Ball Bearing Motor Experiments

Horace Heffner August 2009

PURPOSE

The purpose here is to continue analysis and experimentation with the Marinov Ball Bearing Motor tested prior to 2003 by Richard Hull and Tim Raney, and further explored here:

http://www.mtaonline.net/~hheffner/HullMotor.pdf

http://www.mtaonline.net/~hheffner/HullMotorA.pdf

The above includes photos, oscilloscope traces, links to videos and experimental proof the motor runs on magnetic bearings only, thus is a magnetic effect. Also discovered was a back emf is developed, providing further proof the motor operates on ordinary electromagnetic principles. The deduced principle of operation was documented at length. What follows here is a continuation of the effort.

LENZ'S LAW AND BACK EMF

Now to look at back emf and how Lenz's Law applies.

Suppose we have armature material with an "o" field in it and a current i flowing through it bottom to top.

If the armature material has the "o" field as supposed, and is not moving, then the current flowing upward through the material in Fig. 1 below will clearly induce force in the material to the right, as , and there will be no back emf.

```
(-)  Current driving polarity
 ^
 | i
 |
o|o o
o|o o  F ->
o|o o
 |
(+)

Fig. 1 - material static
```

Now, if the material starts moving to the right, due to the i L B force, or for whatever other reason, it will induce a potential in the current path that opposes the potentials shown in Fig. 2 below.

```
(+)  Induced potential
 |
 |
o|o o o o o
o|o o o o o  => material and field move right
o|o o o o o
 |
(-)
```

Fig. 2 - material in motion, induced potential

The emf induced is in the direction opposed to the driving current. Everything seems to be working nicely according to Lenz's Law. This is why a proper back emf can be expected, and why at least some back emf has been observed.

Now, if the armature material is driven to the right at a high speed by an external added force, the current through the material still exerts the same i L B force. However, the back emf should increase due to the increased material (and thus magnetic field) motion, thus reducing i and thus reducing the energy applied to the armature. The armature should slow down to an equilibrium speed if the external torque is removed.

The hysteresis effect can make testing the back emf difficult because (1) it requires time for the M to be induced and (2) the M has to move into place (the place where i is) without benefit of a sustaining H. Thus condition (1) requires not moving too fast, and condition (2) requires not moving too slowly. The relationship between speed, i, torque, and back emf is therefore complicated.

From experience it appears the ideal speed of the motor is pretty fast. My motor has not had the opportunity to come up to speed from a low speed because I have had to shut it down due to the nichrome resistor overheating and concerns regarding the battery being overloaded by a large factor.

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Examining the potential drop across ball bearing motors at differing speeds and currents will eventually likely show even more clearly that the effect is purely ordinary magnetic, and that Lenz's Law applies. However, it is a major problem the motor is so inefficient, because that masks the basic performance characteristics.

The most curious thing is there appears to be no generator equivalent. The motor runs in either CM or CCW directions equally well, and with A/C or DC input. Without current input nothing happens electrically.

8/13/2009 TEST

At the request of vortex-l list contributor Harry Veeder, I did a test to show how much time it takes to heat up the resistor when the motor is running vs when stopped. I added a little green LED just below the filament so you can see exactly when the current comes on, and also provided a clock to see the time. Here it is:

http://www.youtube.com/watch?v=PWlVn-uqxig

Looks to me like about 8 seconds when the motor is running, and about 5 when stopped. This at first glance appears to be yet another indication this is an ordinary magnetic effect. The reduction in final current can be attributed to a back-emf. To some degree it might also be attributed to non-conduction time when the motor is running, but the scope traces have indicated pretty much full time current conduction in all runs since the bearings were cleaned.

However, the current sense resistor voltage drop doesn't look like what I'd expect.

http://www.mtaonline.net/~hheffner/HullRunningTrace.jpg

http://www.mtaonline.net/~hheffner/HullStoppedTrace.jpg

The traces show: (1) motor running, takes about 5 seconds to go from 7 V to 9.6 V, but about 9 seconds to heat orange, (2) motor stopped, takes about 5 seconds to go from about 6 V to 10.8 V, and to heat orange.

The difference in peak voltage makes sense in that the running motor peaks at 1.2 V less, so the back emf must be about 1.2 V. However, the traces don't make sense with regards to how the filament heats.

$P = I^2 R = V^2/R$

The resistance R = 0.0631 ohms cold.

So, at startup the running resistor heating power Prun and stopped power Pstop are:

$Prun = (7\ V)^2/(0.0631\ ohms) = 777\ watts$

$Pstop = (6\ V)^2/(0.0631\ ohms) = 571\ watts$

The ratio is 1.36, with the running motor circuit initially producing more heating in the current sense resistor by a factor of

$Prun/Pstop = 777\ W / 571\ W = 1.36$!??

This is not what we would expect in that overall the resistor turns orange much faster when the motor is stopped. By the time of orange glow, at resistor voltage and current equilibrium, we don't know the resistance, but the power ratio appears (assuming identical resistance at similar temperature) to be:

$Prun/Pstop = (9.6\ V)^2 / (10.8\ V)^2 = 0.79$

The equilibrium numbers make some sense in that 0.79 * (8 sec) = 6.3 sec, though it is off quantitatively a bit in that the orange temperature was reached in 5 seconds.

The initial power numbers made no sense to me in terms of the way the resistor acted though, and that has nothing to do with the performance of the motor. The resistor should heat according to the energy applied to it, i.e. the voltage across it.

Finally it dawned on me. The resistor was preheated in the second run. It started out with a higher resistance, but heated to orange faster, i.e. with less energy. I ran a quick test. Starting out cold it took 8 seconds to heat the resistor to orange. Doing it again, a few seconds later, it took only 3 seconds. The resistor apparently takes a while to cool down even after it is no longer red or orange.

LOOKING FOR BACK EMF

Fig. 5 shows the circuit used previously for the BB motor testing.

```
                    CH1
                     o
                     |
------(-)battery(+)--o---SW----Motor----
|                                      |
|        LED   4.7 k ohms              |
|    ----|<|---R2--------------        |
|    |                         |       |
-----o-----------R1------------o---------
     |       0.0631 ohms       |
     o                         o
  ground                      CH2
```

Fig. 5 - Initial Marinov BB motor test circuit.

This scope lead placement permitted measuring battery potential drop due to the overall load.

The scope test leads are now as shown in Fig. 2, so as to obtain the voltage drop across the motor itself on the scope Channel 1.

```
                    CH1
                     o
                     |
------(-)battery(+)--o---SW----Motor----
|                                      |
|        LED   4.7 k ohms              |
|    ----|<|---R2--------------        |
|    |                         |       |
-----o-----------R1------------o---------
     |       0.0631 ohms       |
     o                         o
     CH2                      Ground
```

Fig. 6 - Circuit for measuring BB motor voltage drop

Using the Fig. 6 circuit the motor moving and stopped runs were made again, with a few minutes cooling time in between. See:

http://www.mtaonline.net/~hheffner/HullVAmotorRun.jpg

http://www.mtaonline.net/~hheffner/HullVAmotorStop.jpg

The traces indicate, upon current stabilization, a voltage drop across the motor of about 2.1 V running, 0.7 V stopped, giving a back emf of about 1.4 V. This then establishes a back emf, and thus the magnetic nature of the motor, as well as Lenz's law at work.

8/14/2009 EXPERIMENTS

The Fig. 6 resistance R1 was increased by adding 4 nichrome shunts, as shown in Photo 1 below. Using the Fig. 6 circuit the motor moving (Photo 2) and stopped (Photo 3) runs were made again, with a few minutes cooling time in between.

The results show a clear back emf effect. The resistors reach a resistance plateau in 2-3 seconds when (and as) the motor runs (See Photo 2), and not when the motor is stopped (See Photo 3). Two of the filaments glowed, the old large blackened one, third filament from the top in Photo 1, and the new one with fewest turns in it, second filament from the top in Photo 1.

The stopped motor current stabilizes at 1.5 V across it or less, the running motor stabilizes at about 2.7 V, giving a back emf of 1.2 V when running.

I don't know why the back emf isn't higher than for the prior run, which had a stopped voltage across the motor of 0.7 V, and running 2.1 V, giving a back emf of 1.4 V. Perhaps the reason is in the prior run the manual start put the motor at a higher rpm than where it stabilizes, but the motor didn't get a chance to stabilize speed because I had to cut it off due to the filament overheating. I don't see how it might have affected this, but I recharged the battery before taking this last set of data.

Photo 1: New probe configuration and shunts added:

http://www.mtaonline.net/~hheffner/HullShunt1.jpg

Photo 2: Traces with motor running:

http://www.mtaonline.net/~hheffner/HullShuntRun1.jpg

Photo 3: Traces with motor stopped:

http://www.mtaonline.net/~hheffner/HullShuntStop1.jpg

I thought one way to validate a back emf is to drive the motor to a higher rpm and look for an increase in the back emf measured. I stuck a half inch round buffing pad on my Dremel tool and stuck it into the partly exposed 1/2" shaft hole in the pulley and revved the pulley and armature up to at least twice normal speed. I expected the back emf to double and that turning on the power would slow down the motor. It didn't slow down when power was turned on. If anything it just ran faster when I closed the power switch than where the Dremel tool set the rpm. It appeared to take much longer for the filaments to heat up though, and the Channel 2 trace in Photo 4 below bears this out, showing the voltage across the current resistor is almost flat at -7 V. The voltage drop across the motor, shown in Channel 1 is nearly flat also at about 2.8 V. The prior run stabilized at about 2.7 V, with the stopped motor voltage drop at 1.5 V. This means the back emf only increased by about 0.1 V over the prior run even though the rpm doubled, and the motor power output apparently doubled, due to doubled rpms, with a *decrease* in overall current draw. The voltage across the current sense resistor dropped from 7.8 V Pk - Pk in the low rpm run to 7.2 V Pk - Pk in the high rpm run.

From my hysteresis model, I expected torque to increase with RPMs to an optimum point where the magnetized material migrates into the current i such that i * M is at peak strength, and then to decline as RPMs increase beyond that point because the material doesn't have time to be magnetized. What I would *not* expect is that the back emf would not change significantly at all even though the RPMs doubled. It also appears *superficially* that the motor power doubled and the heating of the current resistor dropped significantly, even though the voltage across the resistor is measured at 7.20 V Pk - Pk, not too different from the 8.8 V for the stopped motor.

Weird. By starting at a higher RPM, the motor runs faster, system current is less, yet back EMF is unchanged. If the motor were not so inefficient this would be a monumental discovery. The inefficiency and quirky behavior of the hysteresis effect make quantifying individual variables difficult.

Google ("brush drop" volt).

Photo 4: High rpm start, voltage drop traces:

http://www.mtaonline.net/~hheffner/HullShuntHighRPM2.jpg

The cause of the above “anomalous” 3 V or so voltage drop across the motor was identified by Frank Stenger. It is something called "brush drop" caused by the graphite. It is about 0.5 to 1.0 volts per brush, and for two bearings, two sides to each ball, that's 4 equivalent brushes the current traverses to go throught the balls.

Google (“brush drop”)

New steel bearings have been obtained and meaurements of the motor voltage drops will be taken for a magnetic motor without a graphite lubricant.

Figures follow.

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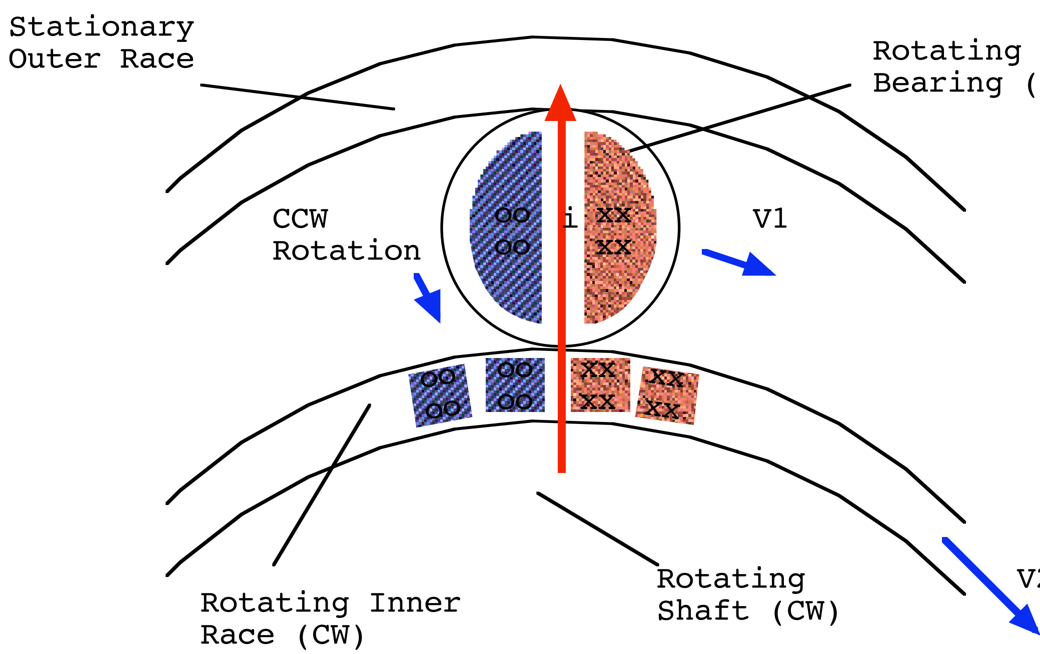

Fig. 3 - Field H from the current i
in the races and ball bearing,
(cross sectional view)