A SIMPLE ROLLING HOMOPOLAR MOTOR

Seán M. Stewart*

The Petroleum Institute
PO Box 2533
Abu Dhabi
United Arab Emirates
sstewart@pi.ac.ae

6 August 2006; Revised 8 August 2006

ABSTRACT

The ready availability of very strong permanent magnets in the form of rare-earth magnetic alloys such as neodymium-iron-boron has lead to renewed interest in one of the oldest types of electric motors – the homopolar motor. The ease with which a demonstration homopolar motor can now be built and operated when neodymium magnets are used is quite remarkable. In this paper two recent types of simple homopolar motors relying on the use of neodymium magnets are reviewed. Recent improvements proposed and demonstrated by the author to the latter 'homopolar roller' type are also described and discussed.

Keywords: Homopolar motor, homopolar roller, neodymium magnets

INTRODUCTION

Simple electric motors are always sure to please. First invented in 1821 by the famous ninetieth century English scientist Michael Faraday (1791–1867), he built a type of electric motor which nowadays is referred to as a *homopolar* motor [1]. In essences such a motor consists of a conducting disc in the neighbourhood of a permanent magnet that is free to rotate.[1] A source of direct current is then allowed to pass through two arbitrary points on the disc. A well-known early example of such a motor, which until quite recently was a familiar demonstration apparatus in many a physics laboratory, was the *Barlow Wheel* [2, 3], first conceived and built by Peter Barlow (1776–1862) in 1822 [4].

In contrast to most dc motors found today where commutators are used to reverse the direction of current flow in order to maintain continuous rotation, a homopolar motor is able to produce continuous rotation without the need for any such reversal in current. In fact, it is from its very means of operation that the motor takes its name. Requiring only the same electric polarity for its operation, substituting the word 'same' with its Greek equivalent *homos* one arrives at the name homopolar. Occasionally a homopolar motor may also be referred to as *unipolar* for similar etymological reasons.

The cheap and ready availability of very strong permanent magnets in the form of rare-earth magnetic alloys such a neodymium-iron-boron (NeFeB); so-called neodymium magnets; has lead to renewed interest in the design and construction of new forms of ever simpler homopolar motors. Replacement of the conducting disc used in a homopolar motor with a conducting disc which produces a magnetic field of

*Discussions held with Jorge Guala-Valverde from the *Fundacion Julio Palacios* are gratefully acknowledged.

[1] Faraday's original 1821 motor consisted of a rigid straight wire hung vertically. Its upper end was free to rotate while its lower end was dipped into a pool of mercury. Positioned in the centre of the pool of mercury was a permanent magnet. On passing current through this arrangement the hanging wire rotated about the magnet.

its own, as first suggested by Thomas Strickler [5], allows for a fortuitous simplification in the design of a homopolar motor particularly when coupled with the use of strong neodymium magnets.

Below, two very recent examples of simple homopolar motors are described. For convenience, each of the two types described in this paper will herein be referred to as either a 'dangling' or a 'rolling' type.

THE SIMPLE 'DANGLING' HOMOPOLAR MOTOR

In the dangling homopolar motor [6, 7], one side of a small neodymium disc magnet is stuck to the level head of a ferromagnetic screw. The screw, in turn, becomes magnetised owing to the strength of the neodymium magnet. The pointy end of the screw can now be stuck to the bottom terminal of a D-cell battery where it hangs freely under gravity since the battery's casing is ferromagnetic and provides a very low friction connection between the hanging magnet and the battery. If one end of a copper wire is pressed against the top terminal of the battery using your finger, brushing the other end of the wire against the rim of the disc magnet completes the circuit and not only causes current to flow but leads to a spinning in the disc (see Figure 1).

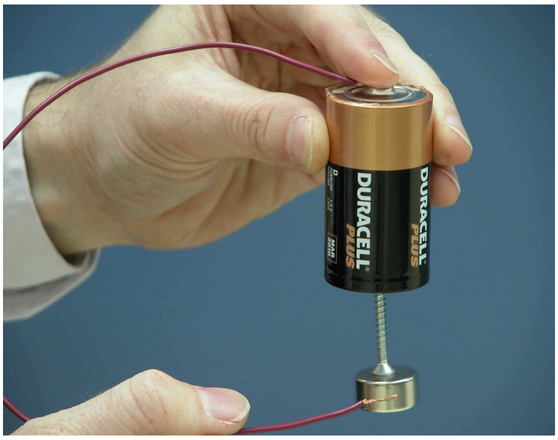

Figure 1: Construction used for a simple homopolar motor of the dangling type.

So what causes the disc to rotate? Referring to Figure 2, on brushing the wire up against the rim of the disc magnet, current flows over its chrome-plated surface to the central connection point at the head of the attached screw. As the disc magnet itself now takes on a current-carrying function, a Lorentz force acts tangentially to the inwardly flowing current in accordance with the right-hand rule. Hence a resultant torque acts on the disc about the axle formed by the attached screw and causes the disc to spin (for directions, refer to Figure 2). It is important to recognise that the disc magnet will only rotate provided it is mechanically decoupled from the closing wire as relative motion between the two is necessary [8]; a fact that can be readily verified experimentally by taping the end of the wire to the rim of the disc magnet. Importantly, brushing the wire up against the rim of the disc magnet allows the latter to slide pass the former whilst maintaining electrical contact between the two.

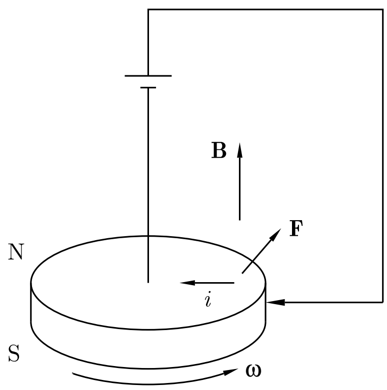

Figure 2: Current, magnetic field and magnetic force directions. Here the exerted torque causes the disc to rotate in an anti-clockwise direction when viewed from above.

A simple upright version of the above dangling type is also possible [9]. Here a spherical neodymium magnet is used in place of the disc magnet such that the magnet is set spinning on the top terminal of a battery on closing the circuit with a hand-held wire. It is also possible to change the basic elements of the motor which actually rotate with suitable modification. In one refinement, the connecting wire rather than the disc magnet can be made to rotate [10, 11].

In another, both the battery and the disc magnet rotate while a connecting copper wire frame in the form of a tripod remains stationary [12]. Both of these later refinements are completely hands-free.

THE SIMPLE 'ROLLING' HOMOPOLAR MOTOR

A more recent incarnation of the homopolar motor using neodymium magnets is of the rolling type. While not a completely new idea in itself [13, 14], it was Sugimoto and Kawada who showed most elegantly how the former spin of the dangler could become a roll [15]. This is achieved by sticking two neodymium disc magnets to either terminal of an AA battery. The electric circuit is completed by placing the entire arrangement onto a flat conducting surface (or conducting rails) from where it is observed to roll. Torques act on each of the disc magnets in a manner identical to those described previously for the dangler with the exception that the conducting surface replaces the connecting wire. In order to get both of these torques to act in the same sense so that rolling can occur, it is necessary to orientate each end magnet so that like poles face one another.

In my own efforts to reproduce Sugimoto and Kawada's homopolar motor, I was led to make a small design modification which not only greatly improved upon the speed of rolling attainable, but also allowed for the arrangement to roll over a non-conducting surface [16]. I found that in attempting to get the double disc magnet and battery arrangement to roll over a conducting surface, not only was it difficult to ensure good electrical contact between the conducting surface and the disc magnets (chemical polishing of the surface was necessary), but the resulting motion was in turn significantly impeded by the effects of magnetic breaking resulting from eddy currents induced within the conducting surface itself.

Problems associated with ensuring good electrical contact and avoiding unwanted magnetic braking effects can both be overcome if the arrangement were to roll over a non-conducting surface. But how is one to complete the circuit between the two disc magnets at either end of the battery while not preventing the entire arrangement from readily rolling? Why with a wire of course! By fashioning a short piece of stranded copper wire into a U-shape, sufficient electrical contact between the upper rim of each disc magnet and the wire can be maintained by moulding either of its ends into an arc of a circle (see Figure 3). Placing the ends of the U-shaped wire onto the upper rim of either disc magnet completes the circuit and causes a current to flow. With the arrangement placed on a smooth horizontal surface, the resultant torques acting on either wheel cause the double disc magnets, battery, and U-shaped wire to happily roll at a comfortable walking pace over a reasonable distance before the connecting wire becomes dislodged.

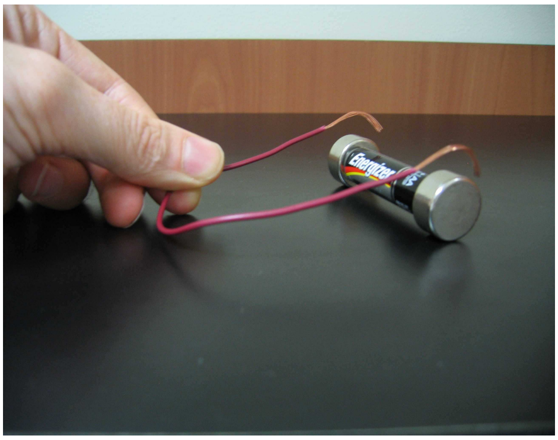

Figure 3: Construction used for a simple homopolar motor of the rolling type.

As with the dangling type, relative motion between the disc magnets and the connecting U-shaped wire in the rolling type motor is again maintained as the arrangement rolls. Free rotation in the U-shaped wire, is, however, prevented by the floor while free rotation in the discs is possible and leads to the observed rolling motion.

A short video clip showing the simple homopolar roller in action can be found either on *The Maxwell Society* website at `www.maxwellsociety.net` or on the *Foudacion Julio Palacios* website at `www.fjp.org.ar`

REFERENCES

[1] M. Faraday, “On some new electromagnetical motions and on the theory of magnetism,” *Quarterly Journal of Science*, **12**, 74–96 (1821).

[2] Richard M. Sutton, *Demonstration Experiments in Physics* (American Association of Physics Teachers, College Park, MD, 2003), No. E-136, p. 306.

[3] Harald C. Jensen, “A modified Barlow’s wheel,” *American Journal of Physics*, **21**(9), 692 (1953).

[4] The original sketch of the wheel accompanied a letter Peter Barlow sent to Michael Faraday in March of 1822. See `www.scienceandsociety.co.uk`

[5] Thomas D. Strickler, “Variation of the homopolar motor,” *American Journal of Physics*, **29**(9), 635 (1961).

[6] Christopher Chiaverina, “The simplest motor?” *The Physics Teacher*, **42**(9), 553 (2004).

[7] H. Joachim Schlichting and Christian Ucke, “Der einfachste Elektromotor der Welt,” *Physik in unserer Zeit*, **35**(6), 272–273 (2004) [in German].

[8] Jorge Guala-Valverde, Pedro Mazzoni and Ricardo Achilles, “The homopolar motor: A true relativistic engine,” *American Journal of Physics*, **70**(10), 1052–1055 (2002).

[9] David Kagan, “Upright homopolar motor,” *The Physics Teacher*, **43**(2), 68 (2005).

[10] Simon Quellen Field, “Electromagnetism: A 10 minute railgun,” `scitoys.com` (2005).

[11] David Featonby, “Inspiring experiments exploit strong attraction of magnets,” *Physics Education*, **41**(4), 292–295 (2006).

[12] Dave Keenan, “Homopolar ‘balancing battery’ motor improvement,” `scitoys.com` (2005). Is available from `scitoys.com/board/messages/8/1257.html?1128906028`

[13] A. Serra-Valis and C. Gago-Bousquet, “Conducting spiral as an acyclic or unipolar machine,” *American Journal of Phsyics*, **38**(11), 1273–1276 (1970).

[14] Bill Layton and Martin Simon, “A different twist on the Lorentz force and Faraday’s law,” *The Phsyics Teacher*, **36**(8), 474–479 (1998).

[15] Norihiro Sugimoto and Hideo Kawada, “The homopolar motor and its evolution,” *The Physics Teacher*, **44**(5), 313 (2006).

[16] Seán Stewart, “The homopolar motor rolls on,” *The Physics Teacher* (submitted for publication).