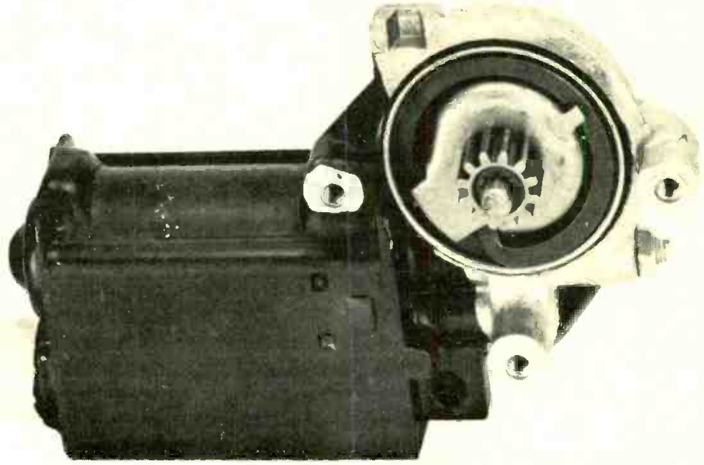
Powering your robot

Building a robot is easy. Making it move is another matter. The key to success is choosing the right motor for the job. These step-by-step procedures should make choosing your robot's motor a snap.

by David Heiserman



Most robots emerging from experimenters' workshops today are wheeled robots. It's nice to think about building walking robots, but the cost and design problems reach discouraging proportions before anything significant gets done. So for the time being anyway, we ought to stick with the idea of building wheeled robots that operate from ordinary, battery-operated dc motors and standard gear arrangements.

The selection and proper application of dc motors and gearboxes are critical to the success of a robot project. In fact it is a good idea to find the motors, gears and wheels first; then design the robot around them.

Before you start running all over the place looking for some motors for your robot project, however, you ought to make up a list of relevant specifications—things such as required torque or horsepower, geared rpm, operating voltage and supply current. The following discussion is intended to help nail down such specifications for wheeled robots of any weight, size and running speed.

Don't become overwhelmed by the sight of so many equations. You will find each term carefully defined here, and you can see exactly how to use the equations in three specific instances.

Defining terms

All the terms and specifications relevant to selecting robot motors and gear assemblies are given in Table 1. You'll have to determine some of these specs for yourself; namely the finished weight of the robot, its maximum straight-line speed across the floor and the diameter of the drive wheels. The best all-around choice for a supply voltage is 12 V, but your own special requirements might call for a different supply voltage. Most of the remaining terms in Table 1 are calculated from the information you can provide ahead of time and from the equations in Table 2.

Incidentally, Table 1 reflects the fact that the efficiency of dc motors increases with their rated horsepower. Once you calculate the amount of horsepower you need, you must use this motor efficiency chart for finding efficiency figures required for calculating the motor's power rating and current drain.

All of the literal terms used in the equations in Table 2 are fully defined in Table 1. Most of these equations are rather precise. However, those based on the efficiency term (e) yield estimated results. Don't worry about that, though, because you'll still end up in the right ballpark when all is said and done.

Table 3 outlines the exact procedure for coming up with the motor specs you need. The information plugged into the first four steps comes from your own ideas about a robot. Only you can estimate how much the final product will weigh and how fast you want it to run. It isn't hard at all to pick out some wheels and measure their diameter, and, as mentioned earlier, you ought to consider using a 12 V supply. At any rate, pick a supply voltage that is characteristic of readily available batteries.

Simple procedure

Step 5 of the procedure provides valuable information concerning the rpm of the drive wheel. This figure must be known in order to make any intelligent selection of a motor/gear arrangement.

Step 6 yields the torque required for doing the job. This is an important specification for smaller motors, but larger motors are more often expressed in horsepower—a figure calculated in Step 7 of this procedure.

Estimate the system efficiency from

Table 1

Definition of terms

Rg — geared wheel speed in rpm.
s — maximum robot straight-line speed in feet per second.
D — diameter of the driven wheel in inches.
W — maximum robot weight when finished in pounds.
Tf — required wheel torque in foot-pounds.
Ti — required wheel torque in inch-ounces.
hp — motor horsepower.
P — motor power rating in watts.
Ip — motor start and stall current in amperes.
k — required gear ratio between motor shaft and wheel.
Es — motor supply voltage in volts.
Rm — motor shaft speed in rpm.
Ir — motor running current in amperes.
e — motor efficiency (see chart below).
π — pi constant, 3.14.

Estimating motor efficiency (e) from horsepower (hp)

hp	e
up to 0.1	0.7
0.1 to 1	0.8
1 or greater	0.9

the chart in Table 1, then use that information for calculating the motor's electrical power dissipation. Motors are rarely specified according to their power rating, but this figure is necessary for determining its peak current demand in Step 10 and normal running current in Step 11. Both of these figures are necessary for specifying the motor's battery characteristics.

At this point, you know what you need in terms of motor speed and horsepower. Most motors are rated according to these two specifications—plus the supply voltage, of course.

Lucky is the experimenter who can find a dc motor that is already geared down to provide an rpm and horsepower that equals or exceeds the specifications found through this procedure. It's sometimes necessary to acquire the dc motor and gear assembly separately. When this is the case, it's important to work through Steps 12, 13 and 14.

Find a motor that has the horsepower rating calculated in Step 7. Then, determine its shaft speed from the motor's nameplate or manufacturer's specification sheet. This is how you complete Step 12.

In Step 13 you'll calculate the necessary gear ratio that steps down the motor shaft rpm to the rate you need for your own robot—see Step 5. Gearboxes are also specified according to the amount of output torque they can tolerate. You have already figured this specification in Step 6. Make sure the gears you select can handle that amount of torque.

Finally, doublecheck the suitability of the motor by calculating the necessary amount of shaft torque in Step 14. A gear arrangement that steps down the rpm decreases the torque demand on the motor shaft by a proportional amount. The greater the gearing ratio, the smaller the torque requirement of the motor. You might be surprised to find out how little torque you need from a high-speed dc motor. Just make sure the motor you select provides at least the amount of torque found in Step 14.

Motors and gear arrangements suitable for robot applications are available from a number of sources. Unfortunately the usual kinds of electronic supply stores is not one of them. Perhaps the best source of robot motors is an automotive parts outlet. Modern autos, especially luxury models, are loaded with suitably geared, 12 VDC motors that can fill the bill quite nicely.

Looking for motors

Window-lifting motors and the motors used for adjusting seat positions are probably the best overall choice for medium-sized robots. They have the necessary starting torques and most are already geared down to a suitable rpm.

Some robot experimenters have used windshield wiper motors quite successfully; but the limited torque from such motors restricts their application to smaller, lighter weight robots. Electrical

Table 2

Equations

1. $Rg = \dfrac{720s}{\pi D}$

2a. $Tf = \dfrac{WD}{24}$

2b. $Ti = 192Tf \text{ or } 8WD$

3. $hp = 1.8sW \times 10^{-3}$

4. $P = \dfrac{1.36sW}{e}$

5. $Ip = P/Es$

6. $Ir = Ip\,(1\text{-}e)$

7. $k = Rm/Rg$

8. $Tm = Tf/k$

Table 3

Procedure

1. Estimate the maximum robot weight (W) in pounds.
2. Estimate the maximum straight-line speed (s) in feet/second.
3. Determine the drive-wheel diameter (D) in inches.
4. Assign the motor supply voltage (Es) in volts.
5. Calculate the required wheel rpm (Rg) from Equation 1.
6. Calculate the torque of the motor/gear assembly:
   (a) in foot-pounds (Tf) from Equation 2a
   or
   (b) in inch-ounces (Ti) from Equation 2b.
7. Calculate the horsepower (hp) from Equation 3.
8. Estimate the motor efficiency (e) from Table 1.
9. Estimate the motor power rating (P) in watts from Equation 4.
10. Calculate motor start-up and stall current (Ip) from Equation 5.
11. Calculate normal running current (Ir) in amperes from Equation 6.

If it is possible to find a motor/gear assembly that comes close to fitting these specifications, there is no need to go any further. However, the following additional steps must be applied when the motor and gear train are obtained separately.

12. Determine the motor shaft speed (Rm) in rpm.
13. Calculate the required gear ratio (k) from Equation 7.
14. Calculate the required motor shaft torque (Tm) from Equation 8.

Example 1

Motor specs for a moderately large robot

1. Maximum expected weight (W) — 30 lb.
2. Maximum straight-line speed (s) — 2 ft/sec.
3. Drive wheel diameter (D) — 6 in.
4. Motor supply voltage (Es) — 12 V.
5. $Rg = \frac{720(2)}{\pi (6)} = 76.39$ or about 76 rpm.
6. $Tf = \frac{(30)(6)}{24} = 7.5$ ft-lb.
7. $hp = 1.8(2)(30) \times 10^{-3} = .108$ or about 1/10 hp.
8. $e = 0.8$
9. $P = \frac{1.36(2)(30)}{0.8} = 102W.$
10. $Ip = 102/12 = 8.5A.$
11. $Ir = 8.5(1\text{-}0.8) = 1.7A.$

This example thus calls for a motor rated at 12VCD at about 5A, followed by a gear train that will turn the wheel at about 76 rpm at 7.5 ft-lb or about 1/10 hp. The supply should be able to deliver surge currents of 8.5A.

If the motor and gear train are obtained separately:

12. Motor shaft speed from nameplate or spec sheet — 13,500 rmp
13. $k = 13{,}500/76 = 177.6$ or about 176:1
14. $Tm = 7.5/176 = 0.042$ ft-lb or about 8.2 in-oz.

Example 2

A micro-robot

1. Maximum expected weight (W) — 3 lb.
2. Maximum straight-line speed (s) — 1 ft/sec.
3. Drive wheel diameter (D) — 1 in.
4. Motor supply voltage (Es) — 6 V.
5. $Rg = \frac{720(1)}{\pi (1)} = 229$ rpm.
6. $Ti = 8(3)(1) = 24$ in-oz.
7. $hp = 1.8(1)(3) \times 10^{-3} = 5.4 \times 10^{-3}$ hp.
8. $e = 0.7$
9. $P = \frac{1.36(1)(3)}{0.7} = 5.8$ W.
10. $Ip = 5.8/6 = .97$ A.
11. $Ir = .97(1\text{-}0.7) = 0.29$ A.

This little system calls for a 6V motor that normally runs at about 290 mA. The output torque of the gear system should be 24 in-oz at 229 rpm.

Example 3

A monster robot

1. Maximum expected weight (W) — 200 lb.
2. Maximum straight-line speed (s) — 10 ft/sec.
3. Drive wheel diameter (D) — 12 in.
4. Motor supply voltage (Es) — 6 V.
5. $Rg = \frac{720(10)}{\pi (12)} = 190.9$ or about 191 rpm.
6. $Tf = \frac{(200)(12)}{24} = 100$ ft-lb.
7. $hp = 1.8(10)(200) \times 10^{-3} = 3.6$ hp.
8. $e = 0.9.$
9. $P = \frac{1.36(10)(200)}{0.9} = 3022W.$
10. $Ip = 3022/6 = 504$ A.
11. $Ir = 504(1\text{-}0.9) = 50.4$ or about 50 A.

If the motor and gearbox are obtained separately:

12. Motor shaft speed from nameplate or spec sheet — 3200 rpm
13. $k = 3200/191 = 16.75$ or about 17:1
14. $Tm = 100/17 = 5.88$ or about 6 ft-lb.

This system calls for a 4 hp, 6VDC motor. It should draw about 500A at start-up or when stalled, but normally run at about 50A. If the motor shaft runs at 3200 rpm, the gear system should have a step-down ratio of 17:1 and be capable of handling a 100 ft-lb torque at its output.

surplus stores and mail-order houses offer nice 12 Vdc motors at rather reasonable prices, usually less than $10.

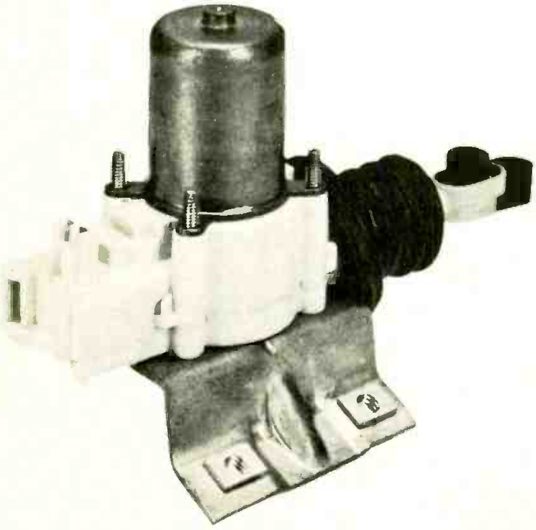
You must exercise some care in such instances, however. Make certain the motors deliver an adequate amount of torque and can be geared down to the right running speed. Sometimes the most attractive motor bargains do not include any gearing at all. In this case, it will be necessary to search out a suitable gear train or even build one from scratch.

Many would-be robot experimenters have a dc motor or two gathering dust somewhere in the workshop. Will that old motor do the job? Assuming you have already gone through the calculations for finding the specs you need, all you have to do is figure out how close the old motor comes to meeting them.

The only bad part about using an old motor is that the specs might be missing. The good part is that it isn't too hard to find out the relevant specs.

The first step is to apply your chosen supply voltage to the motor. If it runs smoothly and without getting too hot, you are on the right track. Then disconnect the motor from the supply voltage and measure the winding resistance with a good ohmmeter. Divide that resistance value into the supply voltage, and you end up with the motor's start-up and stall current, Ip.

Suppose, for example, your motor shows a dc winding resistance of 2 Ohms. If you operate it from a 12 V supply, that means the start-up and stall current will be 6 A. Is that close to the Ip value you calculated earlier? If so, it probably has the right horsepower and torque ratings, too.



The robot in Example 1 is probably typical of most robots people want to build these days. The weight specification is adequate for a nice aluminum mainframe, a good-size battery and plenty of digital logic. It turns out that the drive motor specifications fall into line with some commonly available motors and gear arrangements.

Example 2 considers a micro-robot, probably the smallest robot you can build that does anything interesting. Example 3 goes to the opposite extreme, specifying a monster robot that weighs 200 pounds and is capable of moving at a speed of 10 ft/sec, which is close to 7 mph. Note especially the sobering power requirements in this last example.