Flux Leakage Tests for the Marinov Motor

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Several tests are presented for evaluating the effects of flux leakage in the Marinov Motor. The conclusion is that the leakage may play a significant part, but does not explain the entire operation. A second section explores briefly the electromotive aspects of the motor.

Introduction

Several papers, in particular Wesley[1] and Phipps[2,3] have described and analyzed the operation of the Marinov motor, which is basically composed of a magnetic toroid inside an electrically conducting ring which is fed current at 2 points diametrically opposite, as shown in Fig. 1. Ideally the magnetic flux of the torus is contained entirely within, so that the external $\mathbf{B}$ field is zero, although the magnetic vector potential $\mathbf{A}$ is still nonzero. I refer the reader to these papers for a detailed description. The regular motor has the torus fixed and the ring free to revolve, while the easier to construct "inverse" motor has the ring fixed and the torus free to revolve. The theory is derived from a force term = grad $(\mathbf{V}\times\mathbf{A})$ which is ignored in Lorentzian electromagnetics[4]. Several investigators have achieved operation [5], although the operation of the regular motor is still controversial.

This paper especially follows the spirit of the work of Tom Phipps in [2]. We will use the same notation, except S.I. units.

Leakage Flux

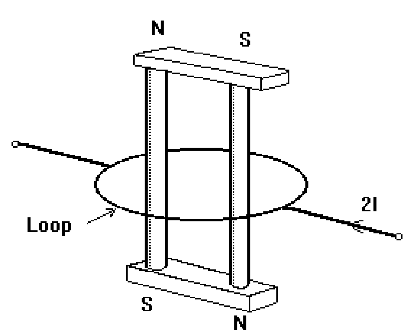

Fig. 1. Diagram of the Marinov motor with an magnetic closed circuit enclosed by a current loop.

Wesley[1] calculates the force and torque on the ring from the torus. The force and torque on the torus in the inverse configuration is assumed from Newton's third law. It is noted in the inverse form the ring does produce a $\mathbf{B}$ field which can interact with the torus, unlike the regular form. I set out to investigate the effects of this field.

Fig 2a shows the $\mathbf{B}$ fields generated by a current I flowing in each side of the Marinov ring. Note that on the line joining the 2 feed wires, the $\mathbf{B}$ field is zero, If a compass is placed parallel to the plane of the ring, it

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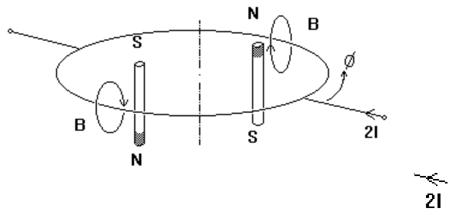

Fig. 2c. Alignment of the 2 permanent magnets when they are rotated by 90 degrees.

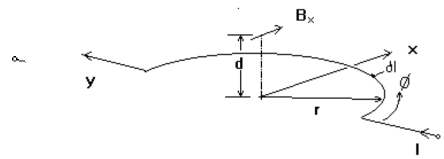

Fig. 3. Schematic for calculating the B_x component from 1/2 of the total loop current.

loop when the current is fed and divided between the 2 sides.

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with the loop fields.

points as shown as it is positioned above or below the ring. FIgure 2b shows the 2 compass needles replaced by permanent magnets in the equilibrium position. It looks just like an implementation of the Marinov torus without the soft iron keepers. This would be the situation of maximum flux leakage from the torus. Any real implementation would have less leakage, so this situation will be a guidepost for the maximum force and torque possible from the leakage. These will be compared to the Hertzian force and torque derived for the Marinov motor.

A further characteristic of this leakage configuration is shown in Fig. 2c. If the 2 magnets are rotated 90 degrees about the axis of the 2 lead wires, the sense of the torque is reversed. The field will also attract a soft iron torus to the same regions of higher magnetic field.

Fig 3 shows the geometry to calculate the torque of a magnet at height d from a semicircular loop carrying a current I. Since the off axis fields are difficult to calculate, the **B** field at (0,0,+/–d)is calculated, and assumed the permanent magnet is small enough so the **B** field can be considered uniform. Note that by symmetry, the y component is zero, and the x component is what is required to calculate the torque on the magnet. For a full ring the resultant torque will be 2X this value, and for 2 magnets as shown in Fig 2b, there will be another factor of 2X.

By the Biot-Savart formula, the x component of the B field can be written

$$dB_x = \frac{m_0 I \sin(q)\cos(f)\,r\,df}{4p\left(r^2+d^2\right)} \quad \text{, where } \sin(q) = d\Big/\sqrt{r^2+d^2}$$

Integrating over f from –p/2 to p/2, we get

$$B_x = \frac{m_0 Ird}{2p\left(r^2+d^2\right)^{1.5}} \qquad (1).$$

Note that this field component is an odd function of d and has a maximum value at $d = \pm\, r\big/\sqrt{2}$.

The torque of a bar magnet in an external **H** field can be written as $Hml\sin(f)$ [6] where m is the magnet moment, l is the length, and f is the angle between the external field and the bar magnet axis. This can be rewritten as:

$$torque = B\left(NI\right)A\sin(f)\ . \qquad (2)$$

where (NI) are the Amperian or magnetizing currents of the magnet and A is the cross-sectional area, both characteristics of a given magnet. (NI) can be calculated from the flux of the magnet, assuming it appears as a solenoid.

Combining eqns. (1) and (2) with a factor of 4 for 2 magnets and a complete ring gives the maximum possible leakage torque in the inverse configuration.

Experiments

A compass was placed 2 cm above the ring such that the **B** field from the ring would deflect the compass from its equilibrium position in the earth's magnetic field. At a current I of 3A in each side, the compass was deflected 45°. Using eqn. (1) the **B** field above the ring is calculated to be 0.21 gauss. From geomagnetic maps, the horizontal component of the earth's field at my location is 0.25 gauss = $25 \cdot 10^{-6}$ T. So there is agreement within 20%, even though the compass needle is not small compared to the ring dimension and the calculated B component is for the center only.

To test the configurations I set up a torsion balance similar to described by Phipps in [2]. I used a stainless steel wire 0.01 inches in diameter (0.25mm) 1 meter long. I also incorporated a self contained power supply at the end of the wire which used 2 NiCd cells and can supply about 2.4 volts at up to 10 Amps. I followed this approach because all my attempts to feed current to the location at the bottom of the balance ran into some sort of problem or another. The power supply can be switched on or off by a light activated switch.

To calibrate the balance, I connected a solenoid to the power supply and placed it 90 deg. from the earth's magnetic field of 0.25 gauss = $25 \cdot 10^{-6}$ T. The solenoid had N = 102 turns, I = 5 Amps, and a diameter of 4.4cm. The observed angular deflection was 30 degrees. The calculated torque from eqn.(2) is $1.68 \cdot 10^{-5}\, N-m$ or $5.6 \cdot 10^{-7}$ N-m/° or 5.6 dyne-cm/°. To compare, the balance Phipps constructed in [2] had a measured calibration of 11.4 dyne-cm/°.

Experiment 1. Inverse motor with fixed ring and suspended magnet torus

My permanent magnet torus had 2 stacks of magnets, each 1cm in diameter, 2.6 cm high, giving d =1.3cm, and a spacing of 2.2 cm giving b = 1.1 cm. The copper ring has a mean diameter of 4.4 cm or r = 2.2 cm. The suspended power supply was not used. Note that this value of d turns out to be close to the value for the maximum **B** field from the ring.

The 2 stacks were connected by 2 soft steel keepers. I do not know the flux of the Neodynium magnets, but for the sake of discussion will use the value Phipps used in [2], 2300 gauss or 0.23T. They may have a flux larger than this, which would give even higher calculated values for the torque.

The form of the leakage flux was measured with a pocket compass. It did seem to have a form of 2 permanent magnets and a value equal to the earth's field of 0.25 gauss at a center to center distance between the torus and compass of 7cm.

For the ring I used a current in each ring half of 10Amps. The current was used in both directions, to get two equal deflections for the ±10 Amps. The deflection measured was ±7.5° giving a measured torque of $4.2 \cdot 10^{-7}$ N-m/Amp.

Experiment 1a.

In another test for leakage flux, the torus was rotated 90° about the axis of the 2 lead wires, as shown in Fig. 2c. The torque reversed direction, an indication that the leakage flux as a cause of the torque. The torque also reversed direction if the torus was rotated 180° in the direction of the torque, f, as expected.

Experiment 1b.

In another test, I removed one of the 2 soft steel keepers and measured a much larger torque. The current was reduced from ±10 A to ±0.8A to get the same deflection. The measured torque for this case is $10.5 \cdot 10^{-6}$ N-m/Amp (105 dyne-cm/Amp).

Experiment 2. Inverse motor with fixed ring and suspended electromagnet round toroid

In this experiment, the permanent magnet torus was replaced with an ferromagnetic core toroid electromagnet. The suspended power supply was used to power this electromagnet. The core has an outer diameter of 4.0 cm OD and 2.4cm ID. It was wound with a winding of 44 turns and a current of 9A was used. I measured the relative permeability by introducing a known steady state sinusoidal current to determine the **H** field, and measured the induced voltage to determine the flux and **B** field.

The relative permeability is calculated to be 55, and the B field for the exciting condition of 44 turns of 9A is thus 0.27 T (2700 gauss). I expected that this configuration would have much less leakage flux than the rectangular permanent magnet torus. This was confirmed with a pocket compass.

The current ring had to be made slightly larger in this case for the toroid to freely fit, $r = 2.5$ cm.

Placing this toroid inside the current ring, a deflection more than 1° could not be measured with the ring current the same as experiment 1. This is about the same deflection as when the suspended electromagnet was switched on/off with zero ring current.

Experiment 3. Regular motor with fixed permanent magnet torus and suspended ring

In order to avoid the problems with brushes, the ring was suspended on the torsion balance, powered by the suspended power supply. The permanent magnet torus was inside, but fixed. The ring had a switched current of 5A, instead of the ±10A for the fixed ring.

Here I measured a deflection of 4°. There is an additional restoring torque from the loop formed by the feed wires interacting with the earth's magnetic field. It was situated for zero torque with zero deflection. The effective size of this loop is 0.16m × 0.19m and a current of $2I = 10$Amp.

Thus the calibrated balance torque of $22.4 \cdot 10^{-7}$ is increased by the torque of the loop by eqn. (2) with $\sin(f = 4°)$. This additional torque is $5.3 \cdot 10^{-7}$ N-m or a total of $27.7 \cdot 10^{-7}$ N-m required or Torque = $5.54 \cdot 10^{-7}$ N-m/Amp. In addition, the torus was rotated 90° as shown in Fig. 2c and the direction of the torque reversed.

Discussion

Wesley[1] uses a pair of infinitely long, thin solenoids for his calculations. The important characteristic of such a solenoid is that its external A field can be calculated in the plane of the ring and its external B field is zero. I did not use this approach, as a closed magnetic loop has the same characteristic. What is required for the calculations is the A field at the plane of the ring, and this can also be calculated for a closed loop or torus.

For a single tube of magnetic flux, Faraday's law states that d(flux)/dt = the contour integral of d**A**/dt which links the flux. Assuming that the **A** is uniform along f, we get by integration that flux= $2p\, rA_f$. In Wesley's notation this gives K= flux/2p for the formula for the A component of the torus composed of 2 parallel, offset tubes of flux:

For the magnets I used, $K = BArea / 2p = 2.6 \cdot 10^{-6}\, Wb$

$$A_f = 2Kb\left(r^2 - b^2\right)\sin(f)Q^4 , \tag{3}$$

where

$$Q^4 = \left(r^2 + b^2\right)^2 - 4b^2r^2\sin^2(f) .$$

The maximum torque on the ring is $2Ir[A(p/2) - A(-p/2)]$ or

$$torque = \frac{8KIbr}{\left(r^2 - b^2\right)} . \tag{4}$$

This torque does not vary with angular position of the torus as just sin(f) as the term Q also has an angular (f) dependance. However Phipps [2, Fig 11] shows a measured torque $vs.$ f that fits much better a sin(f) curve than the Wesley Hertzian theory.

For experiment 1, the Wesley formula for maximum torque (4) gives Torque = $7.7 \cdot 10^{-6}$ N-m/Amp. To calculate the torque on a permanent magnet from the flux, the equivalent amp-turns to give the equivalent magnet flux is calculated to be $4.3 \cdot 10^3$ Amp-turns.

Using the values for b,r, and d, the maximum torque is calculated to be from (1), (2) as Torque = $4.66 \cdot 10^{-6}$ N-m/Amp. The measured torque of $4.2 \cdot 10^{-7}$ N-m/Amp is much smaller than both of these values.

The torque measured in experiment 1b, $10.5 \cdot 10^{-6}$ N-m/Amp is larger than either of these 2 predictions. This may mean that the magnet flux is actually larger than the assumed value and that the actual leakage flux with the keepers is reduced enough to produce the torque in experiment 1. Experiment 2 with a toroid electromagnet seems to confirm this, as it has less leakage flux.

Conclusion

The torque from the interaction of the ring B field and permanent magnets is shown to be comparable to the Hertzian torque. The torque in the inverse configuration fits the form of this leakage interaction in 2 ways:

1. The torque has an observed sin(f) dependence.
2. Rotating the permanent magnet torus by 90° reverses the sign of the torque.

In addition a toroid closer to the ideal of zero leakage flux, as an electromagnet, shows a torque too small to be observed. Experiment 3 does show a torque on the ring, but there is a difference between it and the torque of experiment 1, taking into consideration the factor r/b. The torque from the leakage flux does not explain the continuous rotation of the ring rotor. Although some of the behavior can be explained by the leakage flux, further investigation is warranted.

Induced Voltage

Wesley[1] states that the ponderomotive force cannot be separated from the electromotive force. To explore this, I mounted the permanent magnet torus used in the previous tests on a shaft driven by an external motor. The ring was fixed. The tangential vector potential at the ring can now be written as $A(u)$ as in eqn (3) but now $u = -wf \cdot t$. Now $dA/dt = -wA'(u) = -E$. where E is the tangential or f component of the induced **E** field. The voltage between the 2 connecting leads is $V(t) = r\int E \cdot df$, or $rw\{A(u)$ at $f = p/2 - A(u)$ at $f = -p/2\} = -2rwA(wt)$. Note that the voltage induced around the entire loop = 0, as the closed integral of $dA/dt = -d(\text{flux})/dt$ where the flux is that enclosed by the loop. This also restates that the voltage induced in either half ring is equal.

If A is written as $KG(u)$ where G contains all the geometric factors in eqn 3, the maximum voltage *vs*. time is the voltage using the maximum value of G, in the same manner as for the maximun torque. $V(\max) = 2rwG(\max)K$ Volts. The torus was rotated at 1800 rpm or $w = 60p$..

Using the same values of $K = 2.9 \cdot 10^{-6}$ Wb, $r = 2.2 \cdot 10^{-2}$m, $b = 1.1 \cdot 10^{-2}$ m, $G(\max) = 60m^{-1}$, $V(\max)$ = 1.44 mV. This voltage was measured at a frequency of 30 Hz with a oscilloscope with a maximum sensitivity of 10mV/div. and a low noise preamp with a gain of 100, resulting in a vertical display of 0.1mV/ division. I could not detect any voltage.

Discussion

The oscilloscope measuring instrument forms a complete loop with either half of the ring. Any complete loop will have zero induced voltage as the flux enclosed by the loop is zero. The only way to determine if this voltage exists is a method that does not end up forming a closed contour. A possible method may be a circuit where parts are free to move with respect to others, such as the classic pith ball electrometer. This is an area of future investigation.

References

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