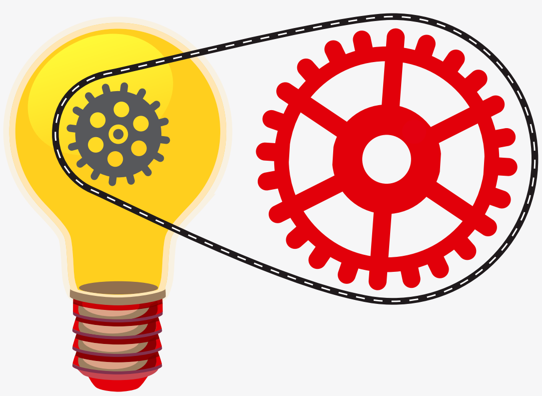
DC motors as generators

Both brushed and brushless DC motors can be operated as generators. However, there are some important points to consider when designing the drive, as Urs Kafader, head of maxon Academy, explains.



Every now and then, I'm asked about the suitability of maxon DC motors for use as a generator. Since our motors are very efficient, this is also true when operated as generators. The basic calculations between speed and voltage as well as current and torque are very simple. In the following, a few rules for a successful selection.

DC or AC voltage?

Rule #1
For generation of DC voltage, select a brushed DC motor or use a brushless EC (BLDC) motor with voltage rectifier. For the generation of AC voltage, select a brushless EC motor and connect 2 phases only. Hall sensors are not needed on brushless motors.

Speed constant kn

Many generators are operated at speeds of 1000 rpm or below. That's quite a low speed for small motors. Generating 10 V or more at 1000 rpm requires a speed constant of only 100 rpm/V or less. Such windings are hard to find in the maxon portfolio. There are only a few high resistance windings on larger motors that satisfy this requirement. Smaller motors have higher speed constants.

Table 1 shows a selection of motors with low speed constant (or high generator constant = generated voltage per speed). Usually, it's the motor winding with the highest resistance only that results in a speed constant of less than 100 rpm/V.

Rule #2
Without considering the load, the winding should have a speed constant of $k_n < \frac{n}{U}$ or smaller.

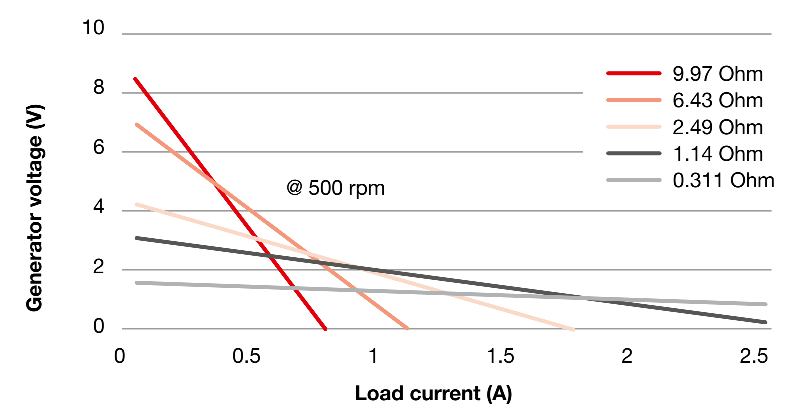
As an alternative, the motor speed can be increased by the use of a gearhead (see next page).

Resistance

Rule #2 requires motors with high a generator constant. Unfortunately, their windings have the highest resistance as well. High resistance reduces the output voltage under load, and the output voltage becomes very sensitive to the load current.

Motor typ	speed constant k_n	voltage per 1000 UpM	terminal resistance	Remarks
DCX 32 L	97.9 rpm/V	10.2 V	4.1 Ω	winding with lowest k_n
DCX 26 L EB	111 rpm/V	9.0 V	11.6 Ω	winding with lowest k_n
RE 50 GB	39.5 rpm/V	25.3 V	3.9 Ω	winding with lowest k_n
RE 40 GB	56.2 rpm/V	17.8 V	10.2 Ω	lower k_n available
RE 25 GB	97.8 rpm/V	10.2 V	36.8 Ω	winding with lowest k_n
EC-max 40	76.1 rpm/V	13.1 V	7.2 Ω	winding with lowest k_n
EC-i 40 HT 70 W	104 rpm/V	9.6 V	2.0 Ω	winding with lowest k_n
EC-i 40 HT 100 W	104 rpm/V	9.5 V	0.9 Ω	winding with lowest k_n
EC-flat 45 50 W	95 rpm/V	10.5 V	7.5 Ω	winding with lowest k_n
EC-flat 45 70 W	72.7 rpm/V	13.7 V	6.9 Ω	winding with lowest k_n
EC-flat 60 100 W	83.4 rpm/V	12.0 V	1.1 Ω	winding with lowest k_n

Selection of maxon motors with low speed constant.



The voltage-current lines of the different windings of the RE 40 with precious metal brushes at 500 rpm. Observe the different slopes of each winding.

Rule #3
For stable output voltage over a certain load range, select a larger motor where the resistance is lower even on motors with high generator constant.
The EC-i 40 High Torque motors are very interesting from this point of view.

Power restrictions

Do not select the motor-generator on power considerations alone. In order to fulfill the torque requirements, you might need a motor with a much higher power rating than the generated power; in particular if the generator speed is rather low compared to typical motor speeds.

Torque and speed limitations

The amount of torque on the generator defines the size and type of the motor-generator. Select a motor type with a continuous torque higher than the generator torque.

When calculating the torque or current load, consider the type of operation. Will the generator run continuously for long periods of time, or in intermittent operation cycles, or during short intervals only? Accordingly, a motor size with sufficient continuous torque or current has to be chosen.

Also respect the maximum speed of the motor type. However, due to the generally low speeds this is hardly ever an issue.

Current and voltage limitations

The most appropriate winding of a given motor type follows from the current and generated voltage requirements. Select a winding that can generate the required voltage U even under load.

Assuming a fixed generator speed n, we require a generated voltage of the winding U_t that is larger than U

$$U_t = \frac{n}{k_n} - R_{mot} \cdot I_L > U$$

Without considering the load, select the speed constant according to Rule #2, i.e. a winding with a sufficiently high resistance. Since the current capacity decreases with increasing resistance, verify that the continuous current is still large enough.

The chart quite nicely shows the ambivalent effects of different windings.

– The higher the winding resistance, the higher the generated (no-load) voltage.
– However, the higher the winding resistance, the more sensitive the generated voltage becomes to load current changes.

These contradictory effects can be eliminated to a certain extent by selecting larger motors that exhibit lower resistances for the same generator constant (according to Rule #3).

Gear-motor combinations

Rule #4
Use gearheads to increase very low speeds. However, maxon gearheads are not really good at being driven from the output. Use gearheads that can be back-driven, i.e. planetary gearheads up to two stages or spur gearheads. (Or use specially designed gearheads.)

The reason to use gear-motor combinations for generators is that the driving mechanism is very slow – e.g. a wind or water turbine, or even a manual drive. A few observations and recommendations:
– The gearheads need to be driven in reverse operation in these cases. However, maxon gearheads are not really designed for reverse operation, and the efficiency is low.
– High reduction gearheads (3 stages and higher) are not back-drivable; i.e. they won't turn when driven from the output with the maximum permissible torque. You may use 1 or 2 stage planetary gearheads; they can be operated from the output.
– Rather use spur gears instead of planetary gearheads. Spur gearheads can more easily be back-driven and the back-driving efficiency generally is higher.

Special case: DC motor as DC tacho

Rule #5
For DC tachos, use DC motors with precious metal brushes that better suit the small currents. Select the winding according to the required tacho voltage and the speed range in your application. Don't worry about the winding resistance, just make sure that there is a load resistance of several kΩ to keep currents small.

Urs Kafader has been supervising the technical training at maxon motor for more than 20 years. He runs training sessions on the technology and use of maxon products – for employees at the maxon headquarters in Sachseln, for the international sales network, and for customers. He holds a Ph.D. in physics as well as an MBA in production science. He began his career at the Laboratory for Solid State Physics at the Swiss Federal Institute of Technology, Zurich.