A Back-EMF Primer

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A basic DC motor of the sort used in model locomotives has a part called an *armature* with a coil of wire wrapped around it, and a shaft through its center. The armature is placed in the center between two permanent magnets, and the armature's coil is connected to the power source through a *commutator*, which flips the polarity of the connections as the armature rotates.

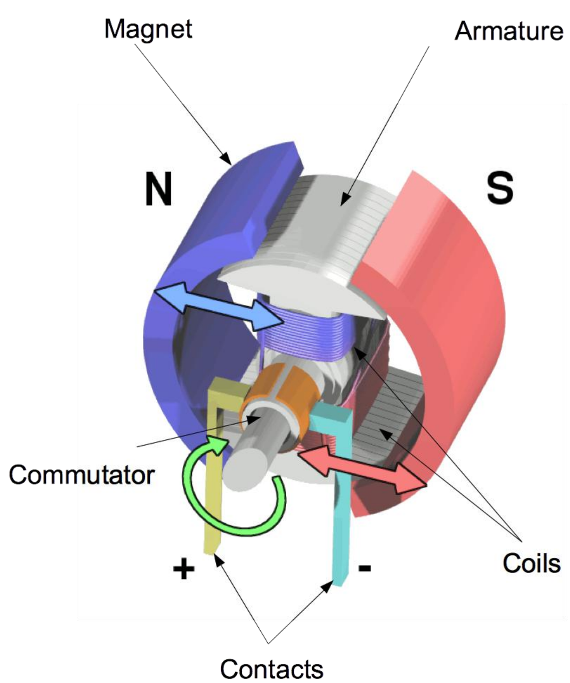

Figure 1 A DC electric motor. The armature is in the center, with the coils in blue and red. The permanent magnets (marked N and S) surround the armature. Blue and red arrows show the direction the armature will be pulled. The yellow and cyan parts are the motor contacts. The orange split ring is the commutator.

When a voltage is applied to the contacts, the armature coils generate a magnetic field, turning the armature into an electrically powered bar magnet, and just like in science class, the armature spins to align its field with the permanent magnets. But just as it gets there, the commutator flips the voltage on the coil, reversing the armature's field. And around and around we go! The higher the voltage applied, the stronger the field, and the faster the armature rotates. 3- and 5-pole motors work in the same way, but have more coils on the armature to provide a smoother rotation.

If you take a motor out of the locomotive and spin it by hand, the process works in reverse. The spinning coil of the armature cuts through the magnetic field of the magnets, which induces a voltage in the coil. The faster you spin, the higher the voltage – just the opposite of using it as a motor. The coil voltage reverses every time the armature spins half a revolution, but the commutator does its job in reverse as well, creating a constant-polarity voltage at the contacts. This voltage generated by the motor's rotation is what we call back-EMF (BEMF).

Now, the fun part is that it will generate this voltage even when you are turning the motor by powering it electrically. The voltage generated by the motor itself cancels out part of the voltage applied by the controller. This is why it's called "back" EMF (EMF -- electro-motive force -- is an old term for voltage), as it pushes back (in a sense) against the applied power. Interestingly, this happens on real locomotives too, and is one of the limiting factors in the train's speed. At some point, as the motor runs faster, the BEMF from the motor completely cancels out the voltage applied by the generator, and the motor can go no faster.

A reasonably clever controller can measure the amount of this BEMF and infer the motor's speed from it. Decoders with "BEMF speed control" or "BEMF compensation" are doing just that... instead of just putting out a voltage and hoping for the best, they are measuring the motor's rotation speed via the BEMF voltage, and adjusting the drive output to keep the motor at a constant speed.

There are a couple of reasons why you might want to disable BEMF control. First, BEMF control gives a constant speed, regardless of the load on the locomotive, the grade, or anything else (up to the limits of the loco, of course). This is not prototypical. Real locomotives definitely slow down and speed up on grades, unless the engineer adjusts the throttle. Real locomotives also require different throttle settings for long, loaded trains than for short or empty trains.

BEMF can also cause problems with consisted locomotives, due to its very precise speed control. If the locos aren't very accurately speed matched, one will try to run slightly faster than the other. The slower loco will drag the faster one, and the faster loco will pull the slower one. This will cause both BEMF systems to “fight” each other, until one or the other loco starts slipping on the rails.

The various decoder manufacturers provide different means of addressing these two issues. Usually, BEMF control can be disabled with a CV setting or a throttle button press. Some decoders disable BEMF control automatically when a loco is consisted, or above a certain speed, and some provide adjustments for how much BEMF control is applied to the motor.

BEMF control is most useful at low, switching speeds, as it can help keep the loco from stalling out on switch frogs or other difficult pieces of track. At higher speeds or for continuous “display” running, it can reduce the amount of throttle interaction needed to keep the train running steadily. Whether or not to enable BEMF control depends on how you want your locomotives to behave.