SmartDrive Motor

Converting a Fisher & Paykel Washing Machine Motor

by Nenad Stojadinovic

Recycled smart drive washing machine motors have been used in countless projects. They can be found in wind turbines, water turbines, and every other type of generator imaginable. This article takes a radical new direction and uses a Fisher & Paykel SmartDrive as . . . *a motor*.

Why would you want to use a SmartDrive as a motor? Possibly you drooled at the possibilities presented by the pan-cake motor used in our eBike article featured in the November 2011 issue.

But that motor has a maximum power output of a few hundred watts, depending on how its controller is programmed.

What if you could use a recycled motor of the same general configuration but with a power output which might peak at 1kW or more?

The SmartDrive used in Fisher & Paykel washing machines is just such a motor. In fact, it is the only such motor which you can pick up either free from roadside clean-ups (ie, in discarded washing machines) or cheaply from recycling centres.

Of course, the SmartDrive is already a motor. What's the point in converting a motor into a motor? Well, apart from its potentially high power output, this motor can be smoothly controlled over a very wide range, up to 1200 RPM.

In Fisher & Paykel washing machines, the SmartDrive dispenses with a gearbox and runs both the wash/rinse cycles and the spin cycles.

But aside from the fact that the SmartDrive motor runs on awkwardly high voltages, it is a class of machinery that comes perilously close to being a computer peripheral, or at least a symbiotic component of a computer.

In this case, the computer is firmly built into a washing machine and having to build a big white box into every project can put a cramp on any young tech's style.

Coil Input	Hall Outputs YBG
A+ B-	0 0 1
A+ C-	0 1 1
B+ C-	0 1 0
B+ A-	1 1 0
C+ A-	1 0 0
C+ B-	1 0 1

Table 1: the six-step commutation sequence with Hall Effect outputs.

Those clever Kiwis

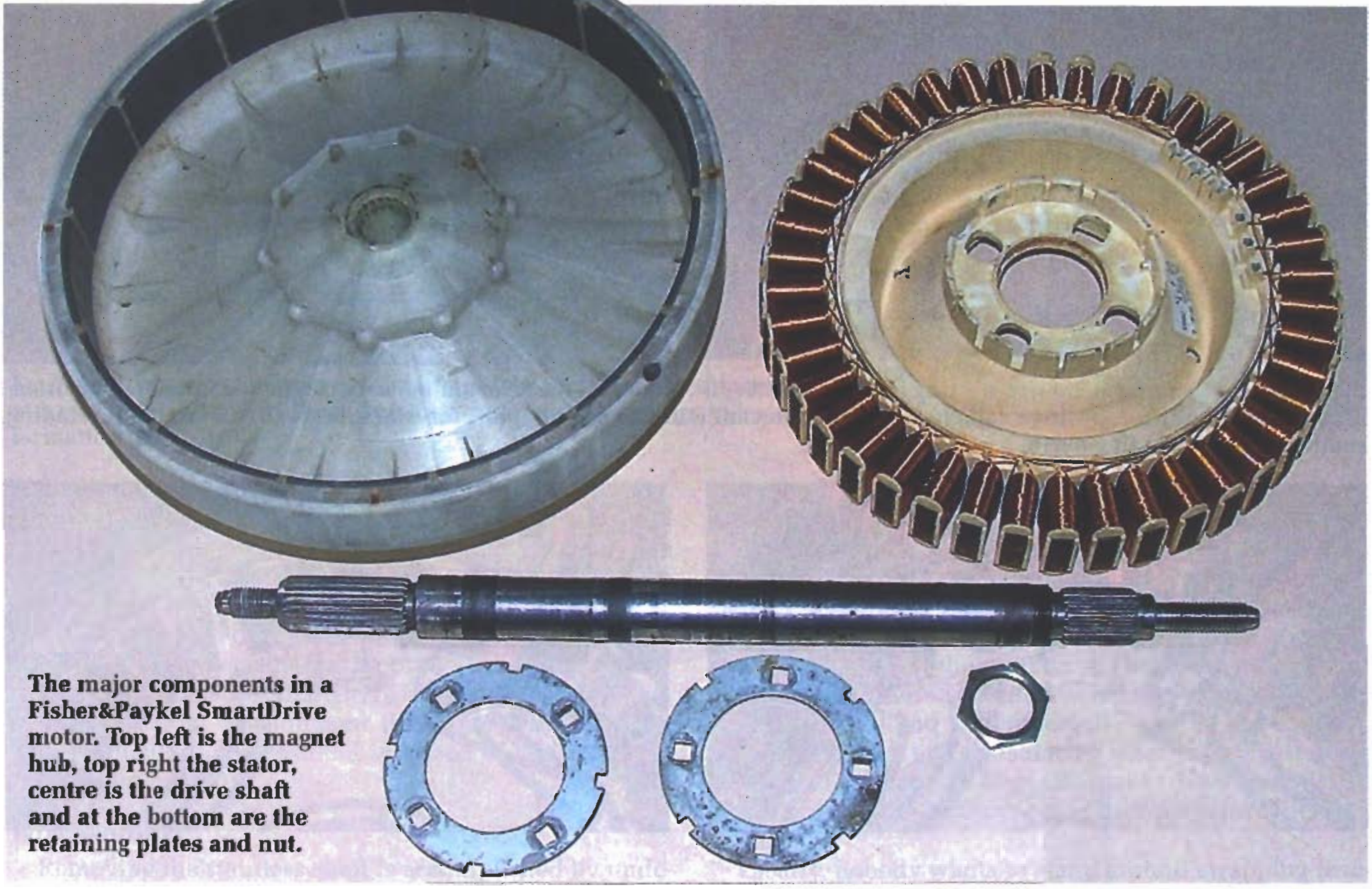
You have to hand it to the Kiwis: the Fisher & Paykel "SmartDrive" is certainly a clever device. In an era where washing machines were powered by conventional single phase induction motors driving a gearbox, the introduction of a microprocessor-controlled, direct drive motor was a great innovation. It has been proved in untold numbers of washing machines over the years and there are now recycling centres full of machines that have been scrapped but still having a perfectly serviceable motor.

The mountains of SmartDrives laying around have not been missed by the tech community and there are countless versions of every type of generator using the SmartDrive as a core.

To our knowledge though, there have not been any devices featuring the SmartDrive as a motor. This is no surprise; at the first sight of a motor with three fat power cables and no less than five control leads, you quickly realise that using it in your particular application might not be a 5-minute conversion.

The SmartDrive can be thought of in two ways: as a huge stepper motor wired in a 3-phase star configuration with a fixed stator (the central non-rotating part) and a hub (the rotor) with embedded magnets.

The stator consists of 42 poles (each a



The major components in a Fisher&Paykel SmartDrive motor. Top left is the magnet hub, top right the stator, centre is the drive shaft and at the bottom are the retaining plates and nut.

coil with a laminated steel core) and is 250mm in diameter. The hub has 56 magnets embedded in plastic and with hidden steel laminations to complete the magnetic circuit.

Or you can regard it as a variable speed, synchronous AC motor or a 3-phase permanent magnet motor. It is also known as brushless DC (or BLDC).

It is not an induction motor. Typical induction motors that run on 3-phase 415VAC have no permanent magnets. Instead they have a series electromagnets arranged in a circle, each connected to a separate phase of mains power, to produce a rotating magnetic field. The magnetic field then induces currents in the rotor which consequently generates its own magnetic field, and the interaction of the magnetic fields then drags the rotor around.

An induction motor always has "slip" which is the difference between the speed of the rotating magnetic field (the "synchronous" speed) and the actual motor speed.

3-phase permanent magnet motors are driven by DC and are completely dependent on their driver, without which they sit there and smoke. The motors have wound coils like the induction motor but those coils are energised by DC from a microcontroller.

As noted above, the process is very much like a stepper motor (see Fig.1) and is referred to as electronic commutation.

Note that each winding is polarised north at one step and south at another so that a full cycle has three phases multiplied by two polarisations which equals six steps. The drive sequence is thus called a 'six step commutation sequence' and is as given in Table 1 – ignore the Hall Effect column for the moment.

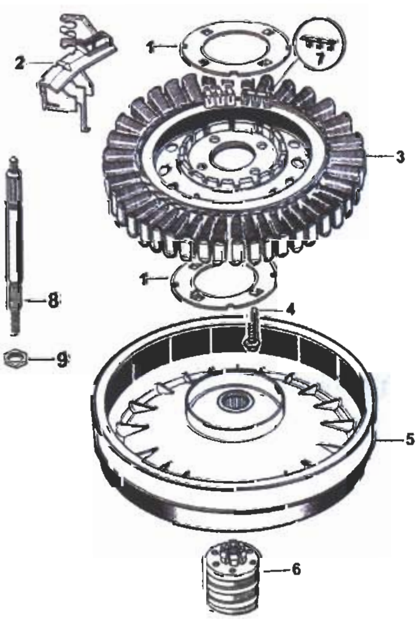
And that's why it is very easy to use a SmartDrive as a generator and so very difficult to use as a motor.

In a generator, the force supplying the rotation (be it from a wind or watermill, etc) simply swings the magnets past the wound coils to generate a voltage in the classic way which we all desperately swotted up before the final year 12 science exam.

Pick up and rectify the generated power as necessary and you're done.

Driving the motor is a vastly more complex matter of monitoring the exact position of the rotor as it goes around and switching current to the appropriate winding at exactly the right instant.

There are two main ways of monitoring the rotor position. Small motors generally monitor the voltage in windings that are not currently energised, the idea being that a rotor magnet will go past the winding and generate a little pulse



Exploded view of the motor, from the F&P service manual. Most of these parts can be seen in the photo above.

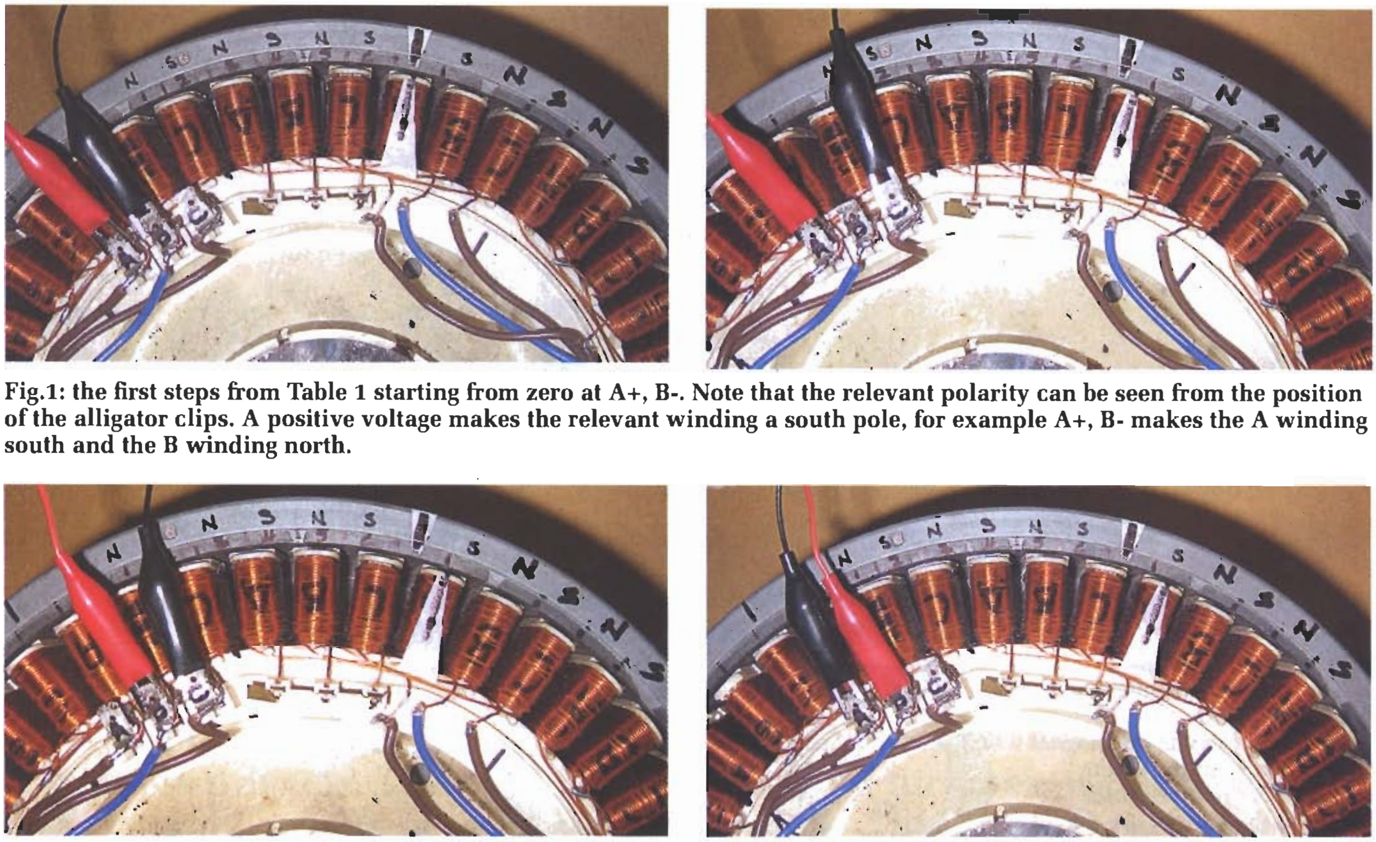


Fig.1: the first steps from Table 1 starting from zero at A+, B-. Note that the relevant polarity can be seen from the position of the alligator clips. A positive voltage makes the relevant winding a south pole, for example A+, B- makes the A winding south and the B winding north.

of voltage that can be detected by the controller.

A bit of fancy maths and the controller will have a very good idea of the rotor position but only once the motor is moving. Without rotor movement there are no voltage pulses so starting up can be a bit problematic.

Larger motors use Hall Effect sensors and these little fellows will report the rotor position all the way down to zero speed.

Modern sensors used in motors are minuscule surface mount chips that output say 5V when facing a north pole and 0V when facing south.

First catch your ~~hare~~ SmartDrive

Having said that dumped washing machines are available in huge piles, I have to admit that I couldn't find one to scavenge and ended up placing a wanted ad in the local free classifieds web site.

That did the trick but I have to warn anybody following this path that one is likely to trigger an avalanche that is not easily stopped.

It seems that everybody knows somebody who has junk to be gotten rid of and is very happy to find someone who is happy to do it, especially for free.

My wife threatened dire consequences and so I ended up with only three complete motors, a very nice pump from a commercial dishwasher, a wood lathe that I later turned into a centrifuge, a refrigerated air dryer and a compressor powered not one but two 15kW motors (don't ask!).

On reflection, it may be easier to simply ring a washing machine repairman and offer to buy a motor – the going price is around $30 – or else keep an eye on the appliance section of the classifieds.

eBay is perhaps another source but you'll probably find anyone who has removed a SmartDrive motor to put on eBay knows that it is worth a few bob (eg, $50-$60!).

The SmartDrive is classed as an "outrunner", meaning that the outside of the motor rotates and is thus the rotor. Tipping the machine onto its side and spinning the plastic rotor, you will see the washing drum rotating in unison. The rotor has a total of 56 magnets and the magnets are contained in strips that are magnetised NSNS (see Fig.2).

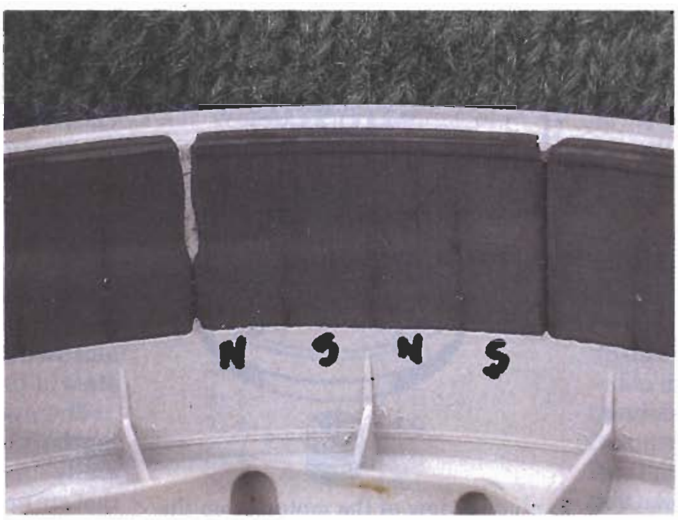


Fig.2: each strip consists of four magnets. You can just see the lines between them.

Having removed the rotor you will see the stator which is secured by four self tapping bolts.

If you count them, the stator appears to consist of 42 wound coils but closer examination shows that they are really three coils that are each made up from 14 coils

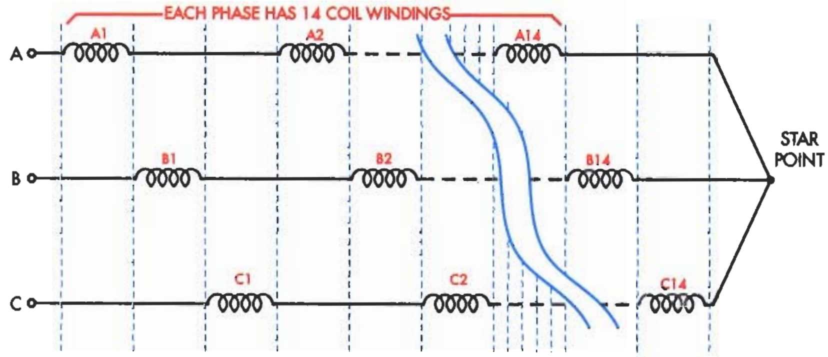


Fig.3: each phase is fourteen coil windings in series terminated together at a star point. Normally these drawings portray the windings in a star formation (like Fig.7).

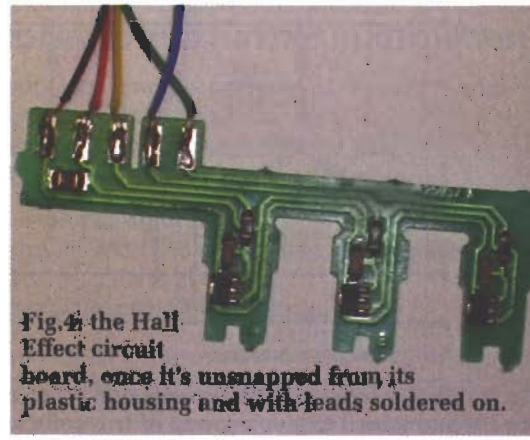


Fig.4: the Hall Effect circuit board, once it's unsnapped from its plastic housing and with leads soldered on.

connected in series (see Fig.3) and terminated in a star point.

Motors are made up this way to decrease their speed and increase their torque. With 56 magnets and 42 coils, each step is tiny and a sequence of six steps will only take the rotor around by a fraction of a turn (look closely at Fig.1). But the torque will be high as each energised coil winding will be attracting a magnet that is only a small distance away.

Don't think that the SmartDrive is slow though; the story goes that during development the motor was tested for maximum speed and resulted in a load of laundry being turned into confetti!

Disassembly

Removing the stainless shaft is accomplished by undoing all of the nuts you can see and pushing the shaft out. It only takes a gentle tap with a soft mallet to get it moving and if you find that it won't go, keep looking for more nuts around the shaft.

There is a little carrier for the Hall sensors. I found it was easy to take off once the rotor was removed and it simply slides out to reveal the circuit board as shown in Fig.4.

Stepping Motor

Once you have the motor mounted so that it will rotate, it's time to take it for a basic test run.

Fig.1 shows the input terminals arbitrarily marked as A, B & C and I also went around and labelled all of the coils in the same way.

I used a series of three 12V batteries to give 36V and applied power to the input terminals in the order shown in Table 1, where A+, B- means to connect A to positive and B to negative.

If you follow the sequence, you will find that the motor steps smartly around and you may also find that you get a bit of a zap from the terminals. That's called inductive kick back and now you know what that term means in a way that you'll find hard to forget!

Standing back and considering what you've just done, you'll realise that you have effectively driven the SmartDrive as a stepping motor; a very useful device in its own right.

Clearly, nobody wants to stand around swapping leads all day but everything else is in place, so the only barrier between you and a high-powered stepping motor is to find some way to drive the motor electronically.

A schematic version of what is desired is shown in Fig.5. Simply closing switches A(high), B(low) will cause the motor to take the first step on Table 1 and then opening B(low) and closing C(low) will take the next step and so on.

Reversing the order of switching will make the motor run in reverse.

Building up the schematic using real switches will give you quite a handy little motor tester but most people will want to replace the switches with Mosfets and drive them with a suitable microcontroller, perhaps an Arduino or Picaxe.

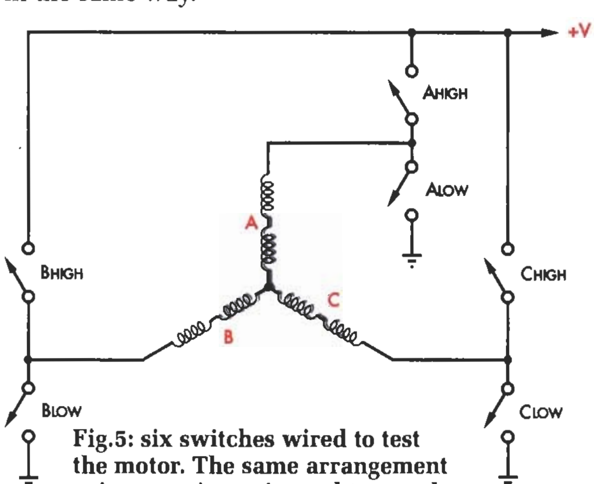


Fig.5: six switches wired to test the motor. The same arrangement using transistors is used to run the SmartDrive as a stepping motor or as a full BLDC motor.

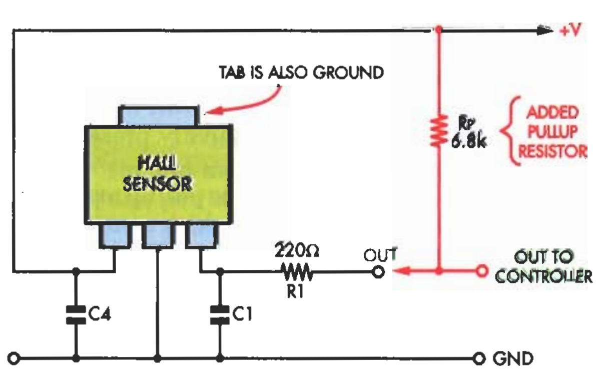


Fig.6: circuit diagram of the Hall Effect sensors. Resistor Rp is added to pull up the Hall chip's open-collector output.

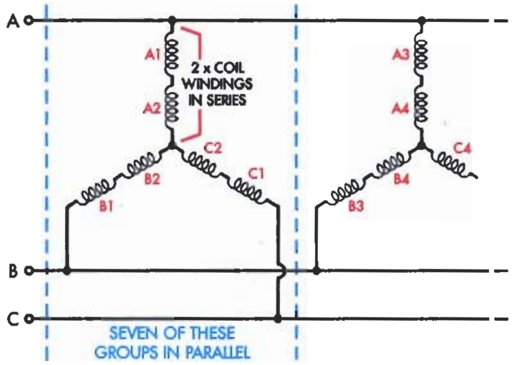


Fig.7: this is a series-parallel connection. The coil windings are cut and joined to give a group of two coils in series and then wired together to form seven groups in parallel.

I never had the need so I didn't do it – I've pulled apart enough copiers and printers to have a good supply of powerful stepping motors (big copiers now have BLDC motors too!).

It shouldn't be too hard to find a suitable H bridge stepping motor driver, though (eg, SILICON CHIP, April 2011 Circuit Notebook).

In fact, there is nothing to stop you hacking the original washing machine controller and driving the Mosfets with your own micro.

A warning about voltages: you must not try to use the SmartDrive as a stepping motor at the original voltage! The motor is made to run at some 200VDC and it needs this voltage to run the motor at high speed.

Stopping the motor with high voltage still applied will result in much smoke. For stepping applications, even fairly fast stepping, you will find that 48VDC is more than adequate.

Having said that, stepping motors can also be used as brakes and I recommend starting with perhaps 12-24V to give a good compromise between strong braking and overheating the motor.

Closing the loop

To run the SmartDrive as a fully fledged BLDC motor, the next part to be addressed is the hall sensor board.

Referring again to Fig.4, you will see that the sensors require a voltage supply (red and black wires) and output their signals on the blue, green and yellow wires. I found that the sensors are open collector, meaning that they are effectively open circuit until a magnetic south pole is brought up to the face of the IC.

To run an open collector circuit, a pull up resistor is needed and the complete circuit is shown in Fig.6, with components C1, C4 & R1 being originally present on the board.

It would be easy enough to solder the pullup resistor onto the original board but I ended up making a super simple extension board with a scrap of Veroboard so I could get my multimeter onto it more easily.

Building shouldn't take more than a half hour or so and then you're ready to test.

Simply apply any reasonable voltage to the power leads, say 12V, and measure the voltage at each output while applying a small magnet to the Hall sensors. By alternating the magnetic poles, you should see the output voltage swing between approximately 12V and 0V.

For interest, you might like to reassemble the motor and run through the manual test sequence while noting the hall voltages. If all is well, you should get the results of Table 1 with '0' being 0V and '1' being 12V.

Motor driver

The last step is to select a suitable motor driver. I originally thought of using the driver that was build into the washing machine but in the end decided that it was more trouble than it was worth.

For a start, the washing machine driver runs on full mains voltage and I wanted a system that would run on 36 or 48V. It is possible to rebuild all of the various power supplies but there is a fair bit of work involved.

The final nail in the coffin was the fact that the central processor appears to run the whole show, including all of the motor functions. The processor would run my motor but I would have to put up with any machine powered by the motor going through periodic wash, rinse and spin dry cycles!

In the end finding a suitable driver turned out to be a fairly simple task. Realising that the SmartDrive is a fairly typical and increasingly common BLDC motor, it was a matter of finding a class of machinery that used such a motor and discovering what they used as a driver.

The answer turned out to be electric vehicles, especially electric mobility devices. The driver I bought will handle 36V and 50A for a total of maybe 1500W output, once a bit is subtracted for losses. There is a slightly more powerful version available that runs 50A at 48V but that was rather more than I needed.

As is increasingly common, the driver is Chinese made and I found the original version on www.made-in-china.com.

A hunt around using the world's favourite search tool will turn up legions more; the only fly in the ointment being that most suppliers are located in China and the Chinese are not big on credit cards and like to ship orders via containers on ships.

I bought a few units and can offer them to readers for $149 plus a few dollars for shipping – see the list of sources at

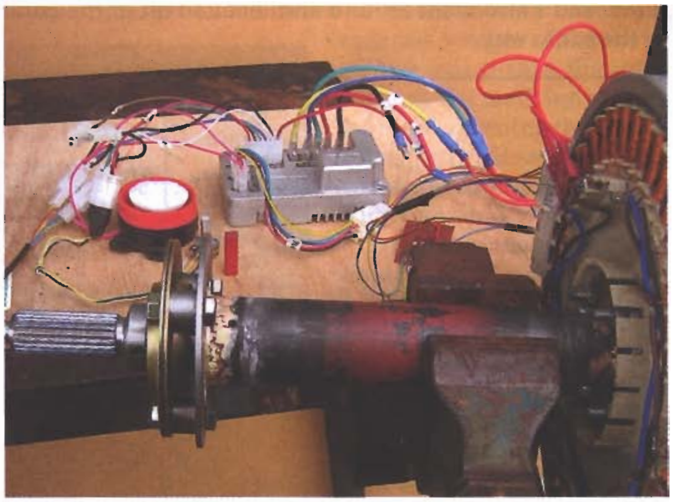


Fig.8a: complete system, ready to run. I built the bearing housing to suit a particular application but most people simply chop out the entire Nylon bearing housing from the bottom of the washing machine drum and strap it down with U bolts.

the end of this article. I'm also in the process of ordering a 60V and 240V version and if you're interested, drop me a line at contact@energy1000.com.au

For the intrepid soul, there is quite a good selection of drivers available on eBay.

The sellers are generally folks who sell a wide variety of goods and so have no product knowledge or factory info available but with the procedures outlined in this article, it should be relatively straightforward to sort out any combination of controller and motor that you might encounter.

Just don't try to drive a SmartDrive motor with a driver intended for a 200W bicycle!

Putting it all together

One of the biggest problems I see being wrestled with on the discussion groups is the matching of a (generic) driver with a (different generic) motor.

Even the best manufacturers are notoriously short on information and there is most certainly no universal colour coding system for the drive and sensors.

The general approach is 'trial and smoke', with hot lists of 'Motor X works with Driver Y' being gleefully circulated once a working combination is found.

The driver I used (see Fig.8b) dispenses with all that unpleasantness by offering a self calibration function. Even more amazingly, it works!

By simply activating self calibration and first pulling the motor backwards and then forwards, the micro gets enough information to sort out the coil to Hall Effect sensor phasing and with a twist of the throttle, away it goes. Gotta love this modern technology!

Self calibration also makes wiring very easy. The driver comes with pre-wired plugs that are nicely labelled and the only thing to be careful of is to wire the Hall Effect power supply from the driver to the correct leads on the Hall Effect board (have another look at Figs. 4 and 6).

I then wired the rest of the Hall Effect leads as shown in Fig.4 to the same colour leads on the driver and then randomly assigned the fat yellow, blue and green power leads to motor phases A, B & C in that order (have a close look at Fig.1). The fat black and red leads are then obviously the 36V power supply.

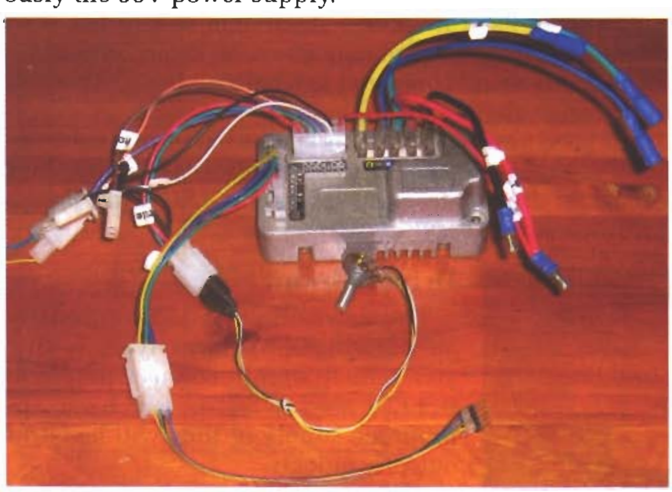


Fig.8b: generic Chinese driver with the leads separated into their functional groups. In front are the Hall Effect sensor leads with the same colour coding as Fig.4. The throttle pot is at front and the fat yellow blue and green leads at top right are power to the motor.

Components and further information

Bearing housings, various parts, windmill blades and all sorts of good information can be found at www.thebackshed.com/windmill and also www.ecoinnovation.co.nz/

Motor drivers of all sorts can be obtained from Millenium Energy Pty Ltd. The driver used in this article is available for $149 at time of writing.
Email: contact@energy1000.com.au

Chinese manufacturers web site having every type of product imaginable: www.made-in-china.com

I used a 5kΩ pot as the throttle but nice twist-grip throttles are readily available from eBay or some SILICON CHIP advertisers.

The driver supplies 5V and ground to the pot and the 0-5V control signal then comes off the pot wiper. Again, all quite simple – and most manufacturers will supply at least a rudimentary wiring diagram.

You will find that the motor will only run fairly slowly, which is to be expected as the coil windings are originally intended for mains voltage and a puny 36V has trouble convincing them to magnetise at any great rate.

Series, parallel or both?

The solution is to realise that the coils are all connected in series and for lower voltage applications it is entirely possible to connect groups of them in parallel.

The process to do it was covered by Glenn Littleford in SILICON CHIP in a series of articles starting in December 2004 (siliconchip.com.au) and can also be found at www.thebackshed.com/windmill/Contents.asp

The final arrangement is as shown in Fig.7, commonly referred to as a 'series – parallel' arrangement because a number of coils are connected in series to form a group and the groups in turn are connected in parallel.

Note that it is also possible to connect the coils together in simple parallel which will allow the highest possible current at the lowest possible voltage, exactly opposite to the original windings.

The choice of exactly how many coils to connect in parallel groups is largely determined by the application and by experience in operation – in fact you may notice that Fisher and Paykel themselves have made many modifications to their motor since it first came out.

For my application, the motor produced good power and speed and hummed along under load without any overheating.

The best advice I can offer is to get a hold of a good book on magnetism and motors (SILICON CHIP sells a couple of good ones) and put in some motor operating hours.

The complete system is shown on the test bench in Fig.8a, with the driver box connected to the coil windings and the Hall Effect sensors. At left, near the spline, is a roller bearing in a pressed metal housing which unfortunately didn't sit flush on its mounting flange and so needed three little bobbins as standoffs.

By the time you're reading this, I will hopefully have machined off the spline and mounted a small pulley to drive a 'V' or cog belt. SC