Theory for the Ball-bearing Motor

1. Introduction

Stefan Marinov first brought the ball-bearing motor to people's attention and it has remained a curiosity ever since. This paper offers an explanation for why the motor works based on the transport of angular-momentum by spin-polarized conduction electrons.

2. Theory

When current passes through a steel ball-bearing it creates a magnetic field within the steel. The field lines form concentric circles about the current flow axis as depicted in figure 1.

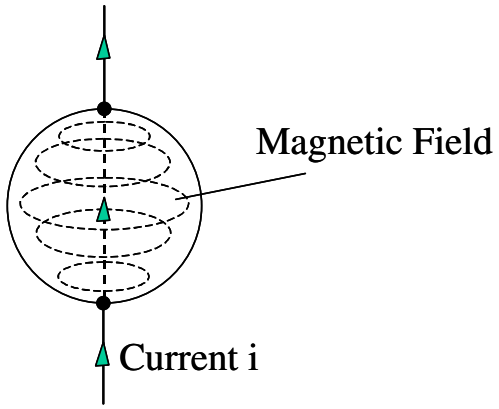

Figure 1. Magnetic field within the ball-bearing

Steel, being an electric conductor, contains mobile conduction electrons that become spin-polarized by the magnetic field. The electron spins align themselves with the field as shown in figure 2. Each electron carries angular momentum by its spin, of value ħ/2 where ħ is Planck's constant 1.0545×10^{-24} joule-seconds.

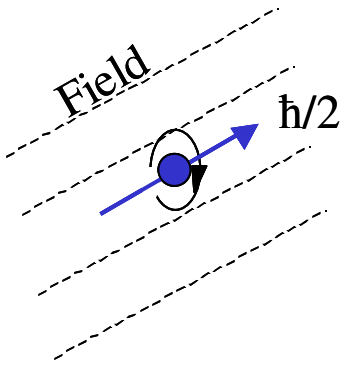

Figure 2. Conduction electron aligns with the field

Of interest are the conduction electrons on the surface of the ball, and in particular on the surface that makes contact with the inner or outer part of the ball-race. Figure 3 shows such a ball with the locus of the contact point across the surface shown in red. The conduction electrons along that line all have their spin aligned with the rotation axis. These spins are shown as blue arrows. Note the reversal of the spin directions on the opposite side of the ball

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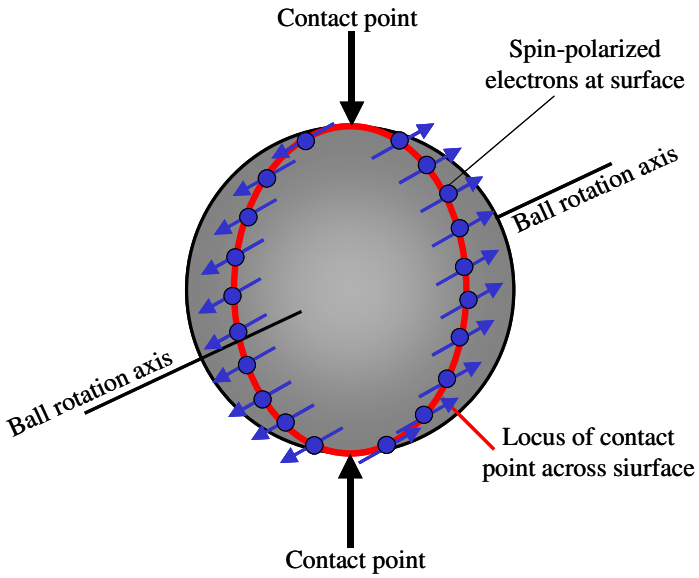

Figure 3. Showing spins along the contact surface

Now let's consider current flowing through the ball while it is stationary. Of course current flow is actually electron flow in the opposite direction. This means that spin polarized electrons can flow out of the ball as shown in figure 4.

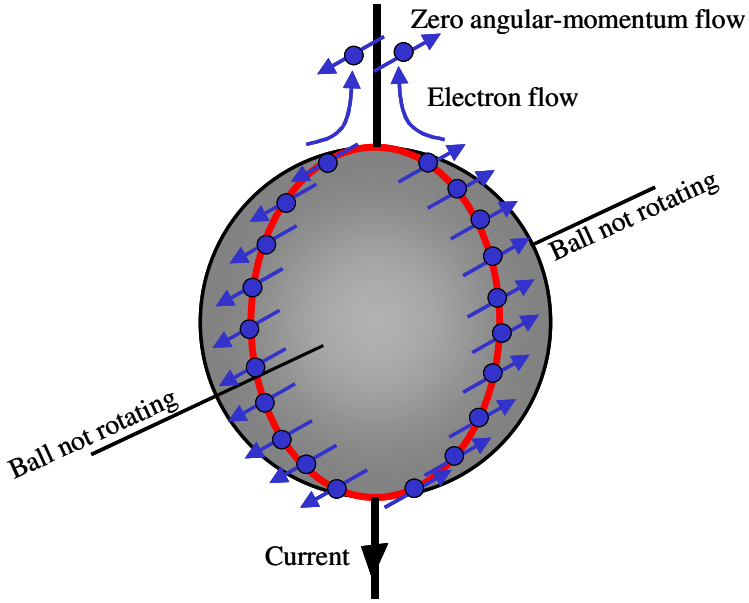

Figure 4. Current flowing through stationary ball.

Because of the symmetry equal numbers of electrons from each side of the ball flow into the next part of the ball-race, hence their angular momentum contributions cancel out, there is no momentum flow. Thus there is no torque produced.

Next let the ball rotate CW as shown in figure 5. Because electron drift velocity is very slow, the surface movement transports electrons faster than that drift velocity, the net result being that electrons from one side of the ball are responsible for the flow. The angular momentum cancellation no longer applies and electrons of a particular spin direction now flow from the ball to the next part of the ball-race.

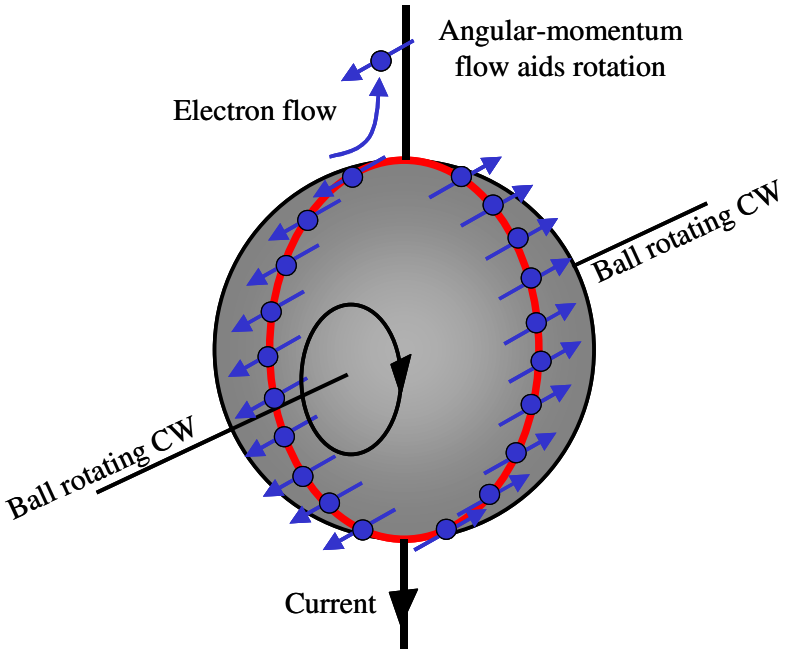

Figure 5. Ball rotating CW.

Since torque is equal to the rate-of-change of angular-momentum a net flow of the latter from the ball induces a torque on the ball in opposition to the electron's spin axis. This drives the other parts of the ball-race in the spin axis direction. Also the net flow of angular-momentum into the outer part induces a torque there in the spin direction. Thus the torques all add to drive the system in the starting direction.

Finally let's consider the ball rotating CCW, figure 6.

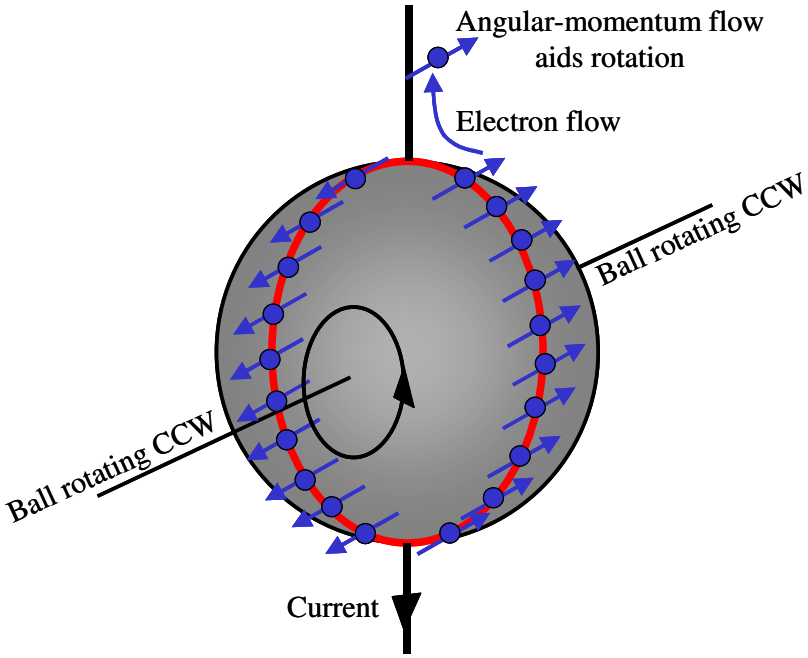

Figure 6. Ball rotating CCW.

Although the electrons leaving the ball now come from the other side, and have the reverse spin direction, it will be seen that the same arguments apply. The torques induced onto the

ball and onto the outer part of the ball-race both drive the system in that reversed starting direction.

3. Discussion

It is interesting to note that under this theory

(a) The balls must be of a conducting ferromagnetic material, non-ferromagnetic won't work.
(b) The motor can run in either direction, as determined by the start rotation.
(c) Because each electron contributes only a small amount of angular momentum, it requires massive current to get any useful torque.

All of these features have been seen in experiments with this type of motor. This bodes well for the theory being correct, but it would be useful if further experiments backed up the theory. If ball-races could be constructed with balls having different degrees of magnetic permeability it might be discovered that the higher permeability balls offer greater torque for a given current and rotation speed due to greater electron spin-polarization. Also combinations of ferromagnetic balls against non-ferromagnetic inner and outer parts of the ball-race could give insight, since the spin-polarized transport across the mating surfaces is enhanced if the other parts are ferromagnetic.

If this theory does hold up it opens the door to other uses of spin-polarized conduction electrons. The movement of these electrons not only represents angular-momentum transport, but also magnetization transport since the electrons also exhibit magnetic dipole moment, and magnetization is simply the volume density of such dipole moments. It is possible that magnetization within permanent magnets made of conducting material can be distorted by electron movement brought about either by electric force acting on their electric charge, that force coming from movement through the magnetic field of a nearby magnet, or by magnetic force acting on their magnetic dipole, that force coming from the non-uniform magnetic field of a nearby magnet. Either way such dynamic magnetization movement has not been recognized by any of the current teachings on magnetism, hence has not been considered as an explanation for seemingly impossible free-running magnetic motors.