How are current and voltage related to torque and speed of a brushless motor?

I know that electric vehicles have different performances depending on battery and motor, but it's not clear how electrical and mechanical units are related.

Can anybody please help?

Will a 100V motor raise against slopes better than a 50V motor?

motor speed torque brushless-dc-motor

edited Dec 3 '13 at 21:00
W5VO ♦ 14k 4 41 81

asked Sep 3 '12 at 11:57
jumpjack 363 1 6 12

Possibly, but it's impossible to say without knowing the current which can be supplied or the efficiency, allowable loading (thermal, magnet damage if a PM design, etc) for the duration of the time it takes to climb the hill, or even the gearing. Consider that a 120v electric eraser is most likely inferior at drilling holes when compared to a 12v cordless drill. – Chris Stratton Sep 3 '12 at 12:46

8 Answers

The relationship between a motor's electrical characteristics and mechanical performance can be calculated as such (note: this is the analysis for an ideal brushed DC motor, but some of it should still apply to a non-ideal brushless DC motor).

A DC motor can be approximated as a circuit with a resistor, and voltage back-emf source. The resistor models the intrinsic resistance of the motor windings. The back-emf models the voltage generated by the moving electric current in the magnetic field (basically a DC electric motor can function as a generator). It's also possible to model the inherent inductance of the motor by adding an inductor in series, however for the most part I've ignored this and assumed the motor is at quasi steady state electrically, or the motor's time response is dominated by the time response of the mechanical systems instead of the time response of the electrical systems. This is usually true, but not necessarily always true.

The generator produces a back EMF proportional to speed of the motor:

$$V_{emf} = k_i * \omega$$

Where:

$$k_i = \text{a constant.}$$

$$\omega = \text{the motor speed in rad/s}$$

Ideally at stall speed there is no back emf, and at no the no-load speed the back emf is equal to the driving source voltage.

The current flowing through the motor can then be calculated:

$$I = (V_S - V_{emf})/R = (V_S - k_i * \omega)/R$$

$$V_S = \text{source voltage}$$

$$R = \text{motor electrical resistance}$$

Now let's consider the mechanical side of the motor. The torque generated by the motor is proportional to the amount of current flowing through the motor:

$$\tau = k_t * I$$

$$k_t = \text{a constant}$$

$$\tau = \text{torque}$$

Using the above electrical model you can verify that at the stall speed the motor has the maximum current flowing through it, and thus the maximum torque. Also, at the no load speed the motor has no torque and no current flowing through it.

When does the motor produce the most power? Well, power can be calculated one of two ways:

Electrical Power:

$$P_e = V_S * I$$

Mechanical Power:

$$P_m = \tau * \omega$$

If you plot these, you'll find that for an ideal DC motor the maximum power comes at half the no-load speed.

So all things considered, how does the motor voltage stack up?

For the same motor, ideally if you apply double the voltage you'll double the no-load speed, double the torque, and quadruple the power. This is assuming of course the DC motor doesn't burn up, reach a state which violates this simplistic ideal motor model, etc.

However, between different motors it's impossible to tell how two motors will perform compared to each other based only on the voltage rating. So what do you need to compare two different motors?

Ideally you'd want to know the voltage rating and stall current so you can design your electronics appropriately and you'd want to know the no-load speed and stall torque so you can calculate the mechanical performance of your motor. You may also want to see the current rating of the motor (some motors can be damaged if you stall them for too long!). This analysis also somewhat neglects the efficiency aspect of the motor. For a perfectly efficient motor, $k_i = k_t$, or rather $P_e = P_m$. This would cause the power calculations using the two equations to be equal (i.e. electrical power equals mechanical power). However, real motors aren't perfectly efficient. Some are close, some aren't.

p.s. In my calculations I used motor speed as rad/s. This can be converted to Hz or rev/s by dividing by 2π..

edited Mar 10 '16 at 23:19
Kaz
16.2k 1 21 65

answered Sep 3 '12 at 19:16
helloworld922
12.1k 6 36 69

4 For many of us non-experts, if we automatically understood what each of the symbols in the formula stood for, we'd have no need for your otherwise fascinating explanation. Perhaps you could improve your answer with a bit of "where τ = fill_in_the_blank" and "where ω = fill_in_the_blank" ? – mickeyf Sep 4 '12 at 1:56

So in brief, V is proportional to ... V :-) and I is proportional to torque. – jumpjack Sep 4 '12 at 19:26

1 I also think that a higher voltage motor is "better" as it involves lower currents, hence lower energy loss due to Joule effect. – jumpjack Sep 4 '12 at 19:27

Defining the constants in the answer would be useful. Showing an ACTUAL example of the calculations would be VERY useful. – zeffur Mar 10 '16 at 23:23

After 4 years using and studying electrical vehicles I figured out that "gradeability" (ability to raise a slope of specific grade) depends on motor torque, and torque depends on current.

Voltage instead "regulates" how fast a motor can run.

How much current a motor can tolerate when a voltage is applied depends on how much thick the coils wires are (thicker = higher current = higher torque), due to coils internal resistance (the higher the resistance, the higher the heat produced, till wires melt).

Considering a 1000W motor:

- providing 100V/10A you'll be able to reach high speed but you won't be able to raise much slope.
- providing 10V/100A you'll move very slowly but you'll be able to climb high-grade slopes (assuming the motor can tolerate 100A).

The maximum current a motor can tolerate is named "rated current", which is way lower than the motor "stall current", i.e. the current flowing in the motor wires when voltage is applied and the motor is kept halted. The motor CANNOT tolerate its own stall current, which will soon melt wires. That's why electronics limits maximum current to rated current value.

answered May 26 '16 at 12:13
jumpjack
363 1 6 12

+1 for actually answering OP's question, instead of effectivey answering "it depends". – U007D Nov 24 '16 at 22:24

Electric motors can be designed over a fairly wide range of voltage and current for the same speed and torque out. Just comparing the intended operating voltage of two motors doesn't tell you much about what those motors can ultimately do. Motors designed for high power do tend to work at higher voltages, but that is mostly so that the current can be within a reasonable limit.

To compare two motors for a particular job, you have to look at the output parameters. These will be the torque, speed range, and power.

answered Sep 3 '12 at 13:24
Olin Lathrop
253k 28 302 693

Would you provide an example of how that is calculated? :) For example: Suppose I wanted to shake a flat grate 6" with a 30 lb load on top of the screen to sift through smaller bits. How would one go about calculating what size motor would be needed to do that? – zeffur Mar 10 '16 at 23:27

In any motor, the basic principle is very simple:

- rotational speed is proportional to voltage applied
- torque is proportional to current pulled

A 100 volt motor is a motor that can take a maximum of 100 volts, and a 50 volt motor a maximum of 50 volts. Since the 100 volt motor can take more volts, if all else is equal, it can give you a higher maximum speed.

But the difference in voltage does not affect the torque. To get more torque to go up a hill, you need to supply your motor with more current. A motor that can take more current (and a battery and motor controller that can supply more current) will give you more torque to help you up the hill.

edited Jun 2 '16 at 22:12 answered Mar 10 '16 at 22:33
Daanii
41 5

You start out right, but reach a mistaken conclusion when you neglect to consider not only the magnetic design, but different wire sizes and turn counts wound on what is otherwise the same motor structure. – Chris Stratton Mar 10 '16 at 23:12

1 To clarify, if you have two otherwise identical motors, but one of them has twice as many turns in its

windings as the other, the low turn count motor will draw the same amount of power at 50 V as the double turn count motor would at 100 V. Both would spin at the same speed, and the 50 V motor would draw twice the current as the 100 V one. – jms Mar 11 '16 at 18:43

1 Certainly the design of the motor affects its torque constant and its velocity constant. But that doesn't change the fact that speed is proportional to voltage, and torque to current. Those are important facts that many people do not seem to understand. – Daanii Mar 11 '16 at 19:29

The mechanical performance of a motor will of course depend mainly on it's physical build, not necessarily its nominal voltage. High power motors will operate on higher voltages, but that does not tell you much.

I won't elaborate on the specifics, but there is a good rule of thumb to use when you want to estimate the parameters of a motor by look. A long motor will achieve higher rpms, and a wide motor will be able to deliver more torque. You can perhaps imagine how this works - a wide motor will have a wide rotor, so the forces of the magnetic fields inside will create a larger torque.

So, if you have two motors of identical length, but one of them is wider, you can expect the wider one to be able to generate higher torque.

answered Sep 3 '12 at 16:47
Jonny B Good
2,430 1 8 21

In very basic terms (helloworld's answer has the science bit covered):

Power is voltage * current (P=IV). For a given power, say 1000 watts / 1 kW, you can design a 10 V motor that uses 100 A or a 100 V motor that uses 10 A for the same *nominal* power:

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10 V * 100 A = 1000 watts
100 V * 10 A = 1000 watts
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Your next consideration is how the various efficiencies stack up - for each part of the power train there will be some optimum way of building each part that gives best efficiency for the price. For example, if you went for the 10 V option you need a lot of big heavy wires (or bus bars) to handle 100 A, whereas 10 A will flow happily down quite skinny little wires.

However, maybe it's harder to build a control unit / charger that works at 100 V than at 10 V (it's certainly safer for the average user if there's no high voltages kicking around for them to stick their fingers in).

So, there's a juggling act to be done to work out how the system stacks up - for each watt of power you put in, how much useful energy can you get out the other end?

It's a bit like the difference between a big lazy V8 and a screaming turbo motor, both can make the same power, but each is a very different answer to the problem.

edited Aug 7 '16 at 0:18
Peter Mortensen
1,524 2 14 21

answered Dec 3 '13 at 22:17
John U
5,449 1 11 26

Voltage and current are the essential components of power a.k.a. the ability to perform work. To do work by means of spinning machinery requires a rotary-acting force - a torque. The rate at which the work proceeds (introduce time) and the measurement becomes of power. More power - increase either current or voltage or both.

edited Aug 7 '16 at 0:11
Peter Mortensen
1,524 2 14 21

answered May 24 '16 at 21:51
Ken Green
49 3

All you have to think about is the power rating and nominal voltage. If the voltage you apply is high (must be within the voltage range) then it can take less current and less torque which indeed can be found out from the speed-torque curve for a fixed voltage.

Voltage is proportional to speed, and torque is proportional to the current. The maximum current it could take is rated current and the corresponding torque can be found out from speed torque curve (as you know the speed from voltage (rpm=k*v)) where k is the speed constant of the motor).

edited Aug 7 '16 at 0:11
Peter Mortensen
1,524 2 14 21

answered Jun 15 '16 at 12:40
Prabhu Yadav
11

2 -1 for sloppy punctuation and capitalization. – Transistor Jun 15 '16 at 13:28

Not everyone is a native English speaker. Stack Exchange sites allow you to edit answers for reasons such as this. – U007D Jun 14 '17 at 13:04

protected by Dave Tweed ♦ Apr 13 '17 at 13:17

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