Smudge's Halbach Motor Analysis

1. Introduction

It would seem from my FEMM simulations that my Halbach motor doesn't work as a rotary version. However there is little doubt that the linear motor version will work over the movement range where the magnet is alongside the array. On that assumption, in this paper we look into where the energy comes from. Clearly it must arise from the perpetual motions of the particles that make up the atoms within the magnets, and especially the electron orbital motions and spins that account for the permanent magnetism. Here we follow previous practice and account for those perpetual electron motions by replacing them with an equivalent surface current flowing around the magnet. Although this surface current doesn't really exist, treating it as an imaginary current in an air-cored solenoid allows us to see how induced voltage into that imaginary solenoid either takes energy from or feeds energy back to the current source. That current being the combined effect of all the atomic dipoles, those energy exchanges then represent energy flow to and from whatever keeps those electrons in perpetual motion. It allows us to see how the forces that control that microscopic inner atomic world can be made to give up energy to our macroscopic outer world.

2. Equivalent Surface Current

Nussbaum [1] devotes a whole chapter to the equivalent current concept, but here we are only interested in the solenoid equivalent of a permanent magnet. The following image taken from Nussbaum shows the magnetic fields of (a) an air cored solenoid and (b) a permanent magnet.

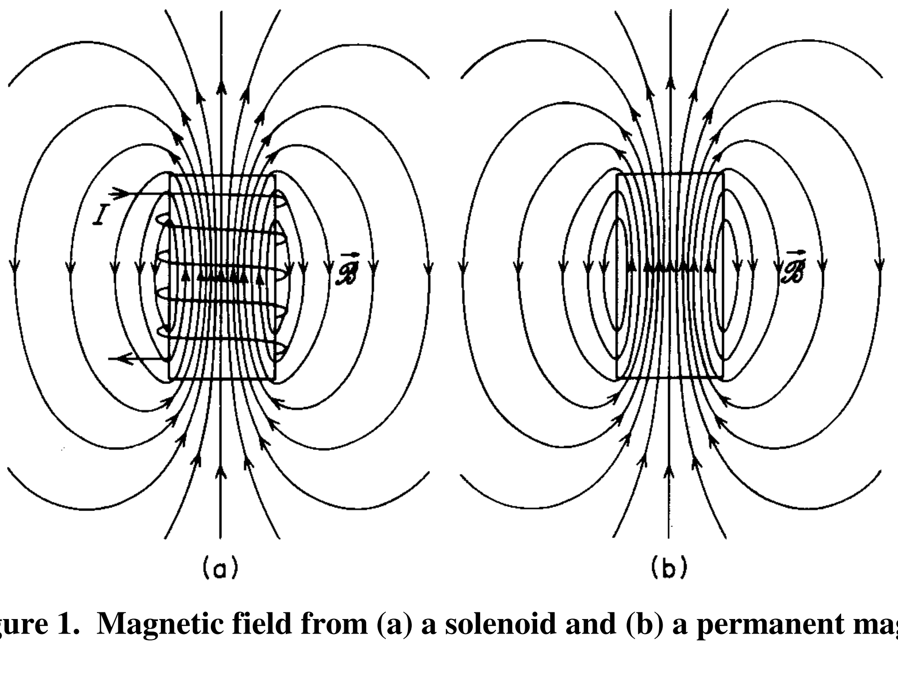


Figure 1. Magnetic field from (a) a solenoid and (b) a permanent magnet

It is seen that the fields are identical showing that the equivalent surface current concept is a valid method for calculating the field from a magnet. But is goes further than that. We now allow the equivalent solenoid to do some work, like pick up a lump of permeable material against gravity. The work done is then *mgh* as shown in Figure 2. Now ignoring any copper loss in the coil (we could use super-conducting material) the source supplying the coil current I will see an induced voltage V due to the increasing field within the coil as the permeable material rises. That voltage represents a load on the current source, the source supplies energy, and the VI power supplied over the time t is energy equivalent to mgh.

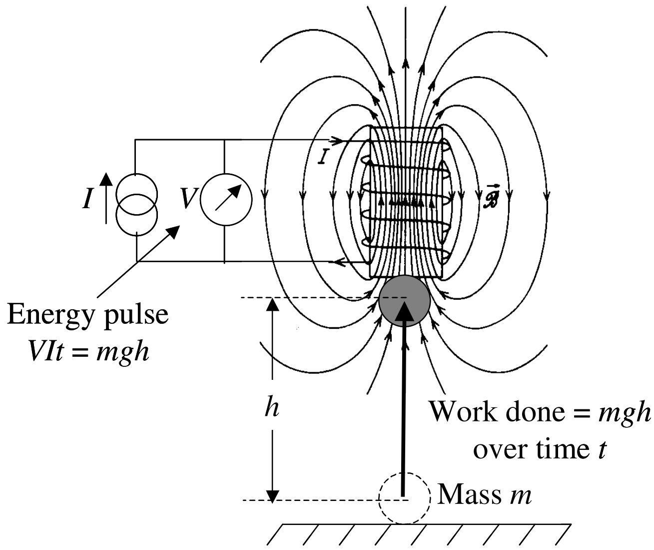


Figure 2. Solenoid doing work

Thus we have a full accounting for the work done, there is no free energy, our current source supplies that energy.

Now when we consider a permanent magnet doing the same work, it is a valid question to ask where the energy comes from.

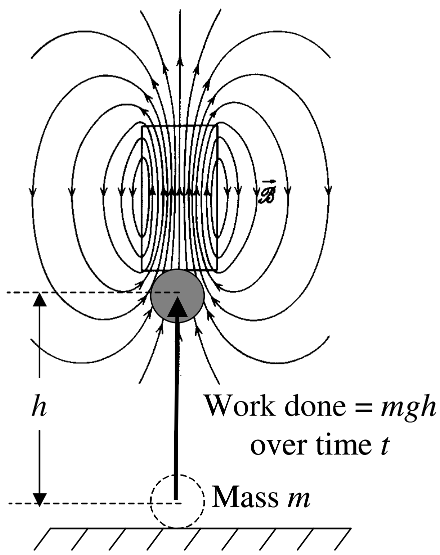


Figure 3. Magnet doing the same work

The magnet will also see an increasing internal field as the permeable material rises, and that will induce voltage into the atomic electron circulations, or rather will induce E field vortices that apply forces to the moving electron charges. Those forces will load the electron circulations attempting to slow them down, which of course can't happen. Whatever is driving those perpetual motions is the source of the energy. Now since the current *I* in the equivalent solenoid represents the net effect of all those atomic electron circulations, then the voltage *V* induced into that equivalent solenoid over the time *t* yields the energy supplied from that inner atomic world. Here we have a means for examining a magnetic motor, placing imaginary coils around each magnet, and seeing where energy is extracted from the atomic domain and where energy is fed back. We can analyse in detail these energy flows, but more importantly we have a method for evolving motor concepts that will work.

3. Analysing the modified Halbach motor.

It is instructive to follow how the standard Halbach array creates fields that are essentially to only one side of the array. Figure 4 shows separately in simplified form the fields that emanate from the transverse magnets in red and the fields from the axial magnets in blue. (Note that we show the magnets as solenoids, the reason for this will become clear later). It is clear that on one side of the array the two fields cancel while on the other side they add.

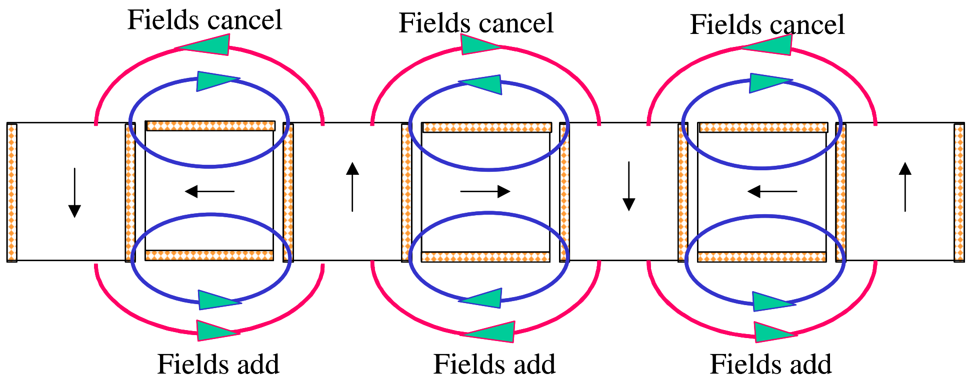


Figure 4. Showing separate fields from transverse and axial magnets.

The resultant fields are shown in simplified form in the next figure.

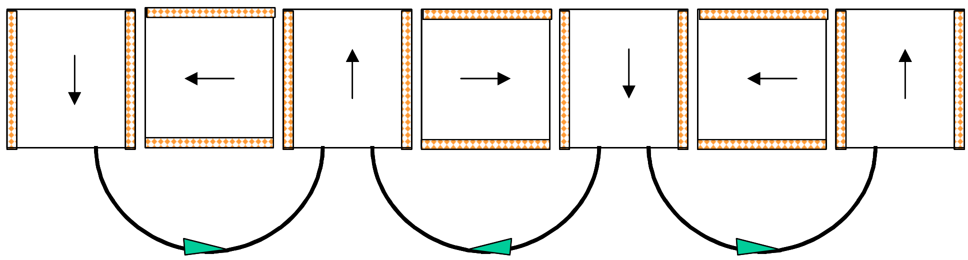


Figure 5. Resultant field for standard Halbach array.

In the modified Halbach array alternate axial magnets are reversed so that all the axial magnets point in the same direction. Hence for those reversed magnets the adjacent field addition and cancellation regions swap sides, resulting in the fields shown in Figure 6.

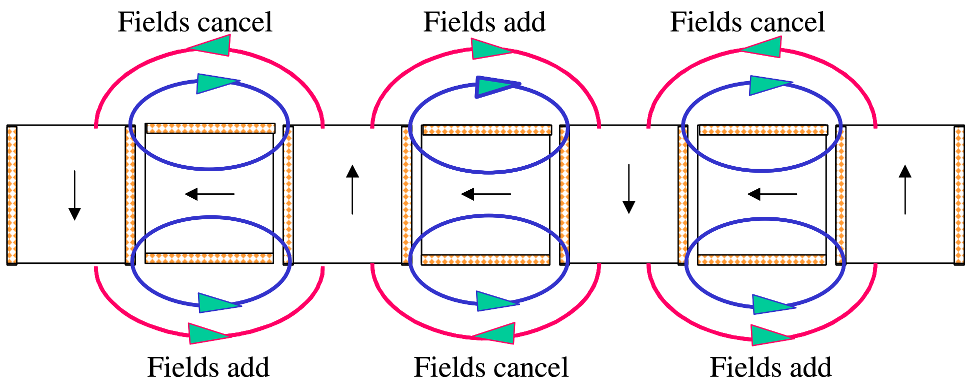


Figure 6. Separate fields for the modified Halbach array.

We then get the simplified fields as depicted in Figure 7.

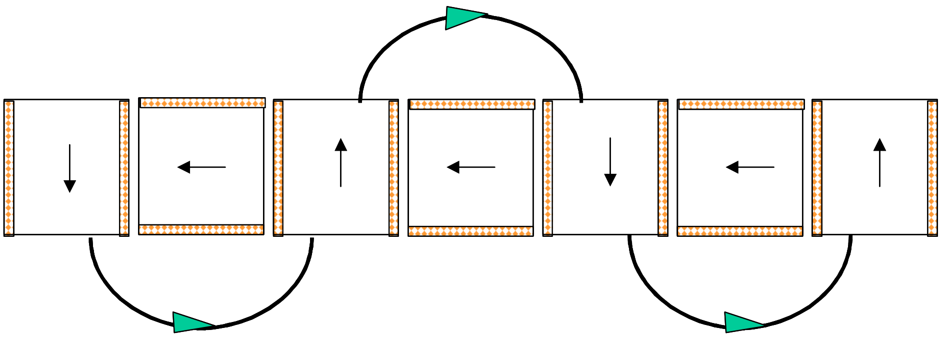
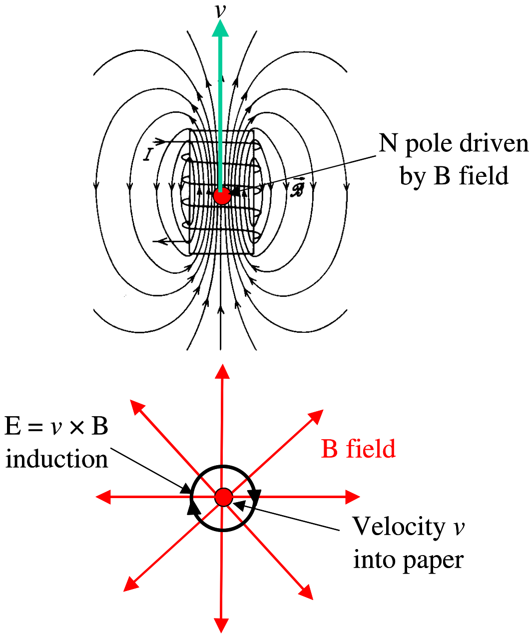


Figure 7. Resultant field of modified Halbach array.

Here we see that on each side of the array all the field regions point in the same direction. It is this feature that allows a magnetic pole travelling alongside the array to receive positive accelerating force impulses with little or no intermediate decelerating forces impulses.

4. Energy exchange with the magnets.

We wish to examine the voltages induced into our imaginary coils around each magnet. There are two forms of induction, (a) induction by the time-changing field within the magnet and (b) motional induction due to magnetic flux lines crossing the conductors. Since we are dealing with moving magnets we must not neglect (b), and that has some surprising results. First let us consider a long solenoid with a magnetic pole moving along its centre line, driven by the internal field, Figure 8. The radial field lines all cut the conductors so as to induce a voltage there, so the coil will see a unidirectional pulse as the pole passes through it. Note that the direction of the induced electric field by Fleming's RH rule (the $\mathbf{E} = \mathbf{v} \times \mathbf{B}$ motional induction) opposes the current drive, thus applying a load to the current source. The kinetic energy gained by the moving pole is accounted for by the energy extracted from the current source. Of course this circular induction is well known as demonstrated by the often repeated experiment of dropping a magnet through a vertical copper pipe where the N and S poles each induce circular eddy current around the pipe, Figure 9. Here the currents induced into the pipe create their own magnetic field that applies a force to the magnet opposing its motion.



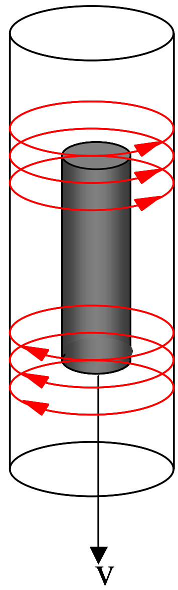


Figure 8. Pole moving within solenoid **Figure 9. Magnet falling through tube**

The question to be asked now is “will a magnetic pole passing along the *outside* of a solenoid induce voltage into the coil?” The answer is yes, see the derivation in the Annex. Figure 10 shows this situation where now the pole is now driven by the external field (in the opposite direction to the internal field). The direction of the induced voltage again loads the current source fully accounting for the kinetic energy gained by the moving pole.

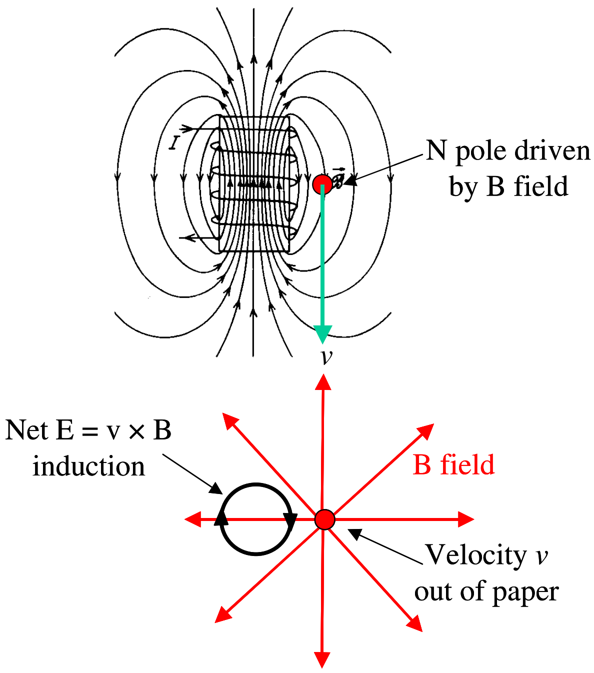


Figure 10. Pole moving alongside a solenoid.

With that knowledge we can look at a magnetic N pole travelling alongside the array of Figure 7, and we can see how its field has components along each solenoid’s axis and how that field is changing with time. That tells us the polarity of the voltage induced into the solenoidal coil, and that tells us whether the voltage loads or feeds energy back to the current source. We initially consider the movement from magnet A to magnet C where the pole is receiving an accelerating force, Figure 11. Initially magnet A sees a field from the N pole that opposes its own field and that opposing field reduces as the pole moves away. Initially axial magnet B also sees a field component that opposes its own field and that opposing field also reduces until the pole reaches the mid position as illustrated when the component changes to an increasing supporting field. Alternatively we can deduce the induction in magnet B from the pole movement. Magnet C sees an increasing field component supporting its own field. In all three cases the voltage induced into the imaginary solenoids is of a polarity to load the current sources, the sources all give up energy that accounts for the mechanical work done by the moving pole.

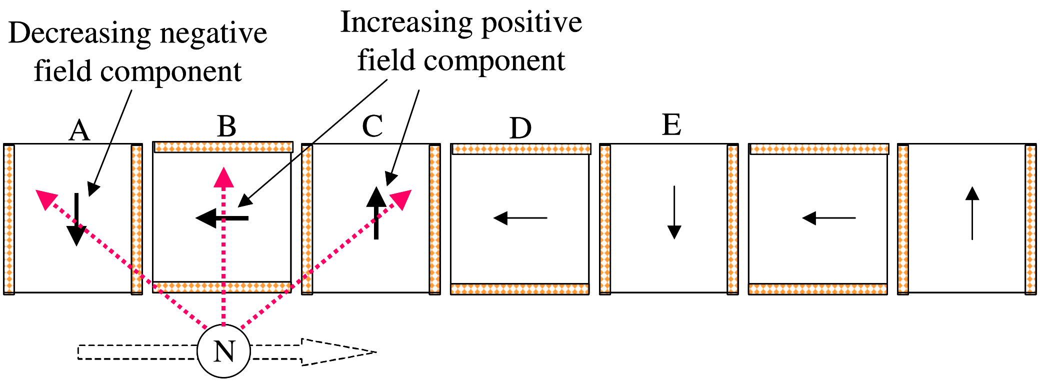


Figure 11. Pole receiving accelerating force

Next we look at the pole moving from C to E where it receives little or no decelerating force.

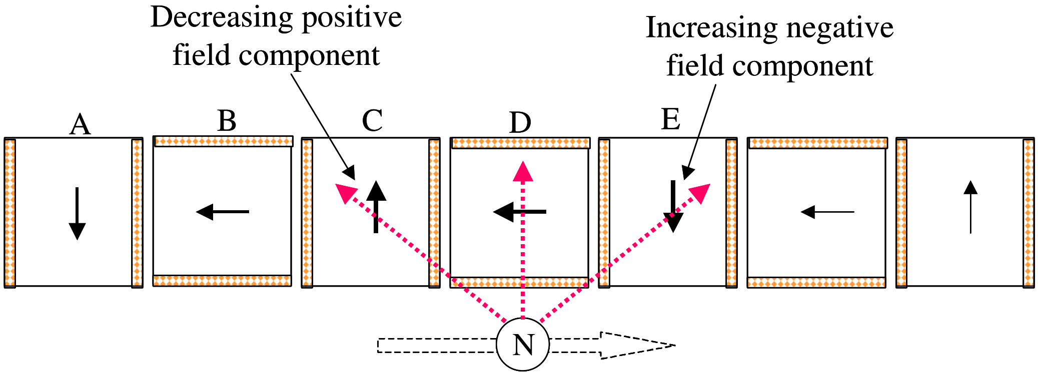


Figure 12. Pole receiving little force

As before the axial magnet D is giving up energy, but the transverse magnets C and D see changing field components that are of a polarity to feed energy back to the current sources. If magnet D had a reversed magnetization (as in the standard Halbach array) then all three magnets C, D and E would be receiving energy supplied by the moving pole, and the pole would have to do work to supply that energy equivalent to the energy gained previously. In this modified array magnet D is supplying energy that doesn't reach the pole, it gets absorbed by magnets C and E. and that accounts for the reduced counter force on the pole in this region. Taking the two movements together the net result is a unidirectional force where the work done is fully accounted for by energy supplied from the atomic current circulations (atomic dipoles) within the magnets.

5. Conclusion

By considering the atomic dipoles responsible for permanent magnetism as tiny current loops, where induction from the field passing though or passing by each loop can either load (extract energy from) or feed energy back to the loop driving force, we obtain a full reconciliation for the energy supplied to a magnetic pole moving alongside a modified Halbach array. The same approach can be used to reconcile the apparent free energy obtained from other known forms of magnetic motor. In all cases each atomic dipole within the permanent magnets can be considered as a form of quantum dynamo, where the power is obtained from whatever keeps those electrons moving or spinning. Induction into those atomic current loops or circulations follows classical known principles of motional and transformer induction, albeit over tiny loop areas. The equivalent surface-current concept, where each magnet is replaced by an imaginary solenoid carrying that surface-current, and where the induced voltage can be deduced from the field movements, allows each magnet to be analysed to see how the atomic dipoles there supply or extract energy. This simple approach takes the mystery out of how and why magnetic motors work, demonstrates the source of the anomalous energy and should allow for better magnetic motor design.

References

[1] Electromagnetic Theory for Engineers and Scientists by Allen Nussbaum, Prentice Hall Inc.

Annex 1.

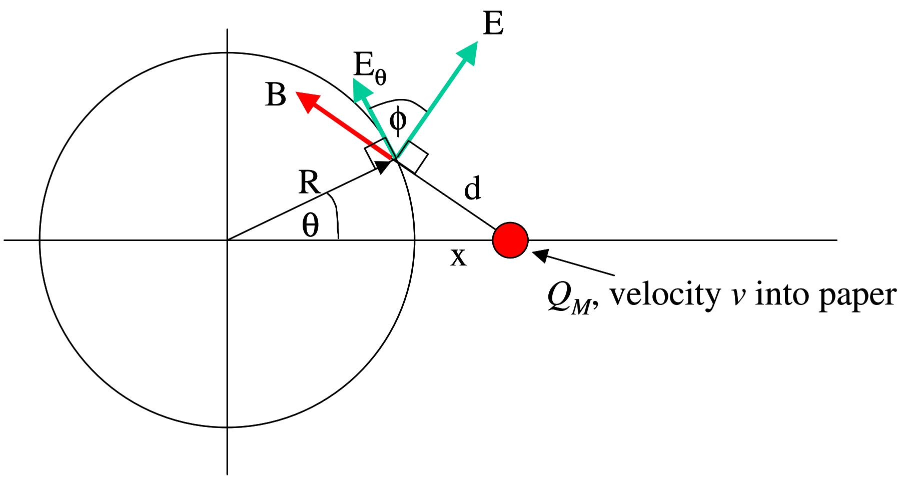


Figure A1. Magnetic pole passing by a current loop.

Figure A1 shows a circular loop or radius R with a magnetic N pole of magnitude Q_M outside the loop and at a distance x from it. Taking a small element δR at an angle θ we obtain the **B** field magnitude at that point as

$$B = \frac{Q_M}{4\pi d^2} \tag{1}$$

By the cosine rule d^2 is given by

$$d^2 = R^2 + (R + x)^2 - 2R(R + x)\cos\theta \tag{2}$$

The pole movement (into the paper) at velocity v gives rise to an E_θ field component along δR directed as depicted in the figure, of magnitude

$$E_\theta = vB\cos\phi \tag{3}$$

By the sine rule

$$\sin\phi = \frac{(R + x)\sin\theta}{d} \tag{4}$$

The voltage induced into the element δR is $E_\theta \delta R$ and the total voltage induced into the loop is

$$V = 2\int_0^\pi E_\theta R.d\theta \tag{5}$$

To avoid my 87 year old brain from damage in trying to solve the full integral I did this in MS Excel summing the voltage increments $E_\theta \delta R$ for ½ degree increments. The result is clearly non zero as the positive voltage induced into the elements closest to the pole far exceeds the negative voltage induced into the elements furthest from the pole.

A magnet moving along the outside of an infinitely long solenoid will induce voltage that cannot be accounted for by flux change (transformer induction), but is accounted for by flux cutting (motional induction).