USE OF BALDOR PERMANENT MAGNET DC MOTORS
as
GENERATORS IN MICRO-HYDRO SYSTEMS

INTRODUCTION
Permanent magnet DC motors can be run as a DC generator without any modification. They are useful and indeed may be the best choice in systems producing up to 1kW.

These notes describe the selection, sizing, performance, maintenance and repair of Baldor motors, which have proved themselves to be particularly suited to this application. They are based on the author's experience dating from 1992 to 2000.

THE BASICS
Any PM DC motor will rotate at a speed which depends principally on the applied voltage. The speed will decrease as a load is applied however over the rated operating range of the motor it is the applied voltage which principally determines the speed. That is, the speed is proportional to the voltage.

Each motor has a nominal voltage rating. The applied voltage can range from a few percent of the nominal voltage up to 125% or more of the nominal voltage. For Baldor motors the useful range is from 15% to 120% of nominal voltage depending on the motor.

The current drawn depends on the applied load ie the torque together with a small overhead due to the rolling resistance of the motor. Ignoring rolling resistance the current is proportional to the torque. Each motor has a maximum full load current that it can handle. This current can be exceeded intermittently, however exceeding the rating risks the motor getting too hot and burning out.

When a PM DC motor is run as a generator the same principles apply. The generated voltage is proportional to the shaft RPM and the current supplied is proportional [ignoring rolling resistance] to the shaft torque. The speed and current limitations which apply when operated as a motor apply equally when operated as a generator.

As a motor, the power required to overcome the rolling resistance and the copper losses in the windings comes from the electrical input, whereas as a generator it is the mechanical input which provides this power. So when operated as a generator, compared to being operated as a motor, the voltage is a little lower for a given RPM and the current is a little lower for a given torque. The difference is a few percent and will be discussed further below.

THE BALDOR RANGE
The motors to be considered here are the standard CDP range and the washdown VPWD range. Go to http://www.baldor.com/information/index.asp and download product brochure FL602.PDF "SCR-Rated Permanent Magnet DC Motor w/integral DC Tachometer 1/4 - 5 HP" for specs on the CDP range and download product brochure ???? for specs on the VPWD range. Also product manual MN1501.

The information in these brochures is sufficient to enable selection of the appropriate generator for your micro-hydro application and to determine an approximate performance estimate. For a more accurate estimate you will need performance curves which are not as yet on-line. I use the performance curves found in a Baldor publication "Direct Current Motors" catalogue no. E-104 dated March 1991.

In general the CDP range will be found to be satisfactory. The VPWD range have a washdown rating making them more suited to outdoor use in areas with a lot of rainfall. They are not however waterproof and will not handle submergence.

RELATIONSHIP BETWEEN R.P.M, VOLTAGE and CURRENT

In this section we look more carefully at the relationship between the output voltage and the current. To follow this section in detail you will need access to the performance curves of the particular generators you are interested in.

To a good approximation the relationship is of the form

$\omega = A(V - RI)$ when operated as a motor and

$\omega = A(V + RI)$ when operated as a generator

where ω = rpm, V is the voltage, I is the current and A and R are constants specific to each motor. R is in ohms and is due principally to the resistance of the windings, the so called "copper losses" being I^2R.

We will show how A and R can be determined from the performance curves using the 1/2 HP CDP3326 model as an example.

- At no load and with an applied voltage of 180V the rpm is 1870.
  Thus A = 10.4 rpm/volt.
- At full load I =2.5A and ω = 1700 rpm and substituting into $\omega = A(V - RI)$ gives
  R = 6.5 ohm.

Similarly for the 1HP CDP3455 model we find A = 10.5 rpm/volt and R = 3.1 ohm.

Let's apply this to the case of a generator, again using the CDP3326 as an example. If the shaft speed is 1700 rpm and it is loaded to its maximum of 2.5A them V = 147V.

So at full load, as a motor with an applied voltage of 180V the shaft speed is 1700 rpm and as a generator with a shaft speed of 1700 rpm the output voltage is 147V. This sort of difference may be taken as typical across the whole range of motors.

GENERATOR SELECTION

The generator is selected having regard to the turbine which drives it and the load which it is required to supply.

The turbine to be continued

MAINTENANCE

Information on maintenance will be found at the Baldor website. A once a year check of the brushes and bearings is sufficient and a two or even three year life of these parts can be expected.

REPAIRS

Brush seating

Occasionally, even with a brand new generator, a brush is not seated properly against the commutator. The obvious signs of this problem are that the turbine is running unloaded and there is no output voltage.

This problem is easily fixed by gently tapping the housing a few times. Use a small hammer and tap gently in the vicinity of the brushes.

Dislodged magnet

The permanent magnets are glued to the inner wall of the housing. In micro-hydro applications they are typically operated out of doors in wet conditions and this can cause the bond between a magnet and the housing to fail.

When this happens, the magnet falls away from the housing to rest against and scrape the armature. Typically the motor will continue to rotate and generate power. The first sign of a problem is that the output is greatly reduced. On inspection the generator will be much hotter than normal and it will produce an easily heard scraping sound. It may appear to be a failed bearing, however once the motor is disassembled the cause of the problem is obvious.

On each occasion I have observed this problem there has been no damage to the armature and the magnet has been successfully glued back using a slow curing two part epoxy [Araldite]. When removing the dislodged magnet note carefully which way it goes back in.

When the magnet is replaced there are considerable magnetic forces to contend with. I have found the most satisfactory method of inserting and positioning the magnet is to use a single gently tapered wooden chock. When gluing:

- pay attention to cleanliness
- position the magnet and apply the epoxy using plastic or other non-magnet tools
- apply a generous skirt of epoxy around the perimeter of the magnet to prevent subsequent entrance of moisture into the area of the glued surfaces.

Submergence

Particularly with low head sites there is always a risk that the generator will become submerged by floodwaters. When this happens the generator is likely to fill up with silt and other debris. It may have been submerged for a week or more.

On recovery one's instinct is to try and turn the shaft to see if it still works. **Don't!** Abrasive particles may be critically lodged against the brushes or commutator or adjacent to the bearing seals and rotation under these conditions may do more damage than the submergence.

The general approach is to completely disassemble, thoroughly clean each and every part of the motor, allow each part to slowly dry out and reassemble. Often it will be found appropriate to replace the bearings.

Submergence may precipitate failure of a magnet/housing bond [described above] and this should be checked for by gentle tapping. It is not unknown for a magnet to dislodge shortly after the generator has been returned to service following submergence.

Please note: This section is not intended to substitute for the services of a qualified and experienced electrical mechanic and you are advised to consult a suitably experienced person if in doubt.

The Baldor generators output DC power, typically in the range of 40VDC to 110VDC. The sizing of the generator depends on head, flow rate and desired output voltage, and until these are specified the generator cannot be sized. A technical note on how this sizing is done is available on request. To date we have used Baldor permanent magnet DC motors run as generators. Typically, the rating of the unit [being thought of as a motor] is two to three times the expected electrical output of the turbine. Help with the selection of an appropriate generator is part of the technical support we provide.

Technical note:The Baldor motors we use are listed in their catalogue as dc variable speed motors and all have a catalogue number starting with CDP. Units that we have supplied recently have been CDP3320, CDP3326 and CDP3603. Our system uses a CDP3326.

The peak power RPM of the turbine depends only on the head. The output voltage of a Baldor depends principally on the RPM and secondarily on the output current. This can be determined for any motor using the data in Baldor catalogue E-104. This information is sufficient to calculate the required gearing between the turbine and the generator. It is usually stepped up by a ratio of between 1:2 and 1:4. It will also become clear at this stage whether a nominal 90VDC or 180VDC motor is the more suitable choice.

The output power can be determined from the flow rate and the net head. Once the transmission voltage has been decided on [i.e. the required Baldor output voltage], the output current can then be calculated. The Baldor selected is the smallest having a current rating that exceeds the maximum output current.

The generator output is then used to charge a battery bank [usually 24V] through a switchmode step-down DC/DC converter. AC power is provided from an inverter operating off the battery.