The magnetic domain differential equations have also been solved in a time-stepping iterative manner similar to Turtur's electrical domain solution and this method also incorrectly predicts overunity when the time steps are too large. It may also be noted that Bob Flower has re-run Turtur's algorithm at finer increments and there too the overunity disappeared.

It is the author's opinion that Turtur is wrong to claim that the electric-field propagation within the copper is the seat for extracting zpe energy. Being a magnetic device, it is the *magnetic-field* propagation that should be considered. To examine this possibility the magnetic domain solution has been modified to include propagation delays. That work shows that capacitive loading can introduce a phase shift that is beneficial. In the limit, assuming zero losses within the machine, the COP can reach infinity and even go negative, i.e. the machine can free run while delivering both mechanical and electrical power. Thus it appears that Prof. Turtur's views on zpe conversion are correct, and perhaps it is unfortunate that he chose to illustrate this incorrectly in the case of his magnetic machine.

2. The Generator

Figure 1 shows a typical generator as analysed. A disc magnet forms the rotor, as this is easily represented by a single-turn current loop. The field from this magnet is channelled by a high permeability stator to pass through the output coil, which is connected to a load resistor shunted by a high value capacitor. The stator is shown in a hairpin configuration as this helps illustrate the separation distance between the rotor and the coil whereby the magnetic flux can be subject to a delay-line effect. The magnet rotates between shaped pole-pieces to (a) ensure that the magnetic drive is sinusoidal and (b) the flux appears as a uniform field between the pole-pieces, thus simplifying the torque calculations.

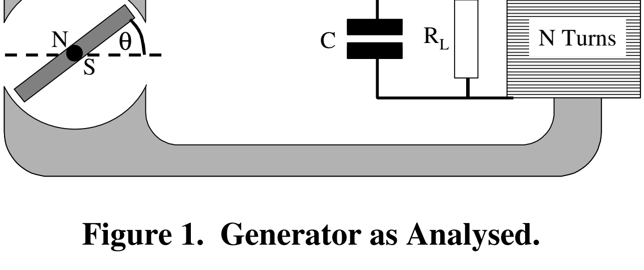

Figure 1. Generator as Analysed.

Figure 2 shows the magnetic circuit where the rotating magnet appears as a sinusoidal mmf generator U_{drive} feeding flux via the air and core reluctances to the magnetic impedances created by the electrical loads. The current through load resistor R_L creates a mmf obeying $U = -\mathcal{L}\dot{\Phi}$ where $\mathcal{L}$ is a magnetic inductance of value $\mathcal{L}=N^2/R_L$ while the capacitor current creates an unusual magnetic impedance $\mathcal{D}$ obeying $U = -\mathcal{D}\ddot{\Phi}$ where $\mathcal{D}=N^2C$.

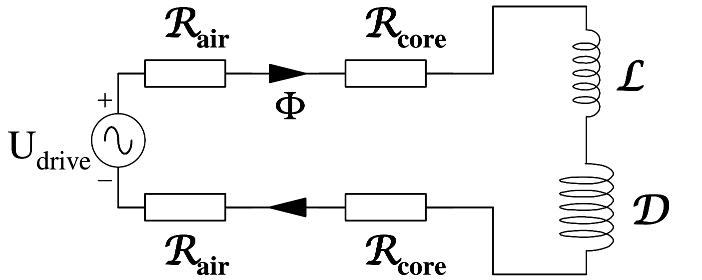

Figure 2. Magnetic Circuit

3. Analysis

Summing the mmf's around the magnetic circuit yields the differential equation

$$U_{drive} - \mathcal{R}\Phi - \mathcal{L}\dot{\Phi} - \mathcal{D}\ddot{\Phi} = 0 \quad (1)$$

where $\mathcal{R}$ is the total reluctance of the air and core reluctances. For sinusoidal waveforms this may be written in phasor version as

$$\hat{U}_{drive} = \mathcal{R}\hat{\Phi} + j\omega\mathcal{L}\hat{\Phi} - \omega^2\mathcal{D}\hat{\Phi} \quad (2)$$

The phasor diagram is shown in figure 3, using Φ as the phase reference.

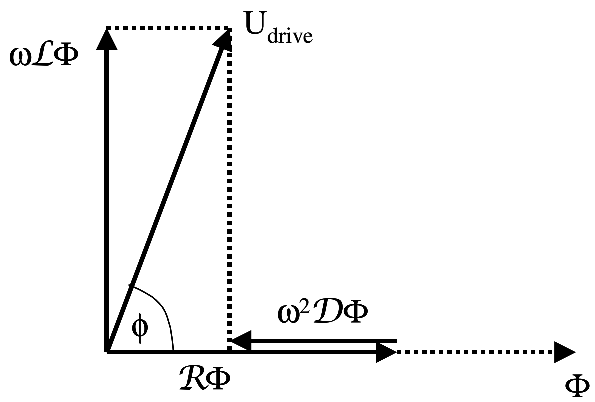

Figure 3. Phasor Diagram

It can be seen that the flux Φ lags the mmf U_{drive} by an angle ϕ given by $\tan\phi = \dfrac{\omega\mathcal{L}}{\mathcal{R}-\omega^2\mathcal{D}}$

and the peak flux is related to the peak mmf by

$$\hat{\Phi} = \frac{\hat{U}_{drive}}{\sqrt{\left(\mathcal{R}-\omega^2\mathcal{D}\right)^2 + \left(\omega\mathcal{L}\right)^2}} \quad (3)$$

If I_m represents the effective amperian current flowing around the disc magnet then this is the peak value for U_{drive} and we can write

$$U_{drive} = I_m\cos(\omega t) \quad (4)$$

and

$$\Phi_{(t)} = \frac{I_m\cos(\omega t - \phi)}{\sqrt{\left(\mathcal{R}-\omega^2\mathcal{D}\right)^2 + \left(\omega\mathcal{L}\right)^2}} \quad (5)$$

Since the mmf $\omega\mathcal{L}\Phi = Ni$ where i is the current through the load resistor R_L we can write the output power i^2R_L as $\frac{(\omega\mathcal{L}\Phi)^2 R_L}{N^2}$, then since $\mathcal{L} = \frac{N^2}{R_L}$ the output power becomes $\omega^2\mathcal{L}\Phi^2$.
Using (5) the output power waveform becomes

$$P_{out(t)} = \frac{\omega^2 \mathcal{L} I_m^{\ 2} \cos^2(\omega t - \phi)}{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2} \qquad (6)$$

The $\cos^2$ function has an average value of 0.5 so the average power out is

$$P_{out} = \frac{0.5\omega^2 \mathcal{L} I_m^{\ 2}}{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2} \qquad (7)$$

Torque for a current loop I_m in a magnetic field B is $T = I_m AB\sin\theta$ where A is the loop area. Then since $B = \Phi/A$ this becomes $T = I_m\Phi\sin\theta$, so using (5), $\theta = \omega t$ and multiplying by ω we obtain the mechanical input power waveform as

$$P_{in(t)} = \frac{\omega I_m^{\ 2} \cos(\omega t - \phi)\sin(\omega t)}{\sqrt{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2}} \qquad (8)$$

The average value of $\cos(\omega t - \phi)\sin(\omega t)$ is $0.5\sin\phi$ and from the phasor diagram figure 3 we get

$$\sin\phi = \frac{\omega\mathcal{L}}{\sqrt{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2}} \qquad (9)$$

Thus the average input power is

$$P_{in} = \frac{0.5\omega^2 \mathcal{L} I_m^{\ 2}}{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2} \qquad (10)$$

which is identical to (7). Thus the machine does not exhibit overunity characteristics.

4. Magnetic Delay Considerations

The previous analysis did not taker account of any propagation effects within the magnetic circuit. Normally in such machines any propagation delay can be ignored, but to complete the analysis and to follow Turtur's argument we should examine what happens when the delay is included. This is easily accomplished by applying an additional phase delay α in (8) which then becomes

$$P_{in(t)} = \frac{\omega I_m^{\ 2} \cos(\omega t - \phi - \alpha)\sin(\omega t)}{\sqrt{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2}} \qquad (11)$$

and α represents the two-way phase delay. The average value of $\cos(\omega t - \phi - \alpha)\sin(\omega t)$ is $0.5\sin(\phi + \alpha)$ which on expansion is $0.5\sin\phi\cos\alpha + 0.5\cos\phi\sin\alpha$. From figure 3 we get

$$\cos\phi = \frac{\mathcal{R} - \omega^2\mathcal{D}}{\sqrt{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2}} \qquad (12)$$

Hence the average input power now becomes

$$P_{in} = \frac{0.5\omega I_m^{\ 2}\left(\omega\mathcal{L}\cos\alpha + \left(\mathcal{R} - \omega^2\mathcal{D}\right)\sin\alpha\right)}{\left(\mathcal{R} - \omega^2\mathcal{D}\right)^2 + (\omega\mathcal{L})^2} \qquad (13)$$

Taking the ratio of (7) and (9) yields the COP as

$$COP = \frac{\omega\mathcal{L}}{\omega\mathcal{L}\cos\alpha + \left(\mathcal{R} - \omega^2\mathcal{D}\right)\sin\alpha} \qquad (14)$$

Note that by increasing the shunt capacitance value the COP reaches infinity (zero drive power required) when

$$\omega\mathcal{L}\cos\alpha + (\mathcal{R} - \omega^2\mathcal{D})\sin\alpha = 0 \qquad (15).$$

That condition occurs when $\tan\alpha = -\tan\phi$ (i.e. when $\alpha+\phi=180°$). Beyond that the COP goes negative indicating that the system can produce negative torque (deliver mechanical power) as well as delivering electrical power. When there is no capacitor (i.e. when $\mathcal{D}=0$) and for small α the COP is always less than unity. However, the use of capacitive loading, which takes ϕ near to 180°, can allow even small α values to obtain large or negative COP's. Whether this leverage occurs in practice remains to be seen. Using $\mathcal{L}=N^2/R_L$ and $\mathcal{D}=N^2C$ condition (15) can be arranged into

$$\omega C = \frac{\cot\alpha}{R_L} + \frac{\mathcal{R}}{\omega N^2} \qquad (16)$$

But we also know that the electrical inductance L of the coil is $N^2/\mathcal{R}$ so we obtain

$$\omega C = \frac{\cot\alpha}{R_L} + \frac{1}{\omega L} \qquad (17)$$

which allows C to be chosen to give infinite COP. However for small propagation delays large C values are required which have significant ESR, and the series ESR plus coil resistance has not been taken into account here.

5. Series Resistance Considerations

All capacitors exhibit loss, i.e. they have an equivalent series resistance (ESR) and this is particularly so for large values that would apply to this type of machine. Also the resistance of the output coil will appear in series, whereas the above analysis only applies to parallel CR components. If we restrict ourselves to just a magnetic motor which will free-run, we can leave out the parallel load R_L and instead insert a series load R_S which is the sum of the coil resistance and the ESR of the capacitance. We then need to modify the phasor diagram to account for the phase angle introduced by this. It is found that we can do this by introducing modified values for $\mathcal{D}$ and $\mathcal{L}$,

$$\mathcal{D} = \frac{N^2C}{\omega^2C^2R_S{}^2 + 1} \qquad (18)$$

which reduces to the previous case $\mathcal{D} = N^2C$ when $R_S=0$.

$$\mathcal{L} = \frac{N^2R_S}{R_S{}^2 + \left(1/\omega C\right)^2} = \frac{N^2R_S\omega^2C^2}{\omega^2C^2R_S{}^2 + 1} \qquad (19)$$

which reduces to the previous case $L = N^2/R_S$ when C is infinite, i.e. is shorted.

Because the electrical load appears in both $\mathcal{D}$ and $\mathcal{L}$ it is found that a negative COP condition (i.e. free running to overcome friction torque while driving power into R_S) is not always achievable. Using these values for $\mathcal{D}$ and $\mathcal{L}$ in (14) we obtain the COP as

$$COP = \frac{1}{\cos\alpha + \left(\dfrac{R_S}{X_L} + \dfrac{X_C{}^2}{X_LR_S} - \dfrac{X_C}{R_S}\right)\sin\alpha} \qquad (20)$$

where for simplicity of expression we have used the electrical reactance X of C and L, ($X_C=1/\omega C$ and $X_L=\omega L$ respectively). A condition for negative COP is then

$$\cot\alpha < \frac{X_C}{R_S} - \frac{X_C{}^2}{X_LR_S} - \frac{R_S}{X_L} \qquad (21)$$

For the small propagation times expected α will be small and the approximation $\cot\alpha=1/\alpha$ can be used. Equation (21) then converts to

$$\alpha > \frac{X_L R_S}{X_L X_C - X_C^{\,2} - R_S^{\,2}} \tag{22}$$

The two-way propagation phase delay α must exceed the value given by (22) for a self-runner. Since (20) is quadratic in both X_C and R_S, achieving negative COP is only assured with very low values of R_S, then the quadratic solution for X_C

$$X_C = \frac{X_L}{2}\left(1 + \sqrt{1 - 4\frac{R_S^{\,2}}{X_L^{\,2}} - 4\frac{R_S}{X_L}\cot\alpha}\right) \tag{23}$$

may be used to obtain the value of C where the COP goes through infinity. If R_S is too large (23) returns an imaginary solution.

6. Increasing Propagation Delay

The propagation velocity can be artificially increased by using a plurality of small coils each loaded by a capacitor mounted at increments along the core. This has been done successfully in the past to demonstrate a transformer where the flux through the secondary was 180° phase shifted from its normal phase, something that electrical engineers would think impossible. Although that experiment was very inefficient, for the sort of delays we need here (just a few degrees would be good) this might work. The system would then look like figure 4.

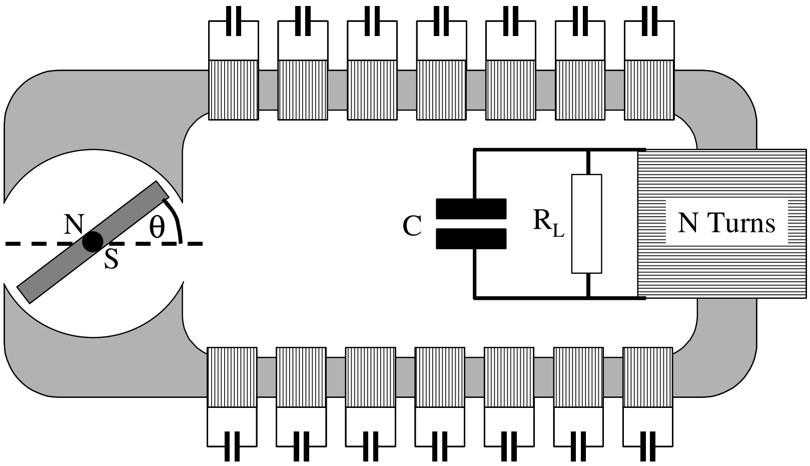

Figure 4. Increased delay

Another method is to increase the frequency, which for rotary machines can be done by using a rotor that contains a number of magnets and a stator having a number of hairpin-shaped cores. For these types of machines advantage can be gained by using a rotor with *n* magnets and a stator with *n*+1 cores, this significantly reduces the overall cogging torque.

7. Conclusion

By a combination of magnetic delay and capacitive loading it appears that a PM generator can be made to free-run, delivering both mechanical and electrical power. Prof. Turtur has offered a machine purported to do this but a magnetic domain analysis shows that his device does not exhibit those characteristics, and it is contended that this is because the magnetic delay through air is negligible. However by introducing magnetically permeable material between the rotating PM and the coil sufficient magnetic delay may be created to make such a machine feasible. The conditions necessary for this to occur have been given.